Vision Sciences Society

10th Annual Meeting, May 7-12, 2010
Naples Grande Resort & Club, Naples, Florida

Abstracts

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Program and Abstracts cover design by Mouna Attarha
T-shirt design (front) by Moran Cerf, T-shirt design (back) by Vu Chu

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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 Ballroom 1-3	1, 2, 3... For talks
2 Saturday	2 Late AM talk session	2 Royal Ballroom 4-5	01, 02, 03... For posters
3 Sunday	3 AM poster session	3 Royal Ballroom 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 Ballroom 1-3, 6th talk
36.513 Sunday, PM poster in Vista Ballroom, poster board 513
53.306 Tuesday, AM poster in Royal Ballroom 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).

Meeting Schedule

Friday, May 7

9:00 am – 8:30 pm	Registration Open	Royal Foyer
1:00 – 3:00 pm	Symposia Session 1	Royal Ballrooms 1-3, 4-5 & 6-8
3:00 – 3:30 pm	Coffee Break	Royal Foyer
3:30 – 5:30 pm	Symposia Session 2	Royal Ballrooms 1-3, 4-5 & 6-8
5:30 – 7:30 pm	Opening Night Reception	Royal Foyer, Orchid Foyer, Sunset Deck, Vista Deck
5:30 – 9:30 pm	Exhibits Open	Orchid Foyer
6:30 – 9:30 pm	Evening Poster Session	Vista Ballroom, Orchid Ballroom

Saturday, May 8

7:30 am – 6:45 pm	Registration Open	Royal Foyer
7:45 – 8:15 am	Coffee	Royal Foyer, Orchid Foyer
8:15 – 10:00 am	Talk Sessions	Royal Ballrooms 1-3 & 4-5
8:30 am – 12:30 pm	Poster Sessions	Royal Ballroom 6-8, Orchid Ballroom, Vista Ballroom
8:30 am – 6:45 pm	Exhibits Open	Orchid Foyer
10:00 – 11:30 am	VSS Public Lecture	Renaissance Academy of Florida Gulf Coast University
10:00 – 11:30 am	Family & Friends Get-Together	Mangrove Pool
10:15 – 10:45 am	Coffee Break	Royal Foyer, Orchid Foyer
11:00 am – 12:45 pm	Talk Sessions	Royal Ballrooms 1-3 & 4-5
12:45 – 2:45 pm	Lunch Break	Purchase a lunch at VSS Marketplace and head to the beach!*
2:45 – 4:15 pm	Talk Sessions	Royal Ballrooms 1-3 & 4-5
2:45 – 6:45 pm	Poster Sessions	Royal Ballroom 6-8, Orchid Ballroom, Vista Ballroom
4:30 – 5:00 pm	Coffee Break	Royal Foyer, Orchid Foyer
5:15 – 6:45 pm	Talk Sessions	Royal Ballrooms 1-3 & 4-5
6:45 – 7:45 pm	Keynote Reception	Royal Foyer
7:45 – 9:15 pm	Keynote Address and Awards Ceremony	Royal Ballroom 4-5

Sunday, May 9

7:30 am – 6:45 pm	Registration Open	Royal Foyer
7:45 – 8:15 am	Coffee	Royal Foyer, Orchid Foyer
8:15 – 10:00 am	Talk Sessions	Royal Ballrooms 1-3 & 4-5
8:30 am – 12:30 pm	Poster Sessions	Royal Ballroom 6-8, Orchid Ballroom, Vista Ballroom
8:30 am – 6:45 pm	Exhibits Open	Orchid Foyer
10:15 – 10:45 am	Coffee Break	Royal Foyer, Orchid Foyer
11:00 am – 12:45 pm	Talk Sessions	Royal Ballrooms 1-3 & 4-5
12:45 – 2:45 pm	Lunch Break	Purchase a lunch at VSS Marketplace and head to the beach!*
2:45 – 4:15 pm	Talk Sessions	Royal Ballrooms 1-3 & 4-5
2:45 – 6:45 pm	Poster Sessions	Royal Ballroom 6-8, Orchid Ballroom, Vista Ballroom
4:30 – 5:00 pm	Coffee Break	Royal Foyer, Orchid Foyer
5:15 – 7:00 pm	Talk Sessions	Royal Ballrooms 1-3 & 4-5
10:00 pm – 1:00 am	CVS-VVRC Social	Vista Ballroom & Sunset Deck

Monday, May 10

7:30 am – 1:15 pm	Registration Open	Royal Foyer
7:45 – 8:15 am	Coffee	Royal Foyer, Orchid Foyer
8:15 – 10:00 am	Talk Sessions	Royal Ballrooms 1-3 & 4-5
8:30 am – 12:30 pm	Poster Sessions	Royal Ballroom 6-8, Orchid Ballroom, Vista Ballroom
8:30 am – 1:15 pm	Exhibits Open	Orchid Foyer
10:00 – 11:00 am	Visual Search Workshop/National Geospatial-Intelligence Agency	Acacia 5
10:15 – 10:45 am	Coffee Break	Royal Foyer, Orchid Foyer
11:00 am – 12:30 pm	Talk Sessions	Royal Ballrooms 1-3 & 4-5
12:30 – 1:15 pm	Business Meeting	Royal Ballroom 4-5
5:00 – 7:00 pm	6th Annual Best Illusion of the Year Contest	Philharmonic Center for the Arts
7:00 – 9:00 pm	Demo Night Dinner	Vista Ballroom, Sunset Deck, Mangrove Pool
7:30 – 10:00 pm	Demo Night Demos	Royal Ballroom 4-5 & Acacia Meeting Rooms
7:30 – 10:00 pm	Exhibits Open	Orchid Foyer

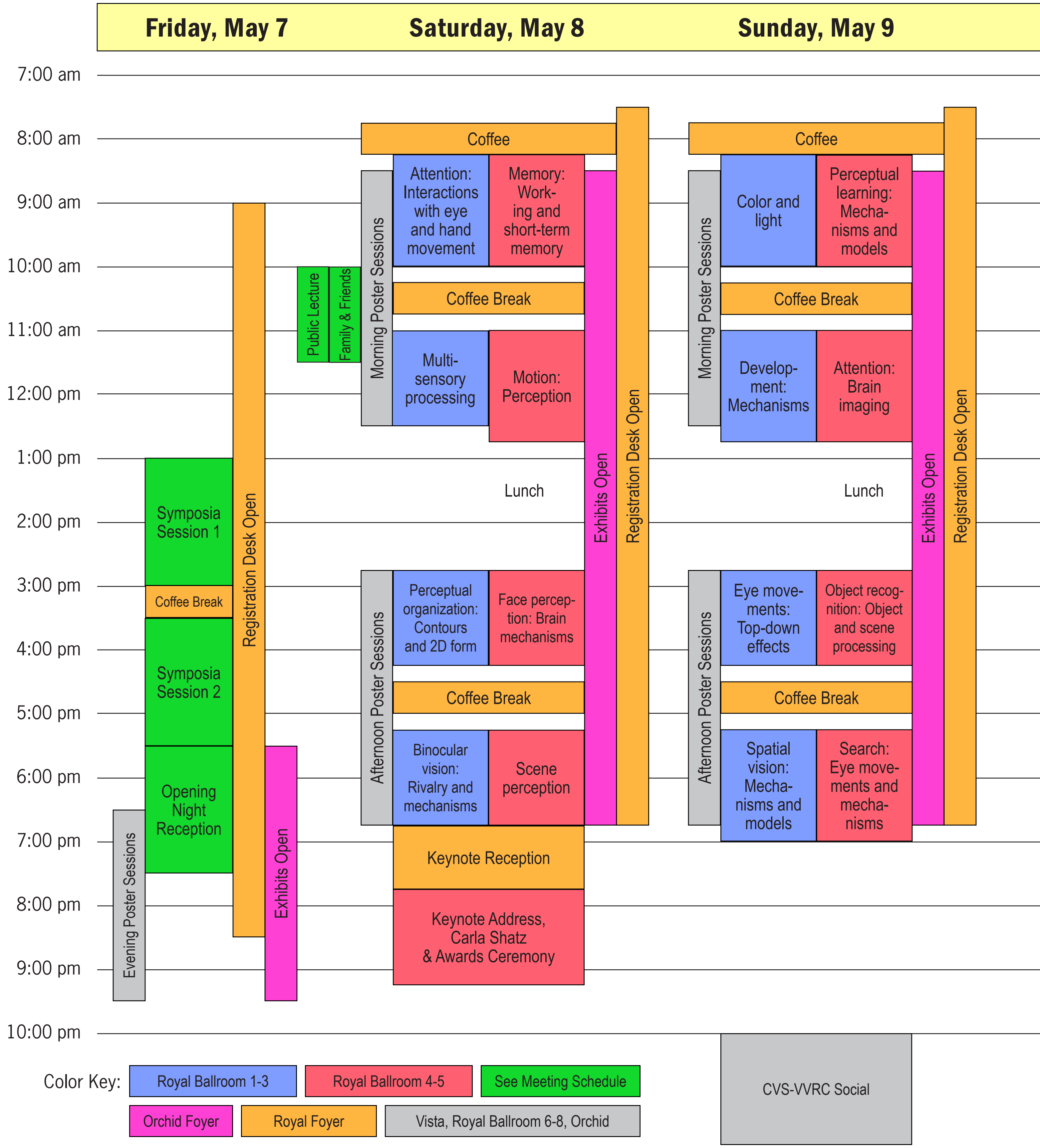
Tuesday, May 11

7:45 – 8:15 am	Coffee	Royal Foyer, Orchid Foyer
8:00 am – 6:45 pm	Registration Open	Royal Foyer
8:15 – 10:00 am	Talk Sessions	Royal Ballrooms 1-3 & 4-5
8:30 am – 12:30 pm	Poster Sessions	Royal Ballroom 6-8, Orchid Ballroom, Vista Ballroom
8:30 am – 6:45 pm	Exhibits Open	Orchid Foyer
10:15 – 10:45 am	Coffee Break	Royal Foyer, Orchid Foyer
11:00 am – 12:45 pm	Talk Sessions	Royal Ballrooms 1-3 & 4-5
12:45 – 2:45 pm	Lunch Break	Purchase a lunch at VSS Marketplace and head to the beach!*
2:45 – 4:15 pm	Talk Sessions	Royal Ballrooms 1-3, & 4-5
2:45 – 6:45 pm	Poster Sessions	Royal Ballroom 6-8, Orchid Ballroom, Vista Ballroom
4:30 – 5:00 pm	Coffee Break	Royal Foyer, Orchid Foyer
5:15 – 7:00 pm	Talk Sessions	Royal Ballrooms 1-3 & 4-5
9:00 – 10:00 pm	Open House for Graduate Students and Postdoctoral Fellows	Mangrove 1-2
10:00 pm – 2:00 am	Club Vision Dance Party	Vista Ballroom, Sunset Deck

Wednesday, May 12

7:45 – 8:15 am	Coffee	Royal Foyer. Orchid Foyer
8:00 am – 12:45 pm	Registration Open	Royal Foyer
8:15 – 10:00 am	Talk Sessions	Royal Ballrooms 1-3 & 4-5
8:30 am – 12:30 pm	Poster Sessions	Orchid Ballroom
10:15 – 10:45 am	Coffee Break	Royal Foyer, Orchid Foyer
11:00 am – 12:45 pm	Talk Sessions	Royal Ballrooms 1-3 & 4-5
12:45 pm	Meeting Ends	

* Salads, sandwiches, and snacks are available for purchase at the VSS Marketplace located on the ballroom level between the Royal and Orchid Foyers.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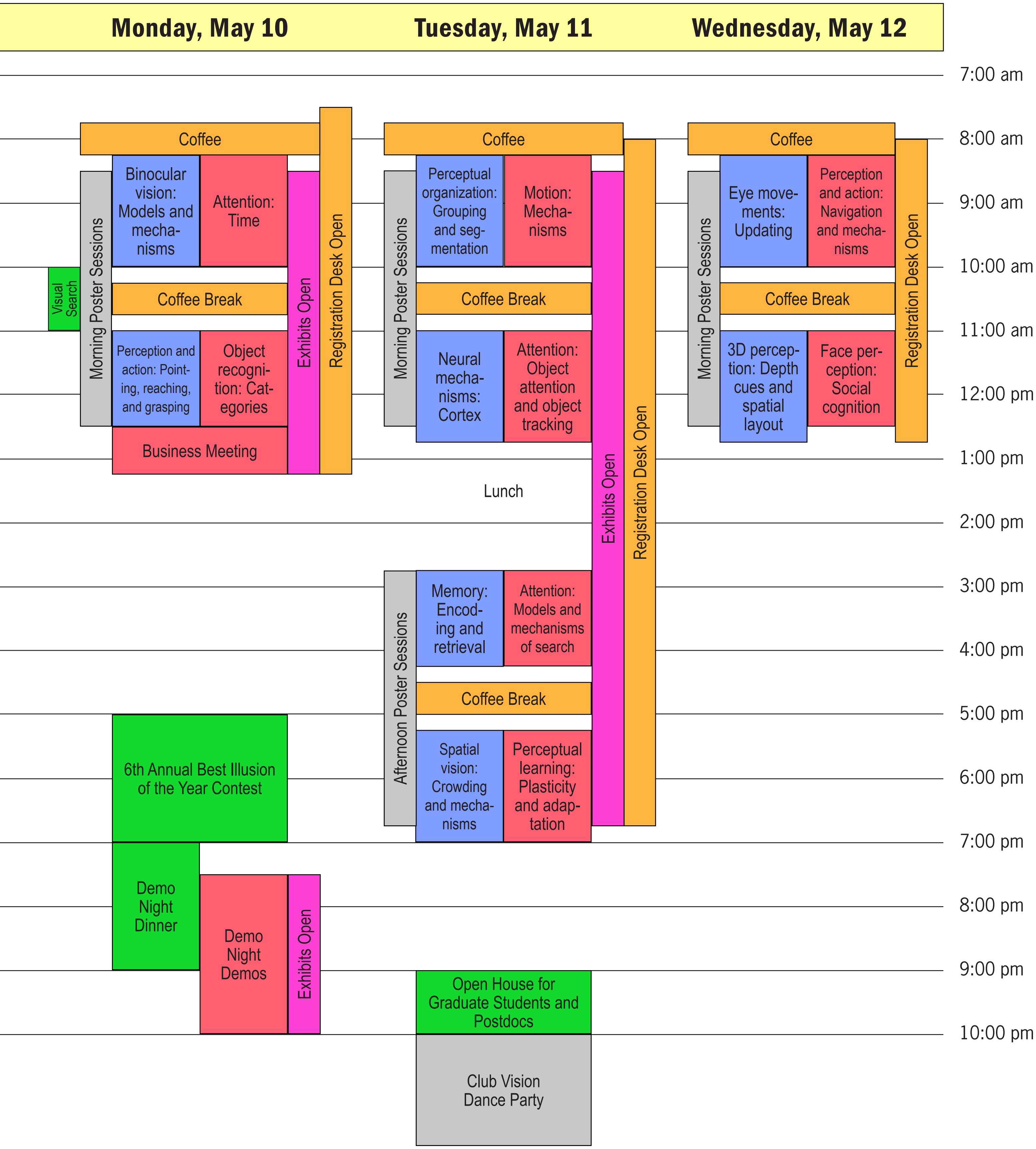
Symposia Session 1
Coffee Break
Symposia Session 2
Opening Night Reception
Evening Poster Sessions
Registration Desk Open
Exhibits Open
Public Lecture
Family & Friends
Coffee
Morning Poster Sessions
Attention: Interactions with eye and hand movement
Memory: Working and short-term memory
Coffee Break
Multi-sensory processing
Motion: Perception
Lunch
Exhibits Open
Registration Desk Open
Afternoon Poster Sessions
Perceptual organization: Contours and 2D form
Face perception: Brain mechanisms
Coffee Break
Binocular vision: Rivalry and mechanisms
Scene perception
Keynote Reception
Keynote Address, Carla Shatz & Awards Ceremony
Coffee
Morning Poster Sessions
Color and light
Perceptual learning: Mechanisms and models
Coffee Break
Development: Mechanisms
Attention: Brain imaging
Lunch
Exhibits Open
Registration Desk Open
Afternoon Poster Sessions
Eye movements: Top-down effects
Object recognition: Object and scene processing
Coffee Break
Spatial vision: Mechanisms and models
Search: Eye movements and mechanisms
CVS-VVRC Social
Color Key:
Royal Ballroom 1-3
Royal Ballroom 4-5
See Meeting Schedule
Orchid Foyer
Royal Foyer
Vista, Royal Ballroom 6-8, Orchid


Monday, May 10
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10:00 pm
Coffee
Visual Search
Morning Poster Sessions
Binocular vision: Models and mechanisms
Attention: Time
Coffee Break
Perception and action: Pointing, reaching, and grasping
Object recognition: Categories
Business Meeting
Exhibits Open
Registration Desk Open
6th Annual Best Illusion of the Year Contest
Demo Night Dinner
Demo Night Demos
Exhibits Open
Coffee
Morning Poster Sessions
Perceptual organization: Grouping and segmentation
Motion: Mechanisms
Coffee Break
Neural mechanisms: Cortex
Attention: Object attention and object tracking
Lunch
Afternoon Poster Sessions
Memory: Encoding and retrieval
Attention: Models and mechanisms of search
Coffee Break
Spatial vision: Crowding and mechanisms
Perceptual learning: Plasticity and adaptation
Exhibits Open
Registration Desk Open
Open House for Graduate Students and Postdocs
Club Vision Dance Party
Coffee
Morning Poster Sessions
Eye movements: Updating
Perception and action: Navigation and mechanisms
Coffee Break
3D perception: Depth cues and spatial layout
Face perception: Social cognition
Registration Desk Open

Poster Schedule

Poster Setup and Takedown

All poster sessions are held in the Royal Ballroom 6-8 and Orchid Ballroom on the Ballroom level, and Vista Ballroom on the Lobby level. The last three digits of your poster number indicate the number of your poster board.

Posters should be put up at the beginning of a session and taken down at the end. Authors of even numbered posters are expected to be present at their posters during the entire "Even Author Presents" time; and authors of odd numbered posters during the entire "Odd Author Presents" time. Authors may be present longer if desired.

Please be courteous and take down your poster promptly at the end of the session so that the board is empty when the next presenter arrives to put up his or her poster.

Push pins are available for your use and are located at the Meeting Registration Desk in the Royal Foyer.

Friday Afternoon, May 7

Setup: 5:30 – 6:30 pm
Session: 6:30 – 9:30 pm
Even Authors Present: 7:30 – 8:30 pm
Odd Authors Present: 8:30 – 9:30 pm
Room: Orchid Ballroom
- Perception and action: Locomotion
- Eye movements: Mechanisms and methods
- Development: Disorders
- Color and light: Adaptation and constancy
- 3D perception: Binocular and motion cues

Room: Vista Ballroom
- Object recognition: Development and learning
- Face perception: Development
- Attention: Reward, motivation, emotion
- Memory: Capacity and resolution of working and short-term memory

Take down: 9:30 – 9:45 pm

Saturday Morning, May 8

Setup: 8:00 – 8:30 am
Session: 8:30 am – 12:30 pm
Even Authors Present: 9:30 – 10:30am
Odd Authors Present: 10:30 – 11:30 am
Room: Royal Ballroom 6-8
- Spatial vision: Image statistics and texture
- Attention: Eye movements

Room: Orchid Ballroom
- Neural mechanisms: Cortical organization
- Color and light: Mechanisms
- Perception and action: Reaching and grasping
- Attention: Spatial selection and modulation

Room: Vista Ballroom
- Binocular vision: Rivalry and bistability
- Face perception: Experience
- Scene perception: Objects and scenes

Take down: 12:30 – 1:00 pm

Saturday Afternoon, May 8

Setup: 2:00 – 2:45 pm
Session: 2:45 – 6:45 pm
Even Authors Present: 3:45 – 4:45 pm
Odd Authors Present: 4:45 – 5:45 pm
Room: Royal Ballroom 6-8
- Attention: Temporal selection and modulation
- Attention: Divided attention
- Attention: Special populations

Room: Orchid Ballroom
- Neural mechanisms: Adaptation, awareness, action
- Perceptual learning: Specificity and transfer
- Motion: Mechanisms and Illusions
- Eye movements: Smooth pursuit
- Memory: Encoding and retrieval

Room: Vista Ballroom
- Object recognition: Features and categories
- Search: Neural mechanisms and behavior
- Search: Attention
- Spatial vision: Mechanisms and models

Take down: 6:45 – 7:00 pm

Sunday Morning, May 9

Setup: 8:00 – 8:30 am
Session: 8:30 am – 12:30 pm
Even Authors Present: 9:30 – 10:30am
Odd Authors Present: 10:30 – 11:30 am
Room: Royal Ballroom 6-8
- Spatial vision: Crowding and eccentricity
- Perception and action: Navigation and mechanisms

Room: Orchid Ballroom
- Perceptual organization: Temporal processing
- Perceptual organization: Objects
- Motion: Biological motion
- Attention: Numbers and things
- Search: Learning, memory and context

Room: Vista Ballroom
- Face perception: Emotional processing
- Face perception: Social cognition
- Scene perception: Categorization and memory
- Object recognition: Selectivity and invariance

Take down: 12:30 – 1:00 pm

Sunday Afternoon, May 9

Setup: 2:00 – 2:45 pm
Session: 2:45 – 6:45 pm
Even Authors Present: 3:45 – 4:45 pm
Odd Authors Present: 4:45 – 5:45 pm
Room: Royal Ballroom 6-8
- Neural mechanisms: Neurophysiology and theory
- Perception and action: Pointing and hitting

Room: Orchid Ballroom
- Perceptual learning: Sensory plasticity and adaptation
- Color and light: Lightness and brightness
- Attention: Capture
- Attention: Brain and behavior I

Room: Vista Ballroom
- 3D perception: Pictorial cues
- Face perception: Features
- Scene perception: Mechanisms
- Binocular vision: Stereo mechanisms
- Temporal processing: Mechanisms and models

Take down: 6:45 – 7:00 pm

Monday Morning, May 10

Setup: 8:00 – 8:30 am
Session: 8:30 am – 12:30 pm
Even Authors Present: 9:30 – 10:30am
Odd Authors Present: 10:30 – 11:30 am
Room: Royal Ballroom 6-8
- Eye movements: Selection and cognition
- Memory: Brain mechanisms of working and short-term memory

Room: Orchid Ballroom
- Attention: Deciding where we look
- Attention: Mechanisms and models
- Attention: Inattention and attention blindness
- Perceptual organization: Grouping and segmentation

Room: Vista Ballroom
- Motion: Mechanisms and models
- Face perception: Neural processing
- Multisensory processing: Visual-auditory interactions
- 3D perception: Spatial layout

Take down: 12:30 – 1:00 pm

Tuesday Morning, May 11

Setup: 8:00 – 8:30 am
Session: 8:30 am – 12:30 pm
Even Authors Present: 9:30 – 10:30am
Odd Authors Present: 10:30 – 11:30 am
Room: Royal Ballroom 6-8
- Memory: Objects and features in working and short-term memory
- Perceptual learning; Mechanisms and models

Room: Orchid Ballroom
- Color and light: Surfaces and materials
- Spatial vision: Cognitive factors
- Attention: Visual working memory
- Multisensory processing: Cross-modal perception
- Multisensory processing: Synesthesia
- Temporal processing: Perception of time

Room: Vista Ballroom
- Development: Early
- Perception and action: Mechanisms
- Object recognition: Recognition processes
- Face perception: Disorders

Take down: 12:30 – 1:00 pm

Tuesday Afternoon, May 12

Setup: 2:00 – 2:45 pm
Session: 2:45 – 6:45 pm
Even Authors Present: 3:45 – 4:45 pm
Odd Authors Present: 4:45 – 5:45 pm
Room: Royal Ballroom 6-8
- Binocular vision: Stereopsis
- Motion: Flow, depth, and spin

Room: Orchid Ballroom
- Neural mechanisms: Human electrophysiology
- Attention: Tracking
- Attention: Endogenous and exogenous
- Perceptual organization: Contours and 2D form
- 3D perception: Distance and size

Room: Vista Ballroom
- Eye movements: Perisaccadic perception
- Development: Lifespan
- Face perception: Eye movements
- Face perception: Parts and configurations

Take down: 6:45 – 7:00 pm

Wednesday Morning, May 12

Setup: 8:00 – 8:30 am
Session: 8:30 am – 12:30 pm
Even Authors Present: 9:30 – 10:30am
Odd Authors Present: 10:30 – 11:30 am
Room: Orchid Ballroom
- Scene perception: Aesthetics
- Color and light: Categories, culture and preferences
- Attention: Brain and behavior II
- Attention: Features and objects
- Spatial vision: Masking

Take down: 12:30 – 12:45 pm

Talk Schedule

Saturday, May 8

Time	Royal Ballroom 1-3	Royal Ballroom 4-5
8:15 – 10:00 am	Attention: Interactions with eye and hand movement	Memory: Working and short-term memory
11:00 am – 12:45 pm	Multisensory processing	Motion: Perception
2:45 – 4:15 pm	Perceptual organization: Contours and 2D form	Face perception: Brain mechanisms
5:15 – 6:45 pm	Binocular vision: Rivalry and mechanisms	Scene perception

Sunday, May 9

Time	Royal Ballroom 1-3	Royal Ballroom 4-5
8:15 – 10:00 am	Color and light	Perceptual learning: Mechanisms and models
11:00 am – 12:45 pm	Development: Mechanisms	Attention: Brain imaging
2:45 – 4:15 pm	Eye movements: Top-down effects	Object recognition: Object and scene processing
5:15 – 7:00 pm	Spatial vision: Mechanisms and models	Search: Eye movements and mechanisms

Monday, May 10

Time	Royal Ballroom 1-3	Royal Ballroom 4-5
8:15 – 10:00 am	Binocular vision: Models and mechanisms	Attention: Time
11:00 am – 12:30 pm	Perception and action: Pointing, reaching, and grasping	Object recognition: Categories

Tuesday, May 11

Time	Royal Ballroom 1-3	Royal Ballroom 4-5
8:15 – 10:00 am	Perceptual organization: Grouping and segmentation	Motion: Mechanisms
11:00 am – 12:45 pm	Neural mechanisms: Cortex	Attention: Object attention and object tracking
2:45 – 4:15 pm	Memory: Encoding and retrieval	Attention: Models and mechanisms of search
5:15 – 7:00 pm	Spatial vision: Crowding and mechanisms	Perceptual learning: Plasticity and adaptation

Wednesday, May 12

Time	Royal Ballroom 1-3	Royal Ballroom 4-5
8:15 – 10:00 am	Eye movements: Updating	Perception and action: Navigation and mechanisms
11:00 am – 12:45 pm	3D perception: Depth cues and spatial layout	Face perception: Social cognition

Speaker Information

Please arrive at the Ballroom no less than 30 minutes before the start of your session. Presenters are welcome to test their presentations between talk sessions. Please give priority to presenters whose talk is scheduled for the subsequent session.

The meeting rooms are equipped with a data/video projector and a projection screen. Presentations can be made from your Mac or PC laptop. A technician will be present in each room to handle any technical problems that may arise.

Member-Initiated Symposia

Symposium summaries are presented below. See the Abstracts book for the full text of each presentation. Pre-registration is not necessary to attend a symposium, but rooms will fill up quickly, so plan to arrive early.

Schedule Overview

Friday, May 7, 1:00 – 3:00 pm

S1 Integrative mechanisms for 3D vision: combining psychophysics, computation and neuroscience, Royal Palm Ballroom 1-3

S2 New Methods for Delineating the Brain and Cognitive Mechanisms of Attention, Royal Palm Ballroom 4-5

S3 Nature vs. Nurture in Vision: Evidence from Typical and Atypical Development, Royal Palm Ballroom 6-8

Friday, May 7, 3:30 – 5:30 pm

S4 Representation in the Visual System by Summary Statistics, Royal Palm Ballroom 1-3

S5 Understanding the interplay between reward and attention, and its effects on visual perception and action, Royal Palm Ballroom 4-5

S6 Dissociations between top-down attention and visual awareness, Royal Palm Ballroom 6-8

S1

Integrative mechanisms for 3D vision: combining psychophysics, computation and neuroscience

Friday, May 7, 1:00 – 3:00 pm, Royal Palm Ballroom 1-3

Organizer: Andrew Glennerster (University of Reading)

Presenters: Roland W. Fleming (Max Planck Institute for Biological Cybernetics), James T Todd (Department of Psychology, Ohio State University), Andrew Glennerster (University of Reading), Andrew E Welchman (University of Birmingham), Guy A Orban (K.U. Leuven), Peter Janssen (K.U. Leuven)

Symposium Summary

Estimating the three-dimensional (3D) structure of the world around us is a central component of our everyday behavior, supporting our decisions, actions and interactions. The problem faced by the brain is classically described in terms of the difficulty of inferring a 3D world from (“ambiguous”) 2D retinal images. The computational challenge of inferring 3D depth from retinal samples requires sophisticated neural machinery that learns to exploit multiple sources of visual information that are diagnostic of depth structure. This sophistication at the input level is demonstrated by our flexibility in perceiving shape under radically different viewing situations. For instance, we can gain a vivid impression of depth from a sparse collection of seemingly random dots, as well as from flat paintings. Adding to the complexity, humans exploit depth signals for a range of different behaviors, meaning that the input complexity is compounded by multiple functional outputs. Together, this poses a significant challenge when seeking to investigate empirically the sequence of computations that enable 3D vision.

This symposium brings together speakers from different perspectives to outline progress in understanding 3D vision. Fleming will start, addressing the question of “What is the information?”, using computational analysis of 3D shape to highlight basic principles that produce depth signatures from a range of cues. Todd and Glennerster will both consider the question of “How is this information represented?”, discussing different types of representational schemes and data structures. Welchman, Orban and Janssen will focus on the question of “How is it implemented in cortex?”. Welchman will discuss human fMRI studies that integrate psychophysics with concurrent measures of brain activity. Orban will review fMRI evidence for spatial correspondence in the processing of different depth cues in the human and monkey brain. Janssen will summarize results from single cell electrophysiology, highlighting the similarities and differences between the processing of 3D shape at the extreme ends of the dorsal and ventral pathways. Finally, Glennerster, Orban and Janssen will all address the question of how depth processing is affected by task.

The symposium should attract a wide range of VSS participants, as the topic is a core area of vision science and is enjoying a wave of public enthusiasm with the revival of stereoscopic entertainment formats. Further, the goal of the session in linking computational approaches to behavior to neural implementation is one that is scientifically attractive.

Presentations

From local image measurements to 3D shape

Roland W. Fleming, Max Planck Institute for Biological Cybernetics

There is an explanatory gap between the simple local image measurements of early vision, and the complex perceptual inferences involved in estimating object properties such as surface reflectance and 3D shape. The main purpose of my presentation will be to discuss how populations of filters tuned to different orientations and spatial frequencies can be ‘put to good use’ in the estimation of 3D shape. I’ll show how shading, highlights and texture patterns on 3D surfaces lead to highly distinctive signatures in the local image statistics, which the visual system could use in 3D shape estimation. I will discuss how the spatial organization of these measurements provides additional information, and argue that a common front end can explain both similarities and differences between various monocular cues. I’ll also present a number of 3D shape illusions and show how these can be predicted by image statistics, suggesting that human vision does indeed make use of these measurements.

The perceptual representation of 3D shape

James T Todd, Department of Psychology, Ohio State University

One of the fundamental issues in the study of 3D surface perception is to identify the specific aspects of an object’s structure that form the primitive components of an observer’s perceptual knowledge. After all, in order to understand shape perception, it is first necessary to define what ‘‘shape’’ is. In this presentation, I will assess several types of data structures that have been proposed for representing 3D surfaces. One of the most common data structures employed for this purpose involves a map of the geometric properties in each local neighborhood, such as depth, orientation or curvature. Numerous experiments have been performed in which observers have been required to make judgments of local surface properties, but the results reveal that these judgments are most often systematically distorted relative to the ground truth and surprisingly imprecise, thus suggesting that local property maps may not be the foundation of our perceptual knowledge about 3D shape. An alternative type of data structure for representing 3D shape involves a graph of the configural relationships among qualitatively distinct surface features, such as edges and vertices. The psychological validity of this type of representation has been supported by numerous psychophysical experiments, and by electrophysiological studies of macaque IT. A third type of data structure will also be considered in which surfaces are represented as a tiling of qualitatively distinct regions based on their patterns of curvature, and there is some neurophysiological evidence to suggest that this type of representation occurs in several areas of the primate cortex.

View-based representations and their relevance to human 3D vision

Andrew Glennerster, School of Psychology and CLS, University of Reading

In computer vision, applications that previously involved the generation of 3D models can now be achieved using view-based representations. In the movie industry this makes sense, since both the inputs and outputs of the algorithms are images, but the same could also be argued of human 3D vision. We explore the implications of view-based models in our experiments.

In an immersive virtual environment, observers fail to notice the expansion of a room around them and consequently make gross errors when comparing the size of objects. This result is difficult to explain if the visual system continuously generates a 3-D model of the scene using known baseline information from interocular separation or proprioception. If, on the other hand, observers use a view-based representation to guide their actions, they may have an expectation of the images they will receive but be insensitive to the rate at which images arrive as they walk.

In the same context, I will discuss psychophysical evidence on sensitivity to depth relief with respect to surfaces. The data are compatible with a hierarchical encoding of position and disparity similar to the affine model of Koenderink and van Doorn (1991). Finally, I will discuss two experiments that show how changing the observer's task changes their performance in a way that is incompatible with the visual system storing a 3D model of the shape or location of objects. Such task-dependency indicates that the visual system maintains information in a more 'raw' form than a 3D model.

The functional roles of visual cortex in representing 3D shape

Andrew E Welchman, School of Psychology, University of Birmingham

Estimating the depth structure of the environment is a principal function of the visual system, enabling many key computations, such as segmentation, object recognition, material perception and the guidance of movements. The brain exploits a range of depth cues to estimate depth, combining information from shading and shadows to linear perspective, motion and binocular disparity. Despite the importance of this process, we still know relatively little about the functional roles of different cortical areas in processing depth signals in the human brain. Here I will review recent human fMRI work that combines established psychophysical methods, high resolution imaging and advanced analysis methods to address this question. In particular, I will describe fMRI paradigms that integrate psychophysical tasks in order to look for a correspondence between changes in behavioural performance and fMRI activity. Further, I will review information-based fMRI analysis methods that seek to investigate different types of depth representation in parts of visual cortex. This work suggests a key role for a confined ensemble of dorsal visual areas in the processing information relevant to judgments of 3D shape.

Extracting depth structure from multiple cues

Guy A Orban, K.U. Leuven

Multiple cues provide information about the depth structure of objects: disparity, motion and shading and texture. Functional imaging studies in humans have been preformed to localize the regions involved in extracting depth structure from these four cues. In all these studies extensive controls were used to obtain activation sites specific for depth structure. Depth structure from motion, stereo and texture activates regions in both parietal and ventral cortex, but shading only activates a ventral region. For stereo and motion the balance between dorsal and ventral activation depends on the type of stimulus: boundaries versus surfaces. In monkey results are similar to those obtained in humans except that motion is a weaker cue in monkey parietal cortex. At the single cell level neurons are selective for gradients of speed, disparity and texture. Neurons selective for first and second order gradients of disparity will be discussed by P Janssen. I will concentrate on neurons selective for speed gradients and review recent data indicating that a majority of FST neurons is selective for second order speed gradients.

Neurons selective to disparity defined shape in the temporal and parietal cortex

Peter Janssen, K.U. Leuven; Bram-Ernst Verhoef, KU Leuven

A large proportion of the neurons in the rostral lower bank of the Superior Temporal Sulcus, which is part of IT, respond selectively to disparity-defined 3D shape (Janssen et al., 1999; Janssen et al., 2000). These IT neurons preserve their selectivity for different positions-in-depth, which proves that they respond to the spatial variation of disparity along the vertical axis of the shape (higher-order disparity selectivity). We have studied the responses of neurons in parietal area AIP, the end stage of the dorsal visual stream and crucial for object grasping, to the same disparity-defined 3D shapes (Srivastava et al., 2009). In this presentation I will review the differences between IT and AIP in the neural representation of 3D shape. More recent studies have investigated the role of AIP and IT in the perceptual discrimination of 3D shape using simultaneous recordings of spikes and local field potentials in the two areas, psychophysics and reversible inactivations. AIP and IT show strong synchronized activity during 3D-shape discrimination, but only IT activity correlates with perceptual choice. Reversible inactivation of AIP produces a deficit in grasping but does not affect the perceptual discrimination of 3D shape. Hence the end stages of both the dorsal and the ventral visual stream process disparity-defined 3D shape in clearly distinct ways. In line with the proposed behavioral role of the two processing streams, the 3D-shape representation in AIP is action-oriented but not crucial for 3D-shape perception.

S2

New Methods for Delineating the Brain and Cognitive Mechanisms of Attention

Friday, May 7, 1:00 – 3:00 pm, Royal Palm Ballroom 4-5

Organizer: George Sperling (University of California, Irvine)

Presenters: Edgar DeYoe (Medical College of Wisconsin), Jack L. Gallant (University of California, Berkeley), Albert J. Ahumada (NASA Ames Research Center, Moffett Field CA 94035), Wilson S. Geisler (The University of Texas at Austin), Barbara Anne Dosher (University of California, Irvine), George Sperling (University of California, Irvine)

Symposium Summary

This symposium brings together the world's leading specialists in six different subareas of visual attention. These distinguished scientists will expose the audience to an enormous range of methods, phenomena, and theories. It's not a workshop; listeners won't learn how to use the methods described, but they will become aware of the existence of diverse methods and what can be learned from them. The participants will aim their talks to target VSS attendees who are not necessarily familiar with the phenomena and theories of visual attention but who can be assumed to have some rudimentary understanding of visual information processing. The talks should be of interest to and understandable by all VSS attendees who have an interest in visual information processing: students, postdocs, academic faculty, research scientists, clinicians, and the symposium participants themselves. Attendees will see examples of the remarkable insights achieved by carefully controlled experiments combined with computational modeling. DeYoe reviews his extraordinary fMRI methods for localizing spatial visual attention in the visual cortex of alert human subjects to measure their ''attention maps''. He shows in exquisite detail how top-down attention to local areas in visual space changes the BOLD response (an indicator of neural activity) in corresponding local areas V1 of visual cortex and in adjacent spatiotopic visual processing areas. This work is of fundamental significance in defining the topography of attention and it has important clinical applications. Gallant is the premier exploiter of natural images in the study of visual cortical processing. His work uses computational models to define the neural processes of attention in V4 and throughout the attention hierarchy. Gallant's methods complement DeYoe's in that they reveal functions and purposes of attentional processing that often are overlooked with simple stimuli traditionally used. Ahumada, who introduced the reverse correlation paradigm in vision science, here presents a model for the eye movements in perhaps the simplest search task (which happens also to have practical importance): the search for a small target near horizon between ocean and sky. This is an introduction to the talk by Geisler. Geisler continues the theme of attention as optimizing performance in complex tasks in studies of visual search. He presents a computational model for how attention and stimulus factors jointly control eye movements and search success in arbitrarily complex and difficult search tasks. Eye movements in visual search approach those of an ideal observer in making optimal choices given the available information, and observers adapt (learn) rapidly when the nature of the information changes. Dosher has developed analytic descriptions of attentional processes that enable dissection of attention into three components: filter sharpening, stimulus enhancement, and altered gain control. She applies these analyses to show how subjects learn to adjust the components of attention to easy and to difficult tasks. Sperling reviews the methods used to quantitatively describe spatial and temporal attention windows, and to measure the amplification of attended features. He shows that different forms of attention act independently.

Presentations

I Know Where You Are Secretly Attending! The topography of human visual attention revealed with fMRI

Edgar DeYoe, Medical College of Wisconsin; Ritobrato Datta, Medical College of Wisconsin

Previous studies have described the topography of attention-related activation in retinotopic visual cortex for an attended target at one or a few locations within the subject's field of view. However, a complete description for all locations in the visual field is lacking. In this human fMRI study, we describe the complete topography of attention-related cortical activation throughout the central 28° of visual field and compare it with previous models. We cataloged separate fMRI-based maps of attentional topography in medial occipital visual cortex when subjects covertly attended to each target location in an array of 3 concentric rings of 6 targets each. Attentional activation was universally highest at the attended target but spread to other segments in a manner depending on eccentricity and/or target size.. We propose an "Attentional Landscape" model that is more complex than a 'spotlight' or simple 'gradient' model but includes aspects of both. Finally, we asked subjects to secretly attend to one of the 18 targets without informing the investigator. We then show that it is possible to determine the target of attentional scrutiny from the pattern of brain activation alone with 100% accuracy. Together, these results provide a comprehensive, quantitative and behaviorally relevant account of the macroscopic cortical topography of visuospatial attention. We also show how the pattern of attentional enhancement as it would appear distributed within the observer's field of view thereby permitting direct observation of a neurophysiological correlate of a purely mental phenomenon, the "window of attention."

Attentional modulation in intermediate visual areas during natural vision

Jack L. Gallant, University of California, Berkeley

Area v4 has been the focus of much research on neural mechanisms of attention. However, most of this work has focused on reduced paradigms involving simple stimuli such as bars and gratings, and simple behaviors such as fixation. The picture that has emerged from such studies suggests that the main effect of attention is to change response rate, response gain or contrast gain. In this talk I will review the current evidence regarding how neurons are modulated by attention under more natural viewing conditions involving complex stimuli and behaviors. The view that emerges from these studies suggests that attention operates through a variety of mechanisms that modify the way information is represented throughout the visual hierarchy. These mechanisms act in concert to optimize task performance under the demanding conditions prevailing during natural vision.

A model for search and detection of small targets

Albert J. Ahumada, NASA Ames Research Center, Moffett Field CA 94035

Computational models predicting the distribution of the time to detection of small targets on a display are being developed to improve workstation designs. Search models usually contain bottom-up processes, like a saliency map, and top-down processes, like a priori distributions over the possible locations to be searched. A case 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. Our models for this situation have incorporated a saccade-distance penalty and inhibition-of-return with a temporal decay. For very small, but high contrast targets, using the simple detection model that the target is detected if it is foveated is sufficient. For low contrast signals, a standard observer detection model with masking by the horizon edge is required. Accurate models of the the search and detection process without significant expectations or stimulus attractors should make it easier to estimate the way in which the expectations and attractors are combined when they are included.

Ideal Observer Analysis of Overt Attention

Wilson S. Geisler, The University of Texas at Austin

In most natural tasks humans use information detected in the periphery, together with context and other task-dependent constraints, to select their fixation locations (i.e., the locations where they apply the specialized processing associated with the fovea). A useful strategy for investigating the overt-attention mechanisms that drive fixation selection is to begin by deriving appropriate normative (ideal observer) models. Such ideal observer models can provide a deep understanding of the computational requirements of the task, a benchmark against which to compare human performance, and a rigorous basis for proposing and testing plausible hypotheses for the biological mechanisms. In recent years, we have been investigating the mechanisms of overt attention for tasks in which the observer is searching for a known target randomly located in a complex background texture (nominally a background of filtered noise having the average power spectrum of natural images). This talk will summarize some of our earlier and more recent findings (for our specific search tasks): (1) practiced humans approach ideal search speed and accuracy, ruling out many sub-ideal models; (2) human eye movement statistics are qualitatively similar to those of the ideal searcher; (3) humans select fixation locations that make near optimal use of context (the prior over possible target locations); (4) humans show relatively rapid adaptation of their fixation strategies to simulated changes in their visual fields (e.g., central scotomas); (5) there are biologically plausible heuristics that approach ideal performance.

Attention in High Precision Tasks and Perceptual Learning

Barbara Anne Dosher, University of California, Irvine; Zhong-Lin Lu, University of Southern California

At any moment, the world presents far more information than the brain can process. Visual attention allows the effective selection of information relevant for high priority processing, and is often more easily focused on one object than two. Both spatial selection and object attention have important consequences for the accuracy of task performance. Such effects are historically assessed primarily for relatively "easy" lower-precision tasks, yet the role of attention can depend critically on the demand for fine, high precision judgments. High precision task performance generally depends more upon attention and attention affects performance across all contrasts with or without noisy stimuli. Low precision tasks with similar processing loads generally show effects of attention only at intermediate contrasts and may be restricted to noisy display conditions. Perceptual learning can reduce the costs of inattention. The different roles of attention and task precision are accounted for within the context of an elaborated perceptual template model of the observer showing distinct functions of attention, and providing an integrated account of performance as a function of attention, task precision, external noise and stimulus contrast. Taken together, these provide a taxonomy of the functions and mechanisms of visual attention.

Modeling the Temporal, Spatial, and Featural Processes of Visual Attention

George Sperling, University of California, Irvine

A whirlwind review of the methods used to quantitatively define the temporal, spatial, and featural properties of attention, and some of their interactions. The temporal window of attention is measured by moving attention from one location to another in which a rapid sequence of different items (e.g., letters or numbers) is being presented. The probability of items from that sequence entering short-term memory defines the time course of attention: typically 100 msec to window opening, maxim at 300-400 msec, and 800 msec to closing. Spatial attention is defined like acuity, by the ability to alternately attend and ignore strips of increasingly finer grids. The spatial frequency characteristic so measured then predicts achievable attention distributions to arbitrarily defined regions. Featural attention is defined by the increased salience of items that contain to-be-attended features. This can be measured in various ways; quickest is an ambiguous motion task which shows that attended features have 30% greater salience than neutral features. Spatio-temporal interaction is measured when attention moves as quickly as possible to a designated area. Attention moves in parallel to all the to-be-attended areas, i.e., temporal-spatial independence. Independence of attentional modes is widely observed; it allows the most efficient neural processing.

S3

Nature vs. Nurture in Vision: Evidence from Typical and Atypical Development

Friday, May 7, 1:00 – 3:00 pm, Royal Palm Ballroom 6-8

Organizer: Faraz Farzin (University of California, Davis)

Presenters: Karen Dobkins (Department of Psychology, University of California, San Diego), Rain G. Bosworth (Department of Psychology, University of California, San Diego), Melanie Palomares (University of South Carolina), Anthony M. Norcia (The Smith-Kettlewell Eye Research Institute), Janette Atkinson (Visual Development Unit, Department of Developmental Science, University College London), Faraz Farzin (University of California, Davis)

Symposium Summary

The interplay between genetics and the environment is a rapidly advancing area in vision, yet it is a classic question in developmental research. In this symposium, each speaker will present empirical evidence supporting the contribution of genetic and/or environmental factors on specific visual processes, and will collectively discuss how these factors affect human visual development. The symposium has three aims: (1) to provide the opportunity for developmental researchers to come together and engage in collaborative dialogue in a single session at VSS, which has been neglected in recent years, (2) to synthesize a working knowledge of the biological and environmental influences on the functional and anatomical organization of the typically and atypically developing visual system, and (3) to advance the role of development in understanding visual mechanisms. Bringing together prominent scientists as well as young investigators, we anticipate that this symposium will appeal to those who share a common interest in understanding the nature of early vision and the factors which shape its development.

Presentations

Infant Contrast Sensitivity: Contributions of Factors Related to Visual Experience vs. Preprogrammed Mechanisms

Karen Dobkins, University of California, San Diego; Rain G. Bosworth, University of California, San Diego

In order to investigate potential effects of visual experience vs. preprogrammed mechanisms on visual development, we have investigated how well variation in contrast sensitivity (CS) across a large group of typical infants (n = 182) can be accounted for by a variety of factors that differ in the extent to which they are tied to visual experience. Using multiple regression analyses, we find that gestational length and gender, which are unlikely to be tied to visual experience, predict Luminance CS (thought to be mediated by the Magnocellular pathway). Other factors, which might be tied to either preprogrammed mechanisms or visual experience, specifically, birth order and small variations in postnatal age, predict Chromatic CS (thought to be mediated by the Parvocellular pathway) and Luminance CS. In addition, we have investigated effects of visual experience vs. preprogrammed mechanisms by studying CS in infant twins (n = 64). Our results show that the CS of both monozygotic (Mz) and dizygotic (Dz) twin pairs are significantly correlated with one another (accounting for ~35% of the variance in CS), which could be due to either shared environment or genetic preprogramming. More data will allow us to determine whether correlations are significantly stronger in Mz vs. Dz twins, which would provide direct evidence of effects of genetic preprogramming. Based on our multiple regression studies (above), as well as our studies of premature infants (presented in this symposium), we predict that genetic preprogrammimg will be more influential for Luminance (Magnocellular pathway) CS than Chromatic (Parvocellular pathway) CS.

Chromatic and Luminance Contrast Sensitivity in Fullterm and Preterm Infants: Effects of Early Visual Experience on Magnocellular and Parvocellular Pathway Processing

Rain G. Bosworth, University of California, San Diego; Karen Dobkins, University of California, San Diego

Study of healthy preterm infants affords an opportunity to investigate the contributions of visual experience vs. preprogrammed mechanisms on visual development. By comparing the developmental trajectories of contrast sensitivity (CS) in preterm vs. fullterm infants, we can determine if development is primarily tied to postterm age, in which visual maturation is governed by preprogrammed mechanisms timed to conception. By contrast, if development is tied to postnatal age, then visual maturation may be affected by visual experience. Using forced-choice preferential looking methods, data from 57 preterm (born 5-9 weeks early) and 97 fullterm infants were collected between 1–6 months postterm age (2-7 month postnatal age). Our visual measures were luminance (light/dark) and chromatic (red/green) CS, which are thought to be mediated by the Magnocellular and Parvocellular subcortical pathways, respectively. In the first few months, luminance CS was found to be predicted by postterm age, suggesting that preprogrammed development is sufficient to account for luminance CS. By contrast, chromatic CS significantly exceeded that predicted by postterm age, which suggests that time since birth (and by extension, visual experience) confers a benefit on chromatic CS. In sum, early Parvocellular pathway development appears to be more influenced by early postnatal visual experience than Magnocellular pathway development. We will present results comparing preterm infants born at different gestational ages, to determine if the slope of postnatal development changes with gestational length at birth. Finally, data will be compared to very preterm infants with retinopathy of prematurity.

Visual Evoked Potentials in Texture Segmentation: Are Boys and Girls Different?

Melanie Palomeres, University of South Carolina; Anthony M. Norcia, The Smith-Kettlewell Eye Research Institute

Texture-defined objects are shapes defined by boundaries based on discontinuities along a feature dimension (Nothdurft, 1993). Psychophysical studies in pediatric observers showed that detecting texture discontinuities based on orientation have been found to appear at 4-6 months of age mature in adolescence (Rieth & Sireteanu, 1992). We evaluated the neural correlates of texture-segmentation across development by measuring high-density visual-evoked potentials in typically-developing children and adults. We found that the formation of texture-defined form elicited VEP responses earlier in adults than in children. While there were no sex differences in VEP responses in adults, we found that response amplitudes in girls were much smaller than in boys of the same age. These results suggest that the neural responses in girls were more adult-like than in boys. This presentation will discuss the possible cortical substrate of this sex difference (e.g. Sowell, et al, 2007).

Experience Dependent Plasticity of human Form and Motion Mechanisms in Anisometropic Amblyopia

Anthony M. Norcia, The Smith-Kettlewell Eye Research Institute; Sean I. Chen, The Galway Clinic, Galway, Ireland; Arvind Chandna, Royal Liverpool Childrens Hospital, Liverpool, UK

Deprivation of visual input during developmental critical periods can have profound effects on the structure of visual cortex and on functional vision (Hubel and Wiesel 1963). Converging evidence from studies in human and animal models of amblyopia suggests that visual deprivation can have differential effects on different cortical pathways, consistent with the presence of multiple critical periods within the visual system as a whole (Harwerth, Smith et al. 1986). Anisometropia (unequal refractive error between the two eyes) is a common clinical condition in humans that can lead to very deep amblyopia if not treated. We studied the effects of visual deprivation secondary to anisometropia in a group of children before and after treatment for amblyopia. We recorded Visual Evoked Potentials (VEPs) evoked by vernier offsets of different sizes. This VEP paradigm (Norcia, Wesemann et al. 1999) elicits two qualitatively dissimilar response components, one associated with relative alignment or spatial position cues (form) and the other with transients due to motion or contrast change (motion) . Prior to treatment, the non-deprived eye shows supernormal form responses and normal motion responses. The amblyopic eye shows markedly reduced form responses and moderately reduced motion responses. Treatment via patching and glasses partially normalized the form responses in both eyes but had less of an effect on motion responses. The results indicate that form mechanisms are differentially susceptible to deprivation of high spatial frequency inputs during a developmental critical period.

Dorsal Stream Vulnerability: Interaction of Intrinsic Programmes and Acquired Developmental Disorders

Janette Atkinson, University College London; Oliver Braddick, University of Oxford

Global motion and global form sensitivity can provide a developmental indicator of extra-striate processing in the dorsal and ventral streams respectively, and measures of spatial cognition, visuo-motor co-ordination and control of attention offer higher level indicators of the integrity of the dorsal cortical stream. We will provide an overview of our own work and others using these measures to show that 'dorsal stream vulnerability' is a feature of many neurodevelopmental disorders, both genetic (Williams syndrome, fragile-X, and probably autism and dyslexia) and acquired (perinatal brain injury, prematurity, congenital cataract). Follow up of prematurely born infants at 6-7 years allows the distinct impacts of white matter injury, weeks gestation, and prematurity per se on different visuo-cognitive measures to be assessed.

Since both genetic and acquired disorders show differential effects on dorsal stream processing, this vulnerability cannot be considered either a direct effect of gene expression or of specific environmental impact. Rather, the unfolding programme by which the visual system is built, with genetic control in an environmental context, appears to make dorsal stream function vulnerable either to interaction with other genetic effects, or to various environmental disruptions. We will consider the developmental demands on dorsal stream function that may be responsible for this vulnerability. We will also review our findings, using novel high-density VERP measures, on the normal development of global motion processing and the reorganization of its cerebral basis between infancy and adulthood, which may help to understand the period(s) of development when the system is vulnerable to disruption.

The Role of the FMR1 Gene in Infant Contrast Sensitivity

Faraz Farzin, University of California, Davis and Center for Mind and Brain; David Whitney, University of California, Berkeley and Center for Mind and Brain, Davis; Flora Tassone, M.I.N.D. Institute; Susan M. Rivera, University of California, Davis, Center for Mind and Brain, Davis, and M.I.N.D. Institute

Fragile X syndrome (FXS) is characterized by the expansion of a CGG trinucleotide repeat within the FMR1 gene located on the X chromosome. Depending on the size of the CGG expansion, the mutation can be categorized as full (> 200 CGG repeats), which is associated with gene silencing and little to no FMR1 protein (FMRP) production, or premutation (55 - 200 CGG repeats), which is associated with high levels of FMR1 mRNA and decreased FMRP levels particularly in the upper permutation range. Several previous studies have reported impaired processing of temporally dynamic stimuli in infants, adolescents and adults with the FXS full mutation (Kogan et al, 2004, Farzin et al, 2008), and most recently in adult premutation carriers (Kéri and Benedek, 2008). Here, we assessed contrast sensitivity for second-order static and dynamic stimuli in male and female infants with the full mutation and the premutation, and compared their performance to mental age-matched typically developing infants. Our goal was to examine the molecular correlates of this visual deficit in infants with the disorder.

A forced-choice preferential looking paradigm was presented on an eye tracker to measure contrast sensitivity for second-order (texture-defined) static and dynamic stimuli. Michelson contrast levels were varied at four points between 10 and 42%. Infants' looking time to the side of the display that contained the stimulus, relative to their overall looking time, was measured to calculate a Visual Preference (VP) score. Logistic psychometric functions were fitted to the mean VP score at each contrast level to determine the minimum contrast value at which a 0.75 VP score was demonstrated. Our results revealed a significant difference in contrast sensitivity for second-order dynamic stimuli between TD infants and infants with the full mutation. Importantly, a significant negative correlation was found between contrast sensitivity for second-order dynamic stimuli and CGG repeat length, but not for sensitivity for second-order static stimuli. These findings confirm the role of the FMR1 gene in infant visual development, and specifically its involvement in sensitivity for parietally-mediated, attention-based dynamic stimuli. Critically, no molecular link was present for sensitivity for static stimuli. This is the first study to correlate performance on a psychophysical visual detection task with molecular measures in individuals with fragile X spectrum disorders. These results support the hypothesis that an abnormal molecular phenotype of the FMR1 gene is associated with the specific visual deficit of processing dynamic stimuli.

S4

Representation in the Visual System by Summary Statistics

Friday, May 7, 3:30 – 5:30 pm, Royal Palm Ballroom 1-3

Organizer: Ruth Rosenholtz (MIT Department of Brain & Cognitive Sciences)

Presenters: Ruth Rosenholtz (MIT Department of Brain & Cognitive Sciences), Josh Solomon (City University London), George Alvarez (Harvard University, Department of Psychology), Jeremy Freeman (Center for Neural Science, New York University), Aude Oliva (Department of Brain and Cognitive Sciences, Massachusetts Institute of Technology), Ben Balas (MIT, Department of Brain and Cognitive Sciences)

Symposium Summary

What is the representation in early vision? Considerable research has demonstrated that the representation is not equally faithful throughout the visual field; representation appears to be coarser in peripheral and unattended vision, perhaps as a strategy for dealing with an information bottleneck in visual processing. In the last few years, a convergence of evidence has suggested that in peripheral and unattended regions, the information available consists of summary statistics. "Summary statistics" is a general term used to represent a class of measurements made by pooling over visual features of various levels of complexity, e.g. 1st order statistics such as mean orientation; joint statistics of responses of V1-like oriented feature detectors; or ensemble statistics that represent spatial layout information. Depending upon the complexity of the computed statistics, many attributes of a pattern may be perceived, yet precise location and configuration information is lost in favor of the statistical summary.

This proposed representation for early vision is related to suggestions that the brain can compute summary statistics when such statistics are useful for a given task, e.g. texture segmentation, or explicit judgments of mean size of a number of items. However, summary statistic models of early visual representation additionally suggest that under certain circumstances summary statistics are what the visual system is "stuck with," even if more information would be useful for a given task.

This symposium will cover a range of related topics and methodologies. Talks by Rosenholtz, Solomon, and Alvarez will examine evidence for a statistical representation in vision, and explore the capabilities of the system, using both behavioral experiments and computational modeling. Freeman will discuss where summary statistics might be computed in the brain, based upon a combination of physiological findings, fMRI, and behavioral experiments.

Finally, we note that a summary statistic representation captures a great deal of important information, yet is ultimately lossy. Such a representation in peripheral and/or unattended vision has profound implications for visual perception in general, from peripheral recognition through visual awareness and visual cognition. Rosenholtz, Oliva, and Balas will discuss implications for a diverse set of tasks, including peripheral recognition, visual search, visual illusions, scene perception, and visual cognition. The power of this new way of thinking about vision becomes apparent precisely from implications for a wide variety of visual tasks, and from evidence from diverse methodologies.

Presentations

The Visual System as Statistician: Statistical Representation in Early Vision

Ruth Rosenholtz, MIT Department of Brain & Cognitive Sciences; B. J. Balas, Dept. of Brain & Cognitive Sciences, MIT; Alvin Raj, Computer Science and AI Lab, MIT; Lisa Nakano, Stanford; Livia Ilie, MIT

We are unable to process all of our visual input with equal fidelity. At any given moment, our visual systems seem to represent the item we are looking at fairly faithfully. However, evidence suggests that our visual systems encode the rest of the visual input more coarsely. What is this coarse representation? Recent evidence suggests that this coarse encoding consists of a representation in terms of summary statistics. For a complex set of statistics, such a representation can provide a rich and detailed percept of many aspects of a visual scene. However, such a representation is also lossy; we would expect the inherent ambiguities and confusions to have profound implications for vision. For example, a complex pattern, viewed peripherally, might be poorly represented by its summary statistics, leading to the degraded recognition experienced under conditions of visual crowding. Difficult visual search might occur when summary statistics could not adequately discriminate between a target-present and distractor-only patch of the stimuli. Certain illusory percepts might arise from valid interpretations of the available – lossy – information. It is precisely visual tasks upon which a statistical representation has significant impact that provide the evidence for such a representation in early vision. I will summarize recent evidence that early vision computes summary statistics based upon such tasks.

Efficiencies for estimating mean orientation, mean size, orientation variance and size variance

Josh Solomon, City University London; Michael J. Morgan, City University London; Charles Chubb, University of California, Irvine

The merest glance is usually sufficient for an observer to get the gist of a scene. That is because the visual system statistically summarizes its input. We are currently exploring the precision and efficiency with which orientation and size statistics can be calculated. Previous work has established that orientation discrimination is limited by an intrinsic source of orientation-dependent noise, which is approximately Gaussian. New results indicate that size discrimination is also limited by approximately Gaussian noise, which is added to logarithmically transduced circle diameters. More preliminary results include: 1a) JAS can discriminate between two successively displayed, differently oriented Gabors, at 7 deg eccentricity, without interference from 7 iso-eccentric, randomly oriented distractors. 1b) He and another observer can discriminate between two successively displayed, differently sized circles, at 7 deg eccentricity, without much interference from 7 iso-eccentric distractors. 2a) JAS effectively uses just two of the eight uncrowded Gabors when computing their mean orientation. 2b) He and another observer use at most four of the eight uncrowded circles when computing their mean size. 3a) Mean-orientation discriminations suggest a lot more Gaussian noise than orientation-variance discriminations. This surprising result suggests that cyclic quantities like orientation may be harder to remember than non-cyclic quantities like variance. 3b) Consistent with this hypothesis is the greater similarity between noise estimates from discriminations of mean size and size variance.

The Representation of Ensemble Statistics Outside the Focus of Attention

George Alvarez, Harvard University, Department of Psychology

We can only attend to a few objects at once, and yet our perceptual experience is rich and detailed. What type of representation could enable this subjective experience? I have explored the possibility that perception consists of (1) detailed and accurate representations of currently attended objects, plus (2) a statistical summary of information outside the focus of attention. This point of view makes a distinction between individual features and statistical summary features. For example, a single object's location is an individual feature. In contrast, the center of mass of several objects (the centroid) is a statistical summary feature, because it collapses across individual details and represents the group overall. Summary statistics are more accurate than individual features because random, independent noise in the individual features cancels out when averaged together. I will present evidence that the visual system can compute statistical summary features outside the focus of attention even when local features cannot be accurately reported. This finding holds for simple summary statistics including the centroid of a set of uniform objects, and for texture patterns that resemble natural image statistics. Thus, it appears that information outside the focus of attention can be represented at an abstract level that lacks local detail, but nevertheless carries a precise statistical summary of the scene. The term 'ensemble features' refers to a broad class of statistical summary features, which we propose collectively comprise the representation of information outside the focus of attention (i.e., under conditions of reduced attention).

Linking statistical texture models to population coding in the ventral stream

Jeremy Freeman, Center for Neural Science, New York University; Luke E. Hallum, Center for Neural Science & Dept. of Psychology, NYU; Michael S. Landy, Center for Neural Science & Dept. of Psychology, NYU; David J. Heeger, Center for Neural Science & Dept. of Psychology, NYU; Eero P. Simoncelli, Center for Neural Science, Howard Hughes Medical Institute, & the Courant Institute of Mathematical Sciences, NYU

How does the ventral visual pathway encode natural images? Directly characterizing neuronal selectivity has proven difficult: it is hard to find stimuli that drive an individual cell in the extrastriate ventral stream, and even having done so, it is hard to find a low-dimensional parameter space governing its selectivity. An alternative approach is to examine the selectivity of neural populations for images that differ statistically (e.g. in Rust & DiCarlo, 2008). We develop a model of extrastriate populations that compute correlations among the outputs of V1-like simple and complex cells at nearby orientations, frequencies, and positions (Portilla & Simoncelli, 2001). These correlations represent the complex structure of visual textures: images synthesized to match the correlations of an original texture image appear texturally similar. We use such synthetic textures as experimental stimuli. Using fMRI and classification analysis, we show that population responses in extrastriate areas are more variable across different textures than across multiple samples of the same texture, suggesting that neural representations in ventral areas reflect the image statistics that distinguish natural textures. We also use psychophysics to explore how the representation of these image statistics varies over the visual field. In extrastriate areas, receptive field sizes grow with eccentricity. Consistent with recent work by Balas et al. (2009), we model this by computing correlational statistics averaged over regions corresponding to extrastriate receptive fields. This model synthesizes metameric images that are physically different but appear identical because they are matched for local statistics. Together, these results show how physiological and psychophysical measurements can be used to link image statistics to population representations in the ventral stream.

High level visual ensemble statistics: Encoding the layout of visual space

Aude Oliva, Department of Brain and Cognitive Sciences, Massachusetts Institute of Technology

Visual scene understanding is central to our interactions with the world. Recognizing the current environment facilitates our ability to act strategically, for example in selecting a route for walking, anticipating where objects are likely to appear, and knowing what behaviors are appropriate in a particular context. In this talk, I will discuss a role for statistical, ensemble representations in scene and space representation. Ensemble features correspond to a higher-level description of the input that summarizes local measurements. With this ensemble representation, the distribution of local features can be inferred and used to reconstruct multiple candidate visual scenes that share similar ensemble statistics. Pooling over local measurements of visual features in natural images is one mechanism for generating a holistic representation of the spatial layout of natural scenes. A model based on such summary representation is able to estimate scene layout properties as humans do. Potentially, the richness of content and spatial volume in a scene can be at least partially captured using the compressed yet informative description of statistical ensemble representations.

Beyond texture processing: further implications of statistical representations

Ben Balas, MIT, Department of Brain and Cognitive Sciences; Ruth Rosenholtz, MIT; Alvin Raj, MIT

The proposal that peripherally-viewed stimuli are represented by summary statistics of visual structure has implications for a wide range of tasks. Already, my collaborators and I have demonstrated that texture processing, crowding, and visual search appear to be well-described by such representations, and we suggest that it may be fruitful to significantly extend the scope of our investigations into the affordances and limitations of a "statistical" vocabulary. Specifically, we submit that many tasks that have been heretofore described broadly as "visual cognition" tasks may also be more easily understood within this conceptual framework. How do we determine whether an object lies within a closed contour or not? How do we judge if an unobstructed path can be traversed between two points within a maze? What makes it difficult to determine the impossibility of "impossible" objects under some conditions? These specific tasks appear to be quite distinct, yet we suggest that what they share is a common dependence on the visual periphery that constrains task performance by the imposition of a summary-statistic representation of the input. Here, we shall re-cast these classic problems of visual perception within the context of a statistical representation of the stimulus and discuss how our approach offers fresh insight into the processes that support performance in these tasks and others.

S5

Understanding the interplay between reward and attention, and its effects on visual perception and action

Friday, May 7, 3:30 – 5:30 pm, Royal Palm Ballroom 4-5

Organizers: Vidhya Navalpakkam (Caltech), Leonardo Chelazzi (University of Verona, Medical School, Italy), Jan Theeuwes (Vrije Universiteit, the Netherlands)

Presenters: Leonardo Chelazzi (Department of Neurological and Visual Sciences, University of Verona – Medical School, Italy), Clayton Hickey (Department of Cognitive Psychology, Vrije Universiteit Amsterdam, The Netherlands), Vidhya Navalpakkam (Division of Biology, Caltech, Pasadena), Miguel Eckstein (Department of Psychology, University of California, Santa Barbara), Pieter R. Roelfsema (Dept. Vision & Cognition, Netherlands Institute for Neuroscience, Amsterdam), Jacqueline Gottlieb (Dept. of Neuroscience and Psychiatry, Columbia University, New York)

Symposium Summary

Adaptive behavior requires that we deploy attention to behaviorally relevant objects in our visual environment. The mechanisms of selective visual attention and how it affects visual perception have been a topic of extensive research in the last few decades. In comparison, little is known about the role of reward incentives and how they affect attention and visual perception. Generally, we choose actions that in prior experience have resulted in a rewarding outcome, a principle that has been formalized in reward learning theory. Recent developments in vision research suggest that selective attention may be guided by similar economic principles. This symposium will provide a forum for researchers examining the interplay between reward and attention, and their effects on visual perception and action, to present their work and discuss their developing ideas.

The goal of this symposium will be to help bridge the existing gap between the fields of vision that focused on attention, and decision-making that focused on reward, to better understand the combined roles of reward and attention on visual perception and action. Experts from different faculties including psychology, neuroscience and computational modeling will present novel findings on reward and attention, and outline challenges and future directions, that we hope will lead to a cohesive theory. The first three talks will focus on behavior and modeling. Leo Chelazzi will speak about how attentional deployment may be biased by the reward outcomes of past attentional episodes, such as the gains and losses associated with attending to objects in the past. Vidhya Navalpakkam will speak about how reward information may bias saliency computations to influence overt attention and choice in a visual search task. Miguel Eckstein will show how human eye movement strategies are influenced by reward, and how they compare with an ideal reward searcher. The last three talks will focus on neurophysiological evidence for interactions between reward and attention. Clayton Hickey will provide behavioral and EEG evidence for direct, non-volitional role of reward-related reinforcement learning in human attentional control. Pieter Roelfsema will present neural evidence on the remarkable correspondence between effects of reward and attention on competition between multiple stimuli, as early as in V1, suggesting a unification of theories of reward expectancy and attention. Finally, Jacqueline Gottlieb will present neural evidence from LIP on how reward-expectation shapes attention, and compare it with studies on how reward-expectation shapes decision-making.

We expect the symposium to be relevant to a wide audience with interests in psychology, neuroscience, and modeling of attention, reward, perception or decision-making.

Presentations

Gains and losses adaptively adjust attentional deployment towards specific objects

Leonardo Chelazzi, Department of Neurological and Visual Sciences, University of Verona – Medical School, Italy; Andrea Perlato, Department of Neurological and Visual Sciences, University of Verona – Medical School, Italy; Chiara Della Libera, Department of Neurological and Visual Sciences, University of Verona – Medical School, Italy

The ability to select and ignore specific objects improves considerably due to prior experience (attentional learning). However, such learning, in order to be adaptive, should depend on the more-or-less favourable outcomes of past attentional episodes. We have systematically explored this possibility by delivering monetary rewards to human observers performing attention-demanding tasks. In all experiments, participants were told that high and low rewards indexed optimal and sub-optimal performance, respectively, though reward amount was entirely pre-determined. Firstly, we demonstrated that rewards adjust the immediate consequences of actively ignoring a distracter, known as negative priming. Specifically, we found that negative priming is only obtained following high rewards, indicating that lingering inhibition is abolished by poor outcomes. Subsequently, we assessed whether rewards can also adjust attentional biases in the distant future. Here, observers were trained with a paradigm where, on each trial, they selected a target while ignoring a distracter, followed by differential reward. Importantly, the probability of a high vs. low reward varied for different objects. Participants were then tested days later in the absence of reward. We found that now the observers' ability to select and ignore specific objects strongly depended on the probability of high vs. low reward associated to a given object during training and also critically on whether the imbalance had been applied when the object was shown as target or distracter during training. These observations show that an observer's attentional biases towards specific objects strongly reflect the more-or-less favourable outcomes of past attentional processing of the same objects.

Understanding how reward and saliency affect overt attention and decisions

Vidhya Navalpakkam, Division of Biology, Caltech; Christof Koch, Division of Engineering, Applied Science and Biology, Caltech; Antonio Rangel, Division of Humanities and Social Sciences, Caltech; Pietro Perona, Division of Engineering and Applied Science, Caltech

The ability to rapidly choose among multiple valuable targets embedded in a complex perceptual environment is key to survival in many animal species. Targets may differ both in their reward value as well as in their low-level perceptual properties (e.g., visual saliency). Previous studies investigated separately the impact of either value on decisions, or saliency on attention, thus it is not known how the brain combines these two variables to influence attention and decision-making. In this talk, I will describe how we addressed this question with three experiments in which human subjects attempted to maximize their monetary earnings by rapidly choosing items from a brief display. Each display contained several worthless items (distractors) as well as two targets, whose value and saliency were varied systematically. The resulting behavioral data was compared to the predictions of three computational models which assume that: (1) subjects seek the most valuable item in the display, (2) subjects seek the most easily detectable item (e.g., highest saliency), (3) subjects behave as an ideal Bayesian observer who combines both factors to maximize expected reward within each trial. We find that, regardless of the motor response used to express the choices, decisions are influenced by both value and feature-contrast in a way that is consistent with the ideal Bayesian observer. Thus, individuals are able to engage in optimal reward harvesting while seeking multiple relevant targets amidst clutter. I will describe ongoing studies on whether attention, like decisions, may also be influenced by value and saliency to optimize reward harvesting.

Optimizing eye movements in search for rewards

Miguel Eckstein, Department of Psychology, University of California, Santa Barbara; Wade Schoonveld, Department of Psychology, University of California, Santa Barbara; Sheng Zhang, Department of Psychology, University of California, Santa Barbara

There is a growing literature investigating how rewards influence the planning of saccadic eye movements and the activity of underlying neural mechanisms (for a review see, Trommershauser et al., 2009). Most of these studies reward correct eye movements towards a target at a given location (e.g., Liston and Stone, 2008). Yet, in every day life, rewards are not directly linked to eye movements but rather to a correct perceptual decision and follow-up action. The role of eye movements is to explore the visual scene and maximize the gathering of information for a subsequent perceptual decision. In this context, we investigate how varying the rewards across locations assigned to correct perceptual decisions in a search task influences the planning of human eye movements. We extend the ideal Bayesian searcher (Najemnik & Geisler, 2005) by explicitly including reward structure to: 1) determine the (optimal) fixation sequences that maximize total reward gains; 2) predict the theoretical increase in gains from taking into account reward structure in planning eye movements during search. We show that humans strategize their eye movements to collect more reward. The pattern of human fixations shares many of the properties with the fixations of the ideal reward searcher. Human increases in total gains from using information about the reward structure are also comparable to the benefits in gains of the ideal searcher. Finally, we use theoretical simulations to show that the observed discrepancies between the fixations of humans and the ideal reward searcher do not have major impact in the total collected rewards. Together, the results increase our understanding of how rewards influence optimal and human saccade planning in ecologically valid tasks such as visual search.

Incentive salience in human visual attention

Clayton Hickey, Department of Cognitive Psychology, Vrije Universiteit Amsterdam; Leonardo Chelazzi, Department of Neurological and Visual Sciences, University of Verona - Medical School; Jan Theeuwes, Department of Cognitive Psychology, Vrije Universiteit Amsterdam

Reward-related midbrain dopamine guides animal behavior, creating automatic approach towards objects associated with reward and avoidance from objects unlikely to be beneficial. Using measures of behavior and brain electricity we show that the dopamine system implements a similar principle in the deployment of covert attention in humans. Participants attend to an object associated with monetary reward and ignore an object associated with sub-optimal outcome, and do so even when they know this will result in bad task performance. The strength of reward's impact on attention is predicted by the neural response to reward feedback in anterior cingulate cortex, a brain area known to be a part of the dopamine reinforcement circuit. These results demonstrate a direct, non-volitional role for reinforcement learning in human attentional control.

Reward expectancy biases selective attention in the primary visual cortex

Pieter R. Roelfsema, Dept. Vision & Cognition, Netherlands Institute for Neuroscience, Amsterdam; Chris van der Togt, Dept. Vision & Cognition, Netherlands Institute for Neuroscience, Amsterdam; Cyriel Pennartz, Dept. Vision & Cognition, Netherlands Institute for Neuroscience, Amsterdam; Liviu Stanisor, Dept. Vision & Cognition, Netherlands Institute for Neuroscience, Amsterdam

Rewards and reward expectations influence neuronal activity in many brain regions as stimuli associated with a higher reward tend to give rise to stronger neuronal responses than stimuli associated with lower rewards. It is difficult to dissociate these reward effects from the effects of attention, as attention also modulates neuronal activity in many of the same structures (Maunsell, 2004). Here we investigated the relation between rewards and attention by recording neuronal activity in the primary visual cortex (area V1), an area usually not believed to play a crucial role in reward processing, in a curve-tracing task with varying rewards. We report a new effect of reward magnitude in area V1 where highly rewarding stimuli cause more neuronal activity than unrewarding stimuli, but only if there are multiple stimuli in the display. Our results demonstrate a remarkable correspondence between reward and attention effects. First, rewards bias the competition between simultaneously presented stimuli as is also true for selective attention. Second, the latency of the reward effect is similar to the latency of attentional modulation (Roelfsema, 2006). Third, neurons modulated by rewards are also modulated by attention. These results inspire a unification of theories about reward expectation and selective attention.

How reward shapes attention and the search for information

Jacqueline Gottlieb, Dept. of Neuroscience and Psychiatry, Columbia University; Christopher Peck, Dept. of Neuroscience and Psychiatry, Columbia University; Dave Jangraw, Dept. of Neuroscience and Psychiatry, Columbia University

In the neurophysiological literature with non-human primates, much effort has been devoted to understanding how reward expectation shapes decision making, that is, the selection of a specific course of action. On the other hand, we know nearly nothing about how reward shapes attention, the selection of a source of information. And yet, understanding how organisms value information is critical for predicting how they will allocate attention in a particular task. In addition, it is critical for understanding active learning and exploration, behaviors that are fundamentally driven by the need to discover new information that may prove valuable for future tasks.

To begin addressing this question we examined how neurons located in the parietal cortex, which encode the momentary locus of attention, are influenced by the reward valence of visual stimuli. We found that reward predictors bias attention in valence-specific manner. Cues predicting reward produced a sustained excitatory bias and attracted attention toward their location. Cues predicting no reward produced a sustained inhibitory bias and repulsed attention from their location. These biases were persisted and even grew with training, even though they came in conflict with the operant requirement of the task, thus lowering the animal's task performance. This pattern diverges markedly from the assumption of reinforcement learning (that training improves performance and overcomes maladaptive biases, and suggests that the effects of reward on attention may differ markedly from the effects on decision making. I will discuss these findings and their implications for reward and reward-based learning in cortical systems of attention.

S6

Dissociations between top-down attention and visual awareness

Friday, May 7, 3:30 – 5:30 pm, Royal Palm Ballroom 6-8

Organizers: Jeroen van Boxtel (California Institute of Technology and Nao Tsuchiya, California Institute of Technology, USA and Tamagawa University, Japan)

Presenters: Nao Tsuchiya (California Institute of Technology, USA, Tamagawa University, Japan), Jeroen J.A. van Boxtel (California Institute of Technology, USA), Takeo Watanabe (Boston University), Joel Voss (Beckman Institute, University of Illinois Urbana-Champaign, USA), Alex Maier (National Institute of Mental Health, NIH)

Symposium Summary

Historically, the pervading assumption among sensory psychologists has been that attention and awareness are intimately linked, if not identical, processes. However, a number of recent authors have argued that these are two distinct processes, with different functions and underlying neuronal mechanisms. If this position were correct, we should be able to dissociate the effects of attention and awareness with some experimental manipulation. Furthermore, we might expect extreme cases of dissociation, such as when attention and awareness have opposing effects on some task performance and its underlying neuronal activity. In the last decade, a number of findings have been taken as support for the notion that attention and awareness are distinct cognitive processes. In our symposium, we will review some of these results and introduce psychophysical methods to manipulate top-down attention and awareness independently. Throughout the symposium, we showcase the successful application of these methods to human psychophysics, fMRI and EEG as well as monkey electrophysiology.

First, Nao Tsuchiya will set the stage for the symposium by offering a brief review of recent psychophysical studies that support the idea of awareness without attention as well as attention without awareness. After discussing some of the methodological limitations of these approaches, Jeroen VanBoxtel will show direct evidence that attention and awareness can result in opposite effects for the formation of afterimages. Takeo Watanabe's behavioral paradigm will demonstrate that subthreshold motion can be more distracting than suprathreshold motion. He will go on to show the neuronal substrate of this counter-intuitive finding with fMRI. Joel Voss will describe how perceptual recognition memory can occur without awareness following manipulations of attention, and how these effects result from changes in the fluency of neural processing in visual cortex measured by EEG. Finally, Alexander Maier will link these results in the humans studies to neuronal recordings in monkeys, where the attentional state and the visibility of a stimulus are manipulated independently in order to study the neuronal basis of each.

A major theme of our symposium is that emerging evidence supports the notion that attention and awareness are two distinctive neuronal processes. Throughout the symposium, we will discuss how dissociative paradigms can lead to new progress in the quest for the neuronal processes underlying attention and awareness. We emphasize that it is important to separate out the effects of attention from the effects of awareness. Our symposium would benefit most vision scientists, interested in visual attention or visual awareness because the methodologies we discuss would inform them of paradigms that can dissociate attention from awareness. Given the novelty of these findings, our symposium will cover a terrain that remains largely untouched by the main program.

Presentations

The relationship between top-down attention and conscious awareness

Nao Tsuchiya, California Institute of Technology, USA, Tamagawa University, Japan

Although a claim that attention and awareness are different has been suggested before, it has been difficult to show clear dissociations due to their tight coupling in normal situations; top-down attention and visibility of stimulus both improve the performance in most visual tasks. As proposed in this workshop, however, putative difference in their functional and computational roles implies a possibility that attention and awareness may affect visual processing in different ways. After brief discussion on the functional and computational roles of attention and awareness, we will introduce psychophysical methods that independently manipulate visual awareness and spatial, focal top-down attention and review the recent studies showing consciousness without attention and attention without consciousness.

Opposing effects of attention and awareness on afterimages

Jeroen J.A. van Boxtel, California Institute of Technology, USA

The brain's ability to handle sensory information is influenced by both selective attention and awareness. There is still no consensus on the exact relationship between these two processes and whether or not they are distinct. So far, no experiment simultaneously manipulated both, which severely hampers discussions on this issue. We here describe a full factorial study of the influences of attention and awareness (as assayed by visibility) on afterimages. We investigated the duration of afterimages for all four combinations of high versus low attention and visible versus invisible grating. We demonstrate that selective attention and visual awareness have opposite effects: paying attention to the grating decreases the duration of its afterimage, while consciously seeing the grating increases afterimage duration. We moreover control for various possible confounds, including stimulus, and task changes. These data provide clear evidence for distinctive influences of selective attention and awareness on visual perception.

Role of subthreshold stimuli in task-performance and its underlying mechanism

Takeo Watanabe, Boston University

Considerable evidence exists indicating that a stimulus which is subthreshold and thus consciously invisible, influences brain activity and behavioral performance. However, it is not clear how subthreshold stimuli are processed in the brain. We found that a task-irrelevant subthreshold coherent motion leads to stronger disturbance in task performance than suprathreshold motion. With the subthreshold motion, fMRI activity in the visual cortex was higher, but activity in the dorsolateral prefrontal cortex (DLPFC) was lower, than with suprathreshold motion. The results of the present study demonstrate two important points. First, a weak task-irrelevant stimulus feature which is below but near the perceptual threshold more strongly activates visual area (MT+) which is highly related to the stimulus feature and more greatly disrupts task performance. This contradicts the general view that irrelevant signals that are stronger in stimulus properties more greatly influence the brain and performance and that the influence of a subthreshold stimulus is smaller than that of suprathreshold stimuli. Second, the results may reveal important bidirectional interactions between a cognitive controlling system and the visual system. LPFC, which has been suggested to provide inhibitory control on task-irrelevant signals, may have a higher detection threshold for incoming signals than the visual cortex. Task-irrelevant signals around the threshold level may be sufficiently strong to be processed in the visual system but not strong enough for LPFC to "notice" and, therefore, to provide effective inhibitory control on the signals. In this case, such signals may remain uninhibited, take more resources for a task-irrelevant distractor, and leave fewer resources for a given task, and disrupt task performance more than a suprathreshold signal. On the other hand, suprathreshold coherent motion may be "noticed", given successful inhibitory control by LPFC, and leave more resources for a task. This mechanism may underlie the present paradoxical finding that subthreshold task-irrelevant stimuli activate the visual area strongly and disrupt task performance more and could also be one of the reasons why subthreshold stimuli tend to lead to relatively robust effects.

Implicit recognition: Implications for the study of attention and awareness

Joel Voss, Beckman Institute, University of Illinois Urbana-Champaign, USA

Recognition memory is generally accompanied by awareness, such as when a person recollects details about a prior event or feels that a previously encountered face is familiar. Moreover, recognition is usually benefited by attention. I will describe a set of experiments that yielded unprecedented dissociations between recognition, attention, and awareness. These effects were produced by carefully selecting experimental parameters to minimize contributions from memory encoding and retrieval processes that normally produce awareness, such as semantic elaboration. Fractal images were viewed repeatedly, and repeat images could be discriminated from novel images that were perceptually similar. Discrimination responses were highly accurate even when subjects reported no awareness of having seen the images previously, a phenomenon we describe as implicit recognition. Importantly, implicit recognition was dissociated from recognition accompanied by awareness based on differences in the relationship between confidence and accuracy for each memory type. Diversions of attention at encoding greatly increased the prevalence of implicit recognition. Electrophysiological responses obtained during memory testing showed that implicit recognition was based on similar neural processes as implicit priming. Both implicit recognition and implicit priming for fractal images included repetition-induced reductions in the magnitude of neural activity in visual cortex, an indication of visual processing fluency. These findings collectively indicate that attention during encoding biases the involvement of different memory systems. High attention recruits medial temporal structures that promote memory with awareness whereas low attention yields cortical memory representations that are independent from medial temporal contributions, such that implicit recognition can result.

Selective attention and perceptual suppression independently modulate contrast change detection.

Alex Maier, National Institute of Mental Health, NIH

Visual awareness bears a complex relationship to selective attention, with some evidence suggesting they can be operationally dissociated (Koch & Tsuchiya 2007). As a first step in the neurophysiological investigation of this dissociation, we developed a novel paradigm that allows for the independent manipulation of visual attention and stimulus awareness in nonhuman primates using a cued perceptual suppression paradigm. We trained two macaque monkeys to detect a slight decrement in stimulus contrast occurring at random time intervals. This change was applied to one of eight isoeccentric sinusoidal grating stimuli with equal probability. In 80% of trials a preceding cue at the fixation spot indicated the correct position of the contrast change. Previous studies in humans demonstrated that such cuing leads to increased selective attention under similar conditions (Posner et al. 1984). In parallel with behavioral cuing, we used binocular rivalry flash suppression (Wolfe 1984) to render the attended stimuli invisible on half the trials. The combined paradigm allows for independent assessment of the effects of spatial attention and perceptual suppression on the detection threshold of the contrast decrement, as well as on neural responses. Our behavioral results suggest that the visibility of the decrement is affected independently by attention and perceptual state. We will present preliminary electrophysiological data from early visual cortex that suggest independent contributions of these two factors to the modulation of neural responses to a visual stimulus.

Perception and action: Locomotion

Orchid Ballroom, Boards 401–412

Friday, May 7, 6:30 - 9:30 pm

16.401 Does Visual Texture Enhance the Recognition of Ramps and Steps?

Tiana M. Bochsler[1](bochs001@umn.edu), Christopher S. Kallie[1], Gordon E. Legge[1], Rachel Gage[1]; [1]Psychology Department, University of Minnesota, Twin Cities

Visual texture on floors may facilitate safe mobility by providing information to pedestrians about surface slant and discontinuities. Often, ground plane texture is composed of fine detail and is beyond the acuity limit or below the contrast threshold of people with low vision. Consequently, we investigated whether a surface with large, high-contrast texture elements would enhance the detectability of steps and ramps for low-resolution viewing. Since the angular size of texture elements depends on viewing distance, we expected any benefits from texture to depend on both acuity and viewing distance. Subjects viewed a sidewalk interrupted by one of five possible targets: a single step up or down (7 inch height), a ramp up or down (7 inch change of height over 8 feet), or flat. Subjects reported which of the five targets was shown, and percent correct was computed from a block of trials. Viewing distance was 5, 10 or 20 feet from the target. Normally sighted subjects viewed the targets monocularly through goggles with two levels of blur having effective acuities of ~20/135 (moderate blur) and ~20/900 (severe blur). For the Texture group, the sidewalk was covered with a black and white, high contrast (0.87) checkerboard pattern with squares 12 inches on a side, surrounded by uniform mid-gray walls and flooring. Performance was compared with a group of subjects tested previously with a textureless gray sidewalk, walls, and floor (No-Texture group). With moderate blur, texture elements were visible and the Texture group outperformed the No-Texture group at all three distances. However, with severe blur, the groups performed comparably, with best performance at 5 feet. The results encourage us to consider the potential value of flooring with large texture elements for enhancing visual accessibility in public spaces.

Acknowledgement: NIH Grant EY017835

16.402 Stepping over obstacles: Are older adults' perceptual judgments consistent with their actions?

Kaylena Ehgoetz Martens[1](ehgo7110@wlu.ca), Michael Cinelli[1]; [1]Department of Kinesiology, Wilfrid Laurier University

Obstacle avoidance includes: stepping over, around or through obstacles. To effectively avoid collisions individuals must use both ventral (perception) and dorsal (action) visual streams. Visual perception guides action and over a lifespan, action capabilities change. The objective was to determine whether these changes were a result of perceptual changes. To test this, we had 15 participants over 60 years of age perform an obstacle avoidance task. At the start of the trial the participants stood approximately 5m away from an obstacle and were asked to elevate their foot to their perceived height of the obstacle. Following this judgment, participants were instructed to walk one meter while looking at the object and make a second perceptual judgment of the same obstacle. After this second judgment, they were asked to step over the obstacle with the same foot used during the two initial perceptual judgments. There were three obstacle heights used (1.5, 10, 20 cm), which were representative of real world obstacles such as a curb height, stair height, and transition from carpet to hardwood such that results can be directly related to behaviours in real settings. The participants performed two blocks (free to look at foot during perceptual judgement and not allowed to look at foot) of 18 (3 obstacle heights x 2 obstacle locations x 3 trials) randomized trials. Preliminary results showed that only three trials were unsuccessful. Of the successful trials participants appear to use a similar toe elevation height for both the 10 and 20cm obstacle. This inability to properly scale toe elevation to obstacle height was reflected in their variable perceptual judgments. This finding suggests that older adults' perceptions and actions are different from those of young adults (Patla & Goodale, 1996), suggesting that older adults do not correctly couple perception with action.

Acknowledgement: WLU Science Technology and Endowment Program

16.403 Static and Dynamic Information about the Size and Passability of Apertures

Aaron Fath[1](yarblockers@gmail.com), Brett Fajen[1]; [1]Cognitive Science Department, Rensselaer Polytechnic Institute

Narrow openings between obstacles are among the most commonly encountered potential impediments to forward locomotion. The size of such apertures can be perceived in intrinsic units based on static, eye-height scaled information (Warren & Whang, 1987), allowing one to decide whether to attempt to pass through or select an alternative route. The aim of this study is to investigate the contribution of two sources of dynamic information about aperture size that are also available during approach to an aperture, one of which specifies aperture size in units of stride length (Lee, 1980), and the other that specifies the future passing distance of the inside edges of the aperture (Peper et al., 1994). Experiments were conducted in a 7 m x 9 m virtual environment that was viewed through a head-mounted display (FOV: 44° H x 35° V). In Experiment 1, subjects judged whether they could fit through an aperture between a pair of vertical posts resting on a ground plane, an aperture between a pair of vertical posts without a ground plane, and an aperture in an untextured frontal wall without a ground plane. Because the ground plane was absent and the posts and wall spanned the entire vertical FOV in the last two conditions, static, eyeheight-scaled information was not available and subjects had to rely on dynamic information. Analyses focused on the accuracy of passability judgments that were made while stationary versus immediately after walking 3 m toward the aperture. In Experiment 2, subjects were instructed to walk toward the aperture and rotate their shoulders if necessary to safely pass through without colliding. Analyses focused on the timing and magnitude of shoulder rotation under the same three viewing conditions used in Experiment 1.

Acknowledgement: NSF 0545141

16.404 The effects of aging on action and visual strategies when walking through apertures

Amy Hackney[1](hack7780@wlu.ca), Michael Cinelli[1]; [1]Department of Kinesiology, Wilfrid Laurier University

Avoiding collisions with objects is a requirement of everyday locomotion. The actions individuals take to move through a cluttered environment are governed by how passable one perceives the open space to be. Naturally, people want to avoid colliding with objects to reduce the risk of injury. In the current study the participants (N=13) walked along an 8m path at their self-selected speed towards a static door aperture. The aperture varied in width from 40-90cm. The participants were instructed to safely pass through the aperture using a suitable method. The objectives of the study were to determine: (1) if the actions of older adults (i.e. critical point, velocity change onset, & shoulder rotation onset) are different from those previously reported with young adults (Warren & Whang, 1987); (2) if gaze behaviours (i.e. fixation locations and durations) are different from those reported from younger adults (Higuchi et al., 2009)); and (3) if fixation patterns are reflective of action differences. Preliminary results indicate that older adults use different action strategies when approaching and passing through apertures than young adults. Older adults appear to have a larger critical point (i.e. aperture width/shoulder width) than previously reported in younger adults (i.e. 1.5 vs. 1.3). Further analysis will determine whether older adults have similar sequential action changes (i.e. velocity change followed by shoulder rotation initiation) as younger adults (Cinelli & Patla, 2007). Preliminary data analysis has also shown that older adults' fixation patterns were different from younger adults when approaching the aperture. Older adults appear to direct fixations towards the floor and more towards the door edges than younger adults during a similar task. These results suggest that the nature of the older adults' fixation patterns are directly influencing their "cautious" actions when passing through door apertures.

Acknowledgement: WLU Science Technology and Endowment Program

16.405 **When walls are no longer barriers: Perception of obstacle height in Parkour**

J. Eric T. Taylor[1](j.eric.t.taylor@gmail.com), Jessica K. Witt[1]; [1]Purdue University

Parkour is an activity characterized by the athletic, acrobatic, and efficient interaction of the athlete with the urban environment. Through training, skilled Parkour athletes (Traceurs) overcome everyday obstacles that are typically thought of as insurmountable, including the most common element of the modern carpentered landscape - walls. According to theories of Action-Modulated Perception (AMP), increased ability to jump and climb walls should correspond with perceiving walls as shorter. Traceurs and novices (age, height and sex matched) performed visual matching tasks on three walls (194 cm, 229 cm, and 345 cm), and also reported their subjective ability to climb the wall. Results show that Traceurs see walls as significantly shorter than novices, but only on the higher two walls. This pattern corresponds to the subjective difficulty ratings given by all participants, as novices reported the higher two walls as being significantly harder to climb than the Traceurs. The role of ability for action in perception is considered.

16.406 **Gait characteristics and gaze behaviours during a modified timed "Up & Go" (TUG) test: a comparison of older adults and Parkinson's disease patients**

Michael Cinelli[1](mcinelli@wlu.ca), Rachel vanOostveen[1], Quincy Almeida[1]; [1]SunLife Movement Disorders Research & Rehabilitation Centre, Department of Kinesiology, Wilfrid Laurier University

The TUG test is a reliable and valid test for quantifying functional mobility (Podsiadlo & Richardson, 1991). Parkinson's disease (PD) patients face many mobility challenges as well as attention deficits. In order to test both mobility and attention, the current study had both PD patients (N=10, 62.8 + 10.5 yrs) and healthy age-matched adults (N=12, 65.7 + 6.3 yrs) perform the TUG test with a dual task. Dual task paradigms determine the amount of interference a secondary task has on the performance of a primary task. The participants were instructed to rise from a chair and walk towards a counter three metres away. Hidden behind a curtain on the counter was either: 1) nothing, 2) an empty tray, or 3) a tray with glasses (TWG). After reaching and grabbing the item located behind the curtain, the participants were ask to turn around and walk back. Kinematic data was collected using an Optotrak system and gaze behaviours (fixations) were collected using an ASL Mobile Eye Tracker. Results showed that during the approach and return, both velocity and step length were significantly lower ($p<0.05$) in PDs compared to the healthy participants, independent of the condition. Gaze behaviours showed that PDs took more time to process visual information; they had fewer fixations but longer fixation durations than the healthy participants. Although both groups of participants directed more attention (total fixation duration) towards the tray during the TWG condition than other conditions, only the PDs demonstrated a significant ($p<0.05$) decrease in stability. This decrease in stability was due to the PDs inability to properly re-direct sufficient amounts of attention towards task-relevant objects, which may be the reason for mobility challenges within this population.

16.407 **An affordance processing hypothesis of gait disturbances in Parkinson's disease**

Dorothy Cowie[1](d.cowie@ion.ucl.ac.uk), Patricia Limousin[1], Amy Peters[1], Brian Day[1]; [1]Sobell Department of Motor Neuroscience and Movement Disorders, UCL Institute of Neurology

The walking pattern of patients with Parkinson's disease (PD) can be profoundly affected by visual stimuli. Lines on the ground can improve walking whereas doorways can cause the patient to come to an involuntary standstill ('freezing of gait'). This apparent paradox can be resolved by supposing that PD patients respond very strongly to visual affordance information: thus lines become readily stepped over but doorways, whose affordance is to constrain walking, can slow progression. In a population of PD patients we measured the relation of visual information to gait disturbances in doorways. First, we asked participants to judge the door width they could just pass through without turning their shoulders. Since the PD group made judgements as well as an age-matched healthy control (HC) group, we can conclude that misperception of the doorway's affordance at an explicit level does not cause gait disturbances. Second, we used a motion capture system to measure walking through a doorway whose width varied between trials. The HC group scaled walking speed and stride length to door width, with a magnitude inversely proportional to door width. The PD group also scaled gait parameters to door width, but with a greatly amplified pattern so that walking speed decreased dramatically before the doorway. These changes could not be explained by motor difficulties, but rather suggest that PD patients respond more strongly than controls to the slowing affordance of the door. Using a novel method to measure freezing of gait, we found that freezes occurred most often in the doorway, with a frequency inversely proportional to door width; and that freezes were preceded by exaggerated gait changes of the type we found. Thus we propose that freezing of gait in doorways results from gait changes, which in turn result from exaggerated responses to the doorway's affordance.

Acknowledgement: Medical Research Council Grant G0502136

16.408 **Visual control of posture as a function of age and cognitive task and its relationship with subjective discomfort**

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Purpose: Older observers tend to be more visually dependent for posture control. It has been suggested that cognitive load can produce postural instability. Very little is known on the relationship between the cognitive tasks and postural control when posture is strongly influenced by dynamic visual inputs and whether the resulting postural reactivity relates to subjective discomfort. Methods: We used a Full Immersive Virtual Environment to simulate a virtual floor. The floor oscillated from right to left with a temporal frequency of 0.25Hz and a slope of four degrees. Three cognitive tasks were performed during the visual stimulation, (1) no mental task, (2) mental countdown task with a random starting number and (3) a Brooks's modified task that consisted in memorising series of 6 numbers. Two young and older groups were tested and asked to stand still with feet together and arms crossed. Body Sway Amplitude (BSA) and Velocity Root Mean Square (VRMS) were calculated from the electromagnetic trackers positioned on the head. After each random condition, subjects were asked their Subjective Unit Discomfort (USI) on a scale ranging from 0 to10. Results: Results show clear effects of age for all three dependent variables BSA, VRMS and USI. Cognitive task conditions had stronger effects on subjective discomfort (USI) measures (reducing subjective discomfort) than on the behavioral outcome of the visually induced posture movement (BSA and VRMS). Conclusions: Visual stimulation had a greater visual induced impact for older observers. They were more sensitive while performing the most complex mental tasks (Brooks). It suggests that older subjects are more sensitive to visually induced postural reactivity during complex multitask cognitive conditions. Subjective discomfort decreased significantly as the mental tasks were more complex suggesting that a concurrent mental task can reduce discomfort related to visual-vestibular-proprioceptive conflicts but at the risk of increasing visually-induced postural instability.

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16.409 **Are the optic flow and egocentric direction strategies for steering control during walking linearly combined?**

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The egocentric direction strategy and the optic flow strategy both play a role in the online control of steering during locomotion. Their relative contribution depends on the structure of the visual environment (i.e. the amount of optic flow) and the flow rate. Moreover, optic flow serves to calibrate the walking direction in the egocentric strategy. However it remains unclear precisely how these two strategies are integrated. Our previous results suggest that they may be linearly combined, with weights of about 0.8 (flow) and 0.2 (egocentric) in visually structured environments. However, this was observed when the heading specified by optic flow was displaced at a single ±10˚ offset (right or left) from the locomotor axis. Here, we test this weighted combination by investigating a broader range of offsets. Participants actively walk in a 40 x 40 ft. virtual environment while wearing a head-mounted display (63˚ H x 53˚ V), and head position is recorded with a sonic/inertial tracker (70 ms latency). The virtual environment contains a textured ground, ceiling, frontal wall, and randomly positioned vertical posts. Participants repeatedly walk to a target (a doorway in the wall) while the heading direction specified by optic flow is displaced randomly to the right or left of the actual walking direction, blocking adaptation. The displacement increases from ±5˚ to ±25˚ in 5˚ steps, in blocks of 8 trials. If the two strategies are linearly combined, we expect that the weights will be

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constant over some range, although there may be an upper limit due to biomechanical and proprioceptive constraints. Results for human heading direction are compared with model predictions based on a control law for steering in which the turning rate is a weighted linear sum of egocentric direction and optic flow.

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16.410 **Visual information about locomotor capabilities and the perception of possibilities for action**

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Navigation through complex, dynamic environments requires people to choose actions that are appropriately calibrated to their locomotor capabilities. For example, when a pedestrian crosses the street, the decision whether to go ahead of an approaching vehicle or wait until it passes must take into account how fast the person can move. When actions are selected before movement is initiated, people can rely on what they know about their locomotor capabilities to select appropriate actions. The aim of this study is to investigate the contribution of visual information picked up on the fly when actions are selected while moving. The experiment was conducted in an immersive virtual environment viewed through a head-mounted display. On each trial, subjects walked 3 m along a tree-lined path, at which point two cylindrical obstacles began to converge toward a location along their future path. Within 1.2 s, subjects had to judge whether they could have safely passed between the obstacles. On a small percentage of trials , the visual gain was increased such that subjects moved through the virtual environment 50% faster than normal. Subjects were more likely to perceive the gap as passable on catch trials with increased visual gain. The increase in "passable" responses is consistent with the use of on-the-fly information, and could be due to global optic flow picked up during the 3 m approach phase or local motion of the converging cylinders. The relative contributions of global flow and local motion were tested in Experiment 2 by increasing the visual gain of the stationary background independently of the moving obstacles. The effect of visual gain was significant, but weaker than in Experiment 1. The findings suggest that when people select actions while moving, they rely on both local and global sources of information that are picked up on the fly.

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16.411 **The role of continuous vs. terminal visual cues in the acquisition of a whole body perceptuo-motor coordination task**

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The incessant adaptation of posture to external visual cues is a complex task that requires the coordination of multiple degrees of freedom in order to maintain balance during performance of everyday actions. In the present study, we investigated the adaptation and learning of a rhythmical Weight Shifting (WS) task while providing either terminal or continuous visual cues during practice. Forty young healthy volunteers were randomly assigned in to one of four visual feedback groups (Continuous Target-Continuous Feedback, Continuous Target-Point Feedback, Point Target-Continuous Feedback, Point Target-Point Feedback). Participants were asked to perform periodic WS in the sagittal plane at a standard oscillation frequency (0.23 Hz) by matching the force exerted on a dual force platform to a target sine wave stimulus. Baseline, post-test, transfer (ankle tendon vibration at 80 Hz) and retention (24hs later) tests required performance of the same task guided by an auditory signal. Ground reaction forces were sampled through an A/D board (50 Hz) and analyzed using spectral and cross-correlation analysis. During practice, participants receiving terminal feedback, either as target or performance, had significantly lower aiming error and cycle variability compared to participants receiving continuous visual cues. On the other hand, the continuous feedback groups displayed significantly lower (closer to 1) performance-target power spectral signal ratios confirming higher accuracy throughout the course of WS. Learning was depicted in a reduction of cycle variability and a decrease of the median oscillation frequency towards the target frequency that was similar across all feedback groups. Nevertheless, participants practicing with terminal feedback showed better transfer of learning as this was confirmed by the reduced impact of the vibration stimulation on performance variables. It is suggested that terminal feedback reinforces the acquisition of a more flexible internal model of the perceptuo-motor transformation required for the performance of externally guided rhythmical whole-body movements.

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

16.412 **The Naïve Physics Curvilinear Impetus Bias does not Occur for Locomotion**

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Past research examining naïve physics tendencies of individuals has confirmed that a notable population exhibits a bias to believe that objects which are constrained to move along curved paths will continue to curve in the same direction after they emerge free from the constraint. The typical example is predicting the path of a rolling ball that emerges from a spiral maze. The present study tests two competing models which could explain this robust cognitive bias. First is the idea that people possess anthropomorphic tendencies which assume that if they or another were running through such a maze they would continue to lean and turn upon emerging. Second is that the curvilinear impetus bias only occurs for cognitive tasks, and disappears when people actually physically navigate out of a curved maze, due to their having access to error-resistant perception-action guidance mechanisms. To test these competing models, we had 50 individuals race out of a spiral maze as fast as they could and we recorded the extent of path curvature that was exhibited between the end-point of the maze and a semicircular end-line 10 feet away. The end-line was designed to be equidistant to the end-point of the maze, with soccer cones placed every two feet to provide discrete alternatives of path curvature. The results revealed a unimodal distribution of path curvature with a mean essentially dead straight ahead (mean=3.1 inches to the side, $t=0.44$, p=n.s.). We also found no significance for the correlation between curvature and running speed ($r=-0.27$, p=n.s.). The findings support the model that people do not exhibit a naïve physics curvilinear impetus bias for perception-action tasks that allow access to error-resistant guidance mechanisms. Thus, in actual real-world cases of directional locomotive priming, individuals appear to accurately minimize path curvature and running distances in order to minimize navigational time.

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Eye movements: Mechanisms and methods

Orchid Ballroom, Boards 414–425

Friday, May 7, 6:30 - 9:30 pm

16.414 **Saccadic target selection and temporal properties of visual encoding**

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Literature shows many tasks in which saccades following short latencies tend to land on salient elements, while those following longer latencies more frequently land on elements similar to the target. This has given rise to the idea that independent bottom-up and top-down processes govern saccadic targeting. Recent findings, however, show that even when the target of a search is the most salient element, the tendency to saccade towards this target decreases as latencies prolong. It is difficult to explain these findings in terms of bottom-up and top-down processes. We investigated whether temporal differences in encoding of peripheral visual information can explain this finding. The visual system processes low spatial frequency (LSF) information faster than high spatial frequency (HSF) information. Similarly, high contrast information is processed faster than low contrast information. The stimuli in our experiments contained two deviating targets on a homogenous grid of non-targets. In the first experiment, one target deviates in its low spatial frequencies, the other target in its high spatial frequencies. The task of the subject was to make a speeded saccade towards either target. For the short saccade latencies, a bias towards the low frequency target was found. Interestingly, with increasing latency this bias disappeared and both targets were selected equally frequent. These results suggest a link between temporal aspects of encoding and saccadic target-

ing. In the second experiment we further tested this theory by varying the contrast of the LSF target. In one condition we raised the contrast of the LSF target, resulting in an increase in the bias towards this target. Lowering the contrast of the LSF target in a second condition resulted in a shift in bias towards the HSF target. These experiments provide converging evidence that temporal aspects of encoding underlie saccadic target selection.

16.415 **The integration of visual and auditory cues for express saccade generation**

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The integration of information gained through various sensory modalities enables living organisms to execute motor acts rapidly. The purpose of the study was to examine how effectively visual cues can be integrated for the rapid generation of saccadic eye movements. Previous work has established that when saccadic eye movements are made to singly appearing visual targets, a bimodal distribution of saccadic latencies is often obtained, the first mode of which has been termed "express saccades."

In this study we examined the rapidity with which saccadic eye movements can be generated to auditory and visual cues when they are presented singly and in combination. The visual display presented on a monitor consisted of a fixation spot which was followed by a single visual target that appeared either to the left and or to the right of the fixation spot. The auditory cue was provided through one of two speakers positioned to the left and right of the monitor. Eye movements were recorded enabling us to obtain a distribution of saccadic latencies. Data obtained from one of the monkeys we have studied showed 5% express saccades to singly appearing visual targets, 1% express saccades to singly presented auditory cues but 36% express saccades when single visual and auditory cues were presented together. Statistical analyses showed these effects to be highly significant ($p < 0.001$). Similar results were obtained in another monkey.

The results establish that auditory and visual cues can be effectively integrated to produce a much higher percentage of express saccades than that obtained to visual and auditory cues alone. Having previously established that following superior colliculus inactivation express saccades are eliminated, we believe that this structure is likely to play a significant role in the integration of visual and auditory information for saccadic eye-movement generation.

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16.416 **Bilateral Involvement of the Right Frontal Eye Field in Saccade Production**

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Transcranial magnetic stimulation (TMS) has been used to stimulate the frontal eye fields (FEFs) to study their functional role in saccade generation. Assorted tasks such as memory guided, auditory triggered and anti-saccades have been investigated previously using TMS. While results varied, the primary effects of TMS have been delayed contralateral saccades and degraded accuracy. We decided to examine the time-course and laterality of right FEF TMS effects on saccade generation during exogenous and endogenous visual attention tasks. For the exogenous task, targets appeared to the left or right of fixation at 10° eccentricity. In the endogenous task the same targets were continuously present, but a cue presented at fixation indicated when and where to make the saccade.

In the exogenous saccade task, TMS increased ipsilateral saccade latency by 43, 33, 35, 27, and 32ms when delivered 60, 70, 80, 90, and 176ms prior to predicted saccade onset, respectively. For the same TMS delivery times the contralateral latencies increased by 51, 20, 56, 34, and 53ms, respectively. In the endogenous saccade task, TMS increased ipsilateral latencies by 43 and 87ms at 45 and 250ms prior to predicted saccade onset. Contralateral saccade latencies increased by 29, 51, 79, and 39ms when TMS was delivered 43, 132, 250, and 315ms prior to the predicted saccade onset. All reported latency increases were significant, $p<.01$. Control sham TMS conditions produced no significant latency effects. For both tasks, when TMS was presented just 20ms prior to saccade onset, no latency changes occurred.

The time course of TMS based saccadic disruption appears to be broad and begins between 20 and 60ms prior to saccade onset. The results indicate consistent bilateral disruptive effects for single pulse TMS applied to the right FEF. These results are consistent with reports of the bilateral fronto-parietal attention network involved with saccade generation.

16.417 **Foveation Time as a Driving Factor of Saccade Adaptation**

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It is well known that the oculomotor system is able to maintain its accuracy despite of changing conditions that otherwise would lead to movement inaccuracy and poor vision. In the laboratory this effect - usually termed saccade adaptation - is typically studied by a perisaccadic displacement of the saccade target either in (forward adaptation) or against the saccade direction (backward adaptation). Both conditions induce a change in saccade gain. Initially, however, errors due to the perisaccadic target step are compensated for by corrective saccades. In general, backward adaptation builds up more quickly and reaches larger adaptation amplitudes than forward adaptation. At present, the reason for this asymmetry is not fully understood. Previous studies suggested that the oculomotor system strives to minimize the saccadic flight time thereby maximizing the time of high resolution vision. In this vein the adaptation process should also be governed by temporal optimization. Accordingly, a faster adaptation would be required in case of longer latencies for corrective saccades. In a first experiment, we measured the latencies of subjects' corrective saccades. To this aim, we displaced the saccade target perisaccadically by a small amount to a random position, thus promoting corrective saccades of different directions and amplitudes. Additionally, we tested the subjects' behavior in forward and backward saccade adaptation paradigms. Our results confirm previous findings. Forward adaptation was slower and less complete than backward adaptation. In line with our hypothesis, we observed shorter latencies for corrective saccades in forward direction compared to those in the opposite direction. The inter-subject variability for the difference in latencies correlated with the observed asymmetry in gain adaptation. Therefore, we suggest foveation time as a driving factor of saccadic gain adaptation.

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16.418 **Target Specificity Of Saccadic Adaptation**

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The predominant view of saccade adaptation is that it is largely guided by retinal error—the postsaccadic distance of the target from the fovea. In laboratory experiments with the target as the only visible stimulus, the retinal error is unambiguous, unlike real life, in which any of a multitude of stimuli might be on or near the fovea after any saccade. To take a first slice at this issue with Occam's Razor, we asked whether saccade adaptation would be prevented if a second stimulus, resembling the target, occupied the original target location, while the target was displaced during the saccade.

A target (on each trial randomly either a green circle or a yellow square) stepped by 10-12 deg. On 400 adapting trials, the target made backward (or, in separate experiments, forward) intrasaccadic steps (ISS, 20% of the initial step amplitude). In some experiments the non-target occupied the original target location, while the target made an ISS; in others, the non-target made the ISS.

Surprisingly, the non-target exerted almost no effect on the adaptation. When it was the target that made the ISS, the gain decreased or increased approximately as much whether or not the original target location was occupied by the non-target. Conversely, if the target did not move during the saccade, but the non-target made an ISS, very little adaptation occurred. Finally, if, after adaptation to the target alone, the non-target was added at the original target location, the gain did not return towards normal, but did if it was the target that remained at the original target location.

Conclusions: Although generally considered a low-level motoric phenomenon, saccade adaptation can be selective for the relevant error signal, using the visual attributes of the target from trial to trial for guidance.

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16.419 **Online and offline trajectories characterize the respective control of pro- and antisaccades**

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The antisaccade task entails decoupling the spatial relations between target and response and looking mirror-symmetrical to the location of a target. Extensive work documents that antisaccade reaction times are longer than prosaccades: a finding attributed to the top-down nature of inhibiting a stimulus-driven response. The present investigation sought to determine whether the top-down nature of antisaccading influences the extent to which saccade trajectories are modified online. Participants completed pro- and antisaccades to target stimuli that were visible (Experiment 1) or occluded (Experiment 2) throughout the response. To index trajectory modifications, we computed the proportion of variance (R2) explained by the spatial location of the eye at 10% increments of normalized movement time (i.e., 10%, 20%, … 80%, 90% of movement time) relative to the saccade's ultimate movement endpoint. The basis for this analysis is that robust R2 values indicate that the location of the eye at any point in the trajectory provides a strong prediction of the ultimate saccade endpoint – thus evidencing a primarily offline mode of control. In turn, modest R2 values indicate that the location of the eye does not reliably predict saccade endpoint - thus evidencing a more online mode of control. Results showed that endpoints for prosaccades were more accurate and less variable than antisaccades. What is more, prosaccades yielded lower R2 than antisaccades from 20% to 70% of movement time: a finding consistent across Experiments 1 and 2. That prosaccades were characterized by weak R2 values in combination with their accurate and stable endpoints suggests that stimulus-driven actions allow for online corrections to the saccade trajectory. In contrast, the robust R2 values and increased endpoint error and variability of antisaccades suggests that top-down decoupling of the spatial relations between target and response renders a primarily offline mode of control.

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16.420 **A common inhibition mechanism underlies both anti and countermanded saccades**

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We rely on our ability to inhibit prepotent reactions to our surroundings and execute appropriate behaviors. Both antisaccade and countermanding tasks have been used extensively to test theories about inhibitory control within the primate saccade system. Although it is believed that each task may tap similar neural mechanisms of inhibition, to date there have been no direct comparisons. Here, we compared performance on antisaccade and countermanding saccade tasks in the same group of subjects to test the hypothesis that a common mechanism underlies inhibiting saccades in both tasks. We predicted that subjects with strong inhibition in one task should show high inhibition in the other task. In both tasks, the predominant response was to make a saccade toward a salient visual cue. In the antisaccade task, subjects were instructed to make a saccade away from the cue, which required that one first inhibit a saccade to the cue. In the countermanding task, subjects were instructed to cancel a planned saccade when an auditory stop signal was emitted at various delays following the appearance of the visual cue, i.e., stop signal delays (SSD). Subjects' eye movements were monitored to measure their ability to suppress unwanted saccades, saccade initiation times, and a latent variable called the stop signal reaction time (SSRT). The SSRT is thought to index the time one needs to inhibit a saccade. In the countermanding task, stop-success rate declined as SSD increased. In the antisaccade task, the probability of successfully generating an antisaccade increased with increasing initiation times. Moreover, estimates of SSRT from the countermanding task correlated with one's ability to successfully generate antisaccades. Our results provide strong evidence that a common mechanism underlies saccade suppression in both tasks.

16.421 **Ongoing EEG oscillations and saccadic latency**

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The state of the cortex at the time of a visual event can affect the way in which the event is processed. While the amplitude of ongoing oscillatory activity is known to correlate with perceptual performance, the influence of oscillatory phase remains less clear; however, it has previously been shown that the phase of ongoing activity can predict near-threshold stimulus detection (Busch, Dubois & VanRullen, J Neurosci. 2009). Here, we aim to determine the relation between the phase of ongoing oscillations in various frequency bands and the trial-to-trial variations in saccadic behavior. Human saccadic response times are known to exhibit bimodal distributions, particularly in "gap" paradigms (i.e., with a delay between fixation offset and target onset). Additionally, motor responses (manual and ocular) can exhibit certain periodicities in their latency histograms. Both of these observations may be suggestive of an underlying oscillatory influence. We employed 3 tasks, accounting for 3 different modes of saccadic behavior: 1) predictable target location, allowing for mostly reflexive and even anticipatory saccadic responses with minimal cognitive demand; 2) unpredictable target location without distractors, allowing for mostly reflexive responses with little cognitive effort, yet minimizing anticipatory responses; 3) unpredictable target location in the presence of a distractor, requiring a cognitive effort (comparison between target and distractor) before a correct saccade could be performed. Eye traces and 64-channel EEG activity were recorded simultaneously using independent, synchronized measuring equipment. The mean saccadic reaction times in the three conditions reflected the expected increase with task difficulty. In addition, the latency distributions often displayed multiple modes or periodicities. Finally, we measured the dependency of saccadic latency on ongoing (pre-stimulus) and evoked (post-stimulus) oscillations in various frequency bands, and the interaction between these periodicities and the cognitive load of the saccadic task.

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16.422 **The timing of oculomotor fixations**

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The mechanism for controlling saccadic timing is not well understood. One possibility is that the eye stays fixated at a given location until the current target is analyzed, while another is that an internal timer is set on the basis of context, with minimal reference to the currently fixated target.

To distinguish these alternatives, subjects estimated the mean location of a cluster of steadily-appearing dots. Dot position was sampled from a Gaussian distribution (SD= 20′) whose mean was to the right or left of a reference line. Dots appeared at a rate of 1 every 53 ms while the reference line was fixated. Task difficulty was modulated by changing the spatial offset between the mean of the distribution and the reference line (offsets = 5′, 7′, 10′). Subjects were instructed to adjust viewing time to accumulate enough dots to achieve 95% accuracy. When task difficulty remained constant throughout an experimental session, viewing time per cluster increased with difficulty level (time/cluster ranged from ~ 1-1.5 s). Performance approximated that of an ideal observer that was limited only by statistical fluctuations in sampling of dot location. However, performance in the most difficult case (offset = 5′) was only about 85% correct, showing a reluctance to prolong viewing time to improve accuracy. When task difficulties were mixed within a single experimental session, viewing time decreased for the harder difficulty levels and increased for the easier levels. Some subjects maintained saccade-free fixation on a cluster for the entire viewing time, while others made small saccades at a relatively constant rate.

These results show that subjects can adopt optimal viewing times (consistent with the ideal observer), but there are also modulations in viewing time reflecting both a preference to avoid prolonged fixation, and an influence of recent past history and task context.

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16.423 **Attention vs. The Eye: Which stabilizes fixation?**

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Purpose: Maculopathy patients with a peripheral retinal locus (PRL) for fixation tend to exhibit fixation instability that worsens with PRL eccentricities. Using an artificial scotoma paradigm with normal observers in an orientation discrimination task, we examined the affect of "eccentric attention", i.e. deviating attention to a PRL (Dang, Renninger & Fletcher, VSS2009). We found the position of the eye in the orbit to be an important factor. In this study, we characterize the relative contribution of gaze and attention deviations to fixation stability and whether it applies to maculopathy patients. Methods: Observers with artificial scotoma performed an orientation discrimination task as a function of eccentricity under three conditions: a) central gaze, eccentric target; b) eccentric gaze, central target; c) eccentric gaze and eccentric target. Maculopathy patients performed a similar task with a) eccentric gaze at the PRL, central target or b) central gaze, eccentric target at the PRL. Results: Artificial scotoma observers experienced a worsening of fixation stability for the eccentric gaze, central target condition as compared to the baseline condition of central gaze, eccentric target. Thus, when the deviation angle of "eccentric attention" is matched, the major cause of eye instability is the position of the eye in the orbit. For zero attentional deviation (eccentric gaze, eccentric target) stability is recovered. Correcting maculopathy patients to use central gaze significantly improved fixation stability. Conclusion: Fixation instability in maculopathy patients may be limited by two factors, 1) the deviation and holding of attention at an eccentric retinal location and 2) the absolute position of the eye in the orbit. If fixation stability is required for an acuity related task, the patient may be able to better stabilize the eye in the center of the orbit by moving their object of regard to an appropriate eccentric location.

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16.424 **Infrared Tracking of the Near Triad**

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The oculomotor response when viewing a near target is characterized by 'the near triad': pupil miosis (constriction), binocular convergence and increased accommodation. Most existing eye-tracking systems lack the ability to measure all three of these parameters and are usually specialized to handle only one. Systems that can measure the complete near triad suffer from slow measurement rates, off-line analysis or are cumbersome and inconvenient to use. Singular specialized systems are usually combined ad-hoc but such systems are often complex in architecture and suffer severe limitations in runtime. We describe a video-based eye tracking system based on eccentric photorefraction that allows for remote, high-speed measurement of all three components of the near triad. This provides for precise, simultaneous measurement of oculomotor dynamics as well as having the benefit of being safe and non-intrusive. An extended infrared source illuminated the subject's eye. The corneal reflex and 'bright pupil' reflections of this source were imaged by an infrared sensitive camera and used to track gaze direction and pupil diameter. Such eccentric illumination combined with a knife-edge camera aperture allowed the accommodative state of the eye to be estimated from measurements of the gradient of image intensity across the pupil. Real-time measurements are facilitated by detection of Purkinje images to define areas of interest for each pupil followed by pupil edge detection and fitting to an ellipse model. Once the pupils are located, data about the brightness profile, diameter, corneal reflex and pupil center are extracted and processed to calculate the near triad. The system will be used in ongoing experiments assessing the role of oculomotor cues in perception of motion in depth.

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16.425 **Simultaneous recordings of ocular microtremor and fixational microsaccades with a piezoelectric sensor and a commercial video tracking system**

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Our eyes continually move even while we fix our gaze. Fixational eye movements include microsaccades, drifts and ocular microtremor (OMT), a high frequency tremor of the eye. Microsaccades and OMT are the fixational eye movements with respectively largest and smallest amplitudes (up to several dozen photoreceptors in the case of microsaccades, and approximately one photoreceptor in the case of OMT). We simultaneously recorded the eye movements of human subjects with a piezoelectric device (adapted from the piezoelectric transducer technique developed by Bengi and Thomas (1968)) and a commercial infrared video tracking system (EyeLink II). The piezoelectric system could detect very small changes in eye velocity, such as those due to OMT. Both recording systems moreover allowed microsaccade detection, thus allowing the direct comparison of microsaccade dynamics between systems. Here we present experimental results concerning the effect of the piezoelectric sensors on the amplitude and other parameters of microsaccades during fixation. The application of a piezoelectric sensor resulted in decreased microsaccade amplitudes (as measured with EyeLink II). Normal amplitudes were restored upon sensor removal. Application of the sensor in one eye only resulted in a simultaneous increase of microsaccade amplitudes in the other eye. We also conducted a perceptual experiment to test the potential role of tremor on target visibility. Whereas microsaccades are known to counteract visual fading, it is not known whether tremor also contributes to visibility during fixation. We found that microsaccades were effective in counteracting fading in both foveal and peripheral target locations, in agreement with previous studies (Martinez-Conde et al., 2006; Troncoso et al., 2008). There was no correlation between OMT and the reappearance of a faded stimulus.

Development: Disorders

Orchid Ballroom, Boards 426–438

Friday, May 7, 6:30 - 9:30 pm

16.426 **The effect of speed, age and amblyopia on the perception of motion-defined form**

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We showed previously that the perception of motion-defined form is immature in school-age children and deficient in both eyes of children with amblyopia. The extent to which these developmental changes reflect the functioning of the M/dorsal or the P/ventral pathway is not known. We used dot speed to bias the relative contribution of the M/dorsal (fast motion) and P/ventral (slow motion) pathways to the processing of motion-defined form. Our first attempt at this, using a sparse dot pattern (VSS 2009), produced inconclusive results. Here we report the effect of speed, age and amblyopia, using a higher-density pattern.

Motion-defined rectangles (vertical or horizontal) were created by moving signal dots inside the shape in one direction (up or down) and signal dots outside the shape in the opposite direction. Noise dots inside and outside the shape moved in random directions. The proportion of signal dots specified the coherence of the pattern. All dots moved at the same speed throughout a run. Monocular motion coherence thresholds, for discriminating rectangle orientation, were determined at slow (0.1 deg/s), medium (0.9 deg/s) and fast speeds (5.0 deg/s) using a staircase procedure.

First we examined typical development in young children (4-6 years), older children (7-10 years), adolescents and adults. Coherence thresholds were: (1) highest at the fast and lowest at the medium speed for all four groups, and (2) higher in the young children than in the three older groups.

Next we examined the fellow eyes of patients with anisometropic and/or strabismic amblyopia. Coherence thresholds were elevated, relative to age-matched controls, in most of the patients at the slow and medium speeds only.

These results suggest that the P/ventral components of the task are deficient in patients with amblyopia. We find no clear maturational differences between the M/dorsal and P/ventral pathways in children with typical visual development.

Acknowledgement: Natural Science and Engineering Research Council of Canada

16.427 **Spatiotemporal differences in local and global pattern perception in human amblyopia investigated with MEG**

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Amblyopia is a monocular loss of vision caused by abnormal early childhood visual experience. Despite prior efforts, the neural basis of amblyopia remains elusive: there is contradictory evidence on whether early visual cortex or higher cortical areas are affected. Some studies indicate normal activation in V1/V2 and diminished activity in higher cortical areas; others have found that V1 and/or V2 are dysfunctional in amblyopia. We employed Glass patterns, which stimulate both early and higher visual cortical areas. Cortical activity was measured using magnetoencephalography (MEG) which was co-registered with anatomical MRI. Five adults with amblyopia and 9 visually normal subjects were tested. Prior to MEG recording, monocular Glass pattern detection thresholds were measured to determine the signal strength (% correlated dot-pairs) for the subject to perceive radial and rotational patterns correctly on 80% of trials. During MEG

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recording the Glass pattern signal strength was fixed at the individual's 80% threshold level so that the amblyopic eye (AE), the fellow (FE) and healthy eyes (HE) were equated for psychophysical performance. Stimuli were presented in two blocked conditions (radial or rotational, each by eye; 200 trials, 50% signal). Behaviorally, amblyopic observers needed higher stimulus signal strengths and exhibited slower reaction times when viewing with their AE compared to their FE. Using event-related beamformer-based spatial filtering, brain activity maps revealed differences in early visual areas (~120 ms), medial temporal complex (~190 ms) and temporal-parietal areas (~250 ms) during Glass pattern stimulation of AE compared to FE and HE. Multivariate analysis of the source waveforms at these brain locations revealed a different spatiotemporal pattern of interaction between early and later visual areas in amblyopic observers. The neural basis of amblyopia may be defined by altered patterns of interaction between striate visual cortex, later retinotopic extrastriate areas and specialized cortex as compared to normal visual brain function.

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16.428 **Deficient Binocular Combination Reveals Mechanisms of Anisometropic Amblyopia**

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Amblyopia is a developmental visual disorder that results in poor spatial vision. Why the amblyopic eye has poor vision remains unclear: some suggested that signals in the amblyopic eye are attenuated; others suggested that they are inhibited by signals in the fellow eye. Huang et al. (2009) measured the perceived phase of the cyclopean image as a function of the contrast ratio between two monocular sinewave gratings of the same spatial frequency but different phases (Ding & Sperling, 2006). Although the study provided empirical measures of the relative strength of the amblyopic eye in binocular phase combination, we could not distinguish attenuation and inhibition models of amblyopia -- they make mathematically equivalent predictions on phase perception. Additional constrains are required. Here, we elaborated the Ding-Sperling paradigm, measuring both the perceived contrast and phase of the cyclopean images. We found that the effective contrast of the amblyopic eye is different in phase and contrast perception, and the perceived contrast of cyclopean images was independent of the relative phase of the monocular sinewave gratings. We developed a new binocular combination model in which each eye exerts gain control on the other eye's signal and over the other eye's gain control, followed by separate phase and contrast computations. The empirical data and computational model enabled us to identify the mechanism of amblyopia: signals in the amblyopic eye are attenuated; And, the amblyopic eye exerts weaker inhibition on the gain control from the fellow eye.

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16.429 **Clinical application of qCSF: Efficient characterization and classification of contrast sensitivity functions in Amblyopia**

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Amblyopia is a developmental disorder which results in poor spatial vision. Many have suggested that the contrast sensitivity function (CSF) characterizes these spatial vision deficits better than letter acuity, which is currently used for the screening, early intervention and treatment evaluation of amblyopia. However, the long testing-times or imprecision of traditional CSF measurements limit their clinical potential. We evaluated the qCSF method (Lesmes et al, 2008) in adults with amblyopia, to test its usefulness for measuring CSF in amblyopia with acceptable testing-time, accuracy and precision. For ten normal and eight amblyopic participants, two sets of CSFs were obtained with a 2AFC contrast detection task in two separate sessions of interleaved qCSF and conventional CSF procedures. We found that: 1) The assumptions used in the qCSF were valid for seven normal participants and all amblyopic participants. 2) For both groups and both methods, threshold estimates in two separate runs were well matched (all $R>0.94$). 3) The qCSF method provided an accuracy of 2.3 dB and 3.7 dB in only 120 trials (~ 5 mins) for normals and amblyopes, respectively. 4) Measures of the area under log CSF (AULCSF) and the cut-off spatial frequency (cSF) were lower in the amblyopic group; these differences were captured within 50 qCSF trials. 5) Using a logistic regression model with AULCSF and cSF as predictors, we detected amblyopia with an about 80% correct rate in 50 trials. We conclude that the qCSF method is rapid, accurate, and precise enough to measure CSFs in normal and amblyopic populations; it has great potential for clinical practice.

Acknowledgement: NEI

16.430 **Fixational eye movements for normal and strabismic amblyopic observers**

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An adaptive optics scanning laser ophthalmoscope (AOSLO) was used to record fixational eye movements in normal and strabismic amblyopic observers, allowing direct viewing of retinal movements and fixation locations. Fixational eye movements were modeled as a stochastic process governed by a potential function. This model integrates various aspects of fixational eye movements, e.g., velocity, fixation position, and time, in a natural way. We applied this approach to both normal and strabismic amblyopic observers to characterize their fixational eye movements quantitatively. Retinal movements were recorded using the AOSLO (at 30 Hz) while subjects fixated a small target generated by selectively modulating the amplitude of the laser beam. Cross correlation was used to estimate relative positions of different frames. The gradient of the potential function assumed to have the form of a quadratic polynomial in the domain of a plane (i.e. fixation position) was fitted to microsaccade and drift velocities (at different times following a microsaccade) for normal subjects; a chain model of microsaccades was developed to characterize fixation patterns on multiple loci for the strabismic amblyopes. We estimated microsaccade rate as a function of location, using a Poisson point process approximation. Our results confirm that microsaccades, on average, correct for fixation inaccuracy. Microsaccades occur more frequently and tend to move faster towards the target at relatively large displacements, as predicted by the microsaccade rate map and the potential function. Drift is modeled as a Brownian motion with constant rate over time plus an error-correcting component initially following a microsaccade. The unstable eccentric fixational eye movements in strabismic amblyopia are characterized by frequent intrusive saccades with large amplitudes and high speeds. The strabismic amblyopic fixation pattern on multiple loci is task dependent, with less eccentric but unstable fixation induced by challenging tasks, and relatively stable fixation by small highly visible static targets.

16.431 **Double dissociation in monocular blindness: Enhanced contrast but impaired motion perception**

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Previous research has shown that early monocular blindness from unilateral enucleation (surgical removal of one eye) results in equivalent or enhanced form perception but impairments in aspects of motion processing (see Steeves et al., 2008). To further investigate the effects of early monocular blindness on form and motion processing, we compared binocularly and monocularly viewing controls to individuals who were unilaterally enucleated within the first few years of life. Thresholds were measured on three tasks that had not before been tested in this population; 1) contrast discrimination, 2) horizontal speed discrimination, and 3) horizontal coherent motion discrimination. Preliminary data are consistent with previous research showing early monocular blindness results in equivalent or enhanced sensitivity compared to binocularly and monocularly viewing controls at some contrasts. It also results in higher motion discrimination thresholds for lower speeds and a nasalward bias in the perception of coherent motion. These results add to the literature showing that the loss of one eye early in life can enhance low contrast form processing, presumably through a lack of binocular interactions. In contrast, this same lack of binocularity can impede the normal maturation of motion processing suggesting that binocularity is required for normal maturation of this system.

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16.432 Is Myopia Affected By Near Work, Outdoor Activities And/Or Level Of Education?

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Introduction: Near work has always been associated with the influence of myopia (S-M. Saw, et al., 2002; B. Kinge, et al., 2002; I.F. Hepsen, et al., 2001). It has been shown to affect the progression of myopia. In this study, we aimed to determine if there is a relationship between outdoor activities and myopia, as the prevalence of myopia seems to be lower in children who are more active outdoor. (K.A. Rose, et al., 2008). In addition, we also aimed to establish if the level of education affects myopia prevalence. Method: A cohort study was carried out on 16,484 male volunteers, aged between 16 to 21 years old, who are pre-enlistees to the Singapore Armed Forces. A demographic survey was conducted to determine their level of education, type of houses they stay and the daily amount of visual work for near and distance. The refractive status and corneal curvature was measured using the Huvitz NRK-3100 auto-refractor. Results: Pearson's correlation test shown no significant correlation between amount of near work and myopia. However, individuals who are more active outdoors tend to be less myopic (pr=0.147, $p<0.01$). The analysis indicated that high myopia is associated with higher levels of education (pr=-0.243, $p<0.01$) and individuals staying in bigger houses (pr=0.121, $p<0.01$). Individuals with higher levels of education are also more likely to stay in bigger houses (pr=0.259, $p<0.01$). Conclusion: The trend suggests lower educational background and longer hours spent on outdoor activities are associated with less myopia, but not as a result of near work. This suggest that near work may not necessarily has a high impact on myopia.

16.433 Optics and Spatial Vision in Children and Young Adults With Autism Spectrum Disorder

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Purpose. Autism spectrum disorder (ASD) is an increasingly diagnosed neurodevelopmental disorder, with an incidence in children now greater than 1%. Surprisingly, given the assumption that ASD impacts the processing of visual stimuli, systematic studies of even basic visual functioning have yet to be conducted on this population, and the limited available reports are equivocal. Here we conduct the first comprehensive study of the development of spatial vision and refractive status in this population. Methods. 44 children and young adults (age range: 3-22 years) with a primary diagnosis of ASD were tested with a battery of tests developed for an early childhood eye and vision screening program (Adams et al: VSS 07, 08). These included measures of visual acuity, alignment, stereoacuity, refractive error, contrast sensitivity (CS), and Vernier acuity. Children were tested monocularly and with optical correction if prescribed. Results. Children were very compliant with 95% completing all tests in both eyes. Compared to controls, 3-to- 6 year-olds (n =21) showed moderate deficits in visual acuity (M = 0.38 LogMAR; 20/48), CS (M= 53 CS units), Vernier acuity (M = 0.70 log min), stereoacuity (M = 2.28 log arcsec) and ocular alignment (31% failed). Older 7-22-year-olds (n = 23) performed even more poorly, showing significant deficits in visual acuity (20/94; 0.67 LogMAR), Vernier acuity (0.85 log min), stereoacuity (2.41 log arcsec) and ocular alignment (65% failed), but only a moderate deficit in CS (M = 56 CS units). Conversely, refractive error showed a relatively normal age distribution. Conclusions. Children with ASD are at risk for eye and visual dysfunction. However, given that most of these children had relatively normal levels of refractive error, the basis of their deficits appears to be within the central visual pathways and/or the visual cortex and is perhaps related to the neural origin of the disease.

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16.434 The Systemizing Trait of Autism Reflects a Shift from Reliance on Global to Local Contextual Cues

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The theory that autism is associated with a decreased reliance on contextual cues (Frith 1989) suggested that individuals with autism might have a decreased susceptibility to visual illusions. However, direct evidence for this was mixed (e.g., Happé 1996; Ropar & Mitchell 1999). Recent work, though, has shown that illusion susceptibility is negatively correlated with the autistic trait of systemizing, when measured across the general population (Walter, Dassonville & Bochsler 2009). However, this relationship seemed to hold only for those illusions that were caused by global distortions of the observer's egocentric reference frame. In the present study, we tested this distinction, using an illusion (the Rod-and-Frame Illusion, or RFI) that is known to have two variants. When shown a large tilted frame, the observer's global perception of vertical is distorted, causing a misperception of the orientation of an enclosed rod. In contrast, a smaller tilted frame has no effect on perceived vertical, but causes a misperception of rod orientation via a local contrast effect between the rod and nearby contours of the frame. In 54 typically-developing undergraduates, we separately measured the magnitude of the global and local effects of the RFI. Participants also completed the questionnaires of Baron-Cohen's Autism, Empathizing and Systemizing Quotients. As hypothesized, global distortions of perceived vertical were negatively correlated with systemizing, as well as the attention-to-detail subscale of the Autism Quotient. Surprisingly, systemizing was also found to be correlated with local contrast effects, but here the correlation was a positive one: higher levels of systemizing were associated with an increased susceptibility to the local contrast effects. These findings indicate that while autism is not simply associated with a decreased reliance on contextual cues, it is associated with a more complex shift from a general reliance on global contextual cues to an exaggerated reliance on local contextual cues.

16.435 Delayed early primary visual pathway development in premature infants: high density electrophysiological evidence

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The aim of the present study was to investigate the effects of premature birth on visual system development in the first six months of life. Early and late visual evoked potential (VEP) components and their topographical distribution related to preferential or combined activation of the magnocellular (M) and parvocellular (P) visual systems were obtained in 21 preterm and 32 fullterm infants. Participants were infants of extremely low birth weight (ELBW), weighing between 688-1360g (mean gestational age: 26.3 wks) and low birth weight (LBW), with a weight between 983-1603g (corrected mean gestational age: 29.8 wks). The fullterm group birth weights ranged from 2700-4439g (mean gestational age: 39.2 wks). Three stimulus conditions, a low spatial frequency (0.5 cpd) presented at either of two Michelson contrast levels (10% and 95%), and a high spatial frequency (2.5 cpd) at 95% contrast, were used in order to preferentially activate the M system, the P system, or both. Results indicate impaired function overall in preterm infants compared to fullterm babies. Furthermore, the severity of this impairment was directly related to the degree of prematurity. The cortical topography showed, by its diffuse nature, that both M and P systems (P1 and N1 components, respectively) remained immature until 6 months of corrected age, after which it normalized. However, at 3 months of age, under the optimal condition (Low95%) that stimulated both pathways simultaneously, the N2 component (generally associated with motion perception) obtained in premature infants was of larger amplitude than in fullterm ones, likely reflecting predominant activation of the M system in this group by the apparent motion inherent in the stimulation procedure. Furthermore, a reduced motion adaptation (expressed in the P2 component) at 6 months of age, in combination with the immature topography, indicate a slowed development of associative visual cortical areas in premature infants.

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16.436 Dissociating higher-order visual processing in typical and atypical development

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Background: Research with adults has established that higher-order visual information is processed along two functionally specialized pathways: a ventral stream and a dorsal stream. Surprisingly, however, less is known about how this dissociation emerges and matures during development. The present study (1) investigated typical development of higher-order visual processes and (2) determined whether the developmental trajectories of these visual processes differed for atypically developing individuals. Methods: In Experiment 1, 30 typically developing adolescents (age 10-16 years) completed four computerized experimental paradigms designed to differentially draw on dorsal or ventral processing resources. These tasks required participants to (a) either decide if two abstract shapes match (ventral task) or fit together (dorsal task) or (b) either pay attention to the identity (ventral) or the location (dorsal) of drawings of buildings, upright faces, and inverted faces. Results show no association between age and accuracy, but reaction times were negatively correlated with age. These relationships held for both dorsal and ventral tasks. Data are compared with accuracy and reaction time results from young adults (age 18-25 years). In Experiment 2, the same computer tasks were completed by a group of atypically developing children with congenital hypothyroidism (CH), a paediatric endocrine disorder caused by lack of thyroid hormone (TH) that is present at birth. TH is a critical endocrine modulator of normal brain development known to affect development of the visual system. CH had significantly poorer accuracy scores on both ventral and dorsal tasks, but were also significantly slower to judge identity than controls. Conclusions: First, our findings suggest that there is very little development in the dorsal and ventral pathways after ten years of age in typically developing individuals, although processing speed does increase with age. Secondly, TH insufficiency during gestation is associated with impairments in higher-order visual processing in adolescence.

Acknowledgement: March of Dimes, Vision Sciences Research Program

16.437 **Magnocellular Deficits in Dyslexia Provide Evidence Against Noise Exclusion Hypothesis**

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There is significant controversy about the mechanism underlying dyslexia. Sperling et al. (2005;2006), for example, hypothesize that the underlying mechanism is an inability to ignore noise in visual stimuli (the noise exclusion hypothesis), and that this inability is not due to a magnocellular deficit, as it shows up in both parvocellular-oriented (static, high frequency gabor filters) and magnocellular-oriented (counterphase flicker low frequency gabors) stimuli in their experiments. Dyslexics are differentially impaired in discriminating these stimuli in noise. However, the noise used in their experiments is a flashed white noise stimulus, which can activate the magnocellular system, a system that has been implicated in figure-ground discrimination. If there is a magnocellular deficit, this would impact both the parvo- and magno-oriented decisions because of poor figure/ground discrimination. Several studies by the first author using sinusoidal test and background patterns that optimally activate magnocellular neurons have shown that dyslexics have reduced contrast sensitivity to direction discrimination. These studies showed that with equal test and background spatial frequencies, dyslexics were initially least sensitive to the direction of movement, but that following training on left-right movement discrimination twice weekly for 12-15 weeks, dyslexics were most sensitive to the direction of movement with equal test and background frequencies. Equal test and background spatial frequencies provide the greatest amount of noise, since test and background patterns are analyzed by neural channels tuned to the same spatial frequencies. Since training rapidly removes this deficit, these data suggest that the deficit in noise exclusion is due to the relatively sluggish magnocellular pathway in dyslexics. Furthermore, this training dramatically improves reading speed in the subjects. Our results are consistent with the view that dyslexia is due to sluggish magnocellular neurons, but not with the view that a noise exclusion deficit, without a concomitant magnocellular deficit, underlies dyslexia

16.438 **The Effects of Acute Alcohol Consumption on the Visual Perception of Velocity and Direction**

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The effects of alcohol on velocity and direction discrimination were examined. Participants completed both tasks under control and alcohol conditions (.08% BAC) conducted at both a “slow” (3os-1) and “fast” velocity (12os-1). Stimuli were dark dots on a light background that could vary in speed or direction. They were presented within a 5º circular field on a computer display spanning 12° × 16° in visual angle. Thresholds were measured using a Method of Constant Stimuli and a 2-interval AFC. In the velocity condition, one stimulus was always moving at the standard speed and the other, comparison, stimulus varied over a range of 85-115% of the standard velocity. Participants made judgments as to which moved faster. Using the same procedure, participants in the direction task judged which of the two drifting patterns was moving vertically. The standard was always vertical, while the comparison stimuli ranged from 0.5 to 3.5 o to the right of the vertical plane. As expected, results of the velocity task demonstrated a small but significant effect of alcohol, demonstrating impairment in the general ability to accurately discriminate stimulus velocity. In the direction discrimination condition, performance was impaired at both velocities, but for the slower speed, the initial range of directions used resulted in a floor effect, with performance at chance for both the alcohol and no alcohol conditions. There was a significant effect of alcohol for the higher velocity pattern. We conclude that, overall, alcohol has a modest effect on the ability to discriminate both the velocity and the direction of moving targets.

Color and light: Adaptation and constancy

Orchid Ballroom, Boards 439–450

Friday, May 7, 6:30 - 9:30 pm

16.439 **Color rendering and the spectral structure of the illuminant**

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The increasing availability of light sources with almost arbitrary spectral distributions, like LED and DLP based sources, poses the problem of selection of a specific spectral profile. To this effect the relationships between spectral structure and the visual effects over rendered scenes need to be taken into consideration, a matter that has not been quantified systematically. In this work we addressed this issue by studying, computationally, the chromatic effects of a large set of illuminants with almost arbitrary spectral structure. The illuminants were metamers of a Plankian radiator with color temperature of 6500 K and metamers of non-Plankian radiators with chromaticity coordinates uniformly distributed over the same isotemperature line. The metamers were generated by the Schmitt’s elements approach and were parameterized by the spectral distance to the equi-energy illuminant E and by the number of non-zero spectral bands, both quantities measuring the spectral structure. The chromatic effects of each illuminant were quantitatively assessed by the CIE color rendering index (CRI), by a chromatic diversity index (CDI) and by the number of discernible colors estimated for a set of indoor scenes digitized by hyperspectral imaging. It was found that CRI decreases as the illuminant spectrum becomes more structured whereas larger values of CDI could only be obtained with illuminants with a small number of non-zero spectral bands, that is, with highly structured spectra. For indoor scenes, the maximum number of discernible colors was also obtained for highly structured spectra. Thus, structured spectra with low number of non-zero spectral bands seem to maximize the chromatic diversity of rendered scenarios but produce only modest CRI. These results suggest that highly structured illuminants may be best for applications where maximization of chromatic diversity is important.

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16.440 **A low-cost, color-calibrated reflective high dynamic range display**

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High dynamic range (HDR) displays are enabling new advances in visual psychophysics, but commercial HDR displays are both expensive, and difficult to calibrate colorimetrically. Homebrew HDR displays incorporating LCD panels and digital projectors are relatively inexpensive and can be calibrated, but building such displays requires sophisticated technical skills. We have developed a low-cost, color-calibrated HDR display for vision research that can be constructed and used by researchers without the need for specialized equipment or advanced engineering abilities. Inspired by the work of Bimber et al., this reflective HDR display incorporates an inkjet printer, a digital video projector and a digital camera. To display an HDR image, the image is first processed through the iCAM06 image appearance model to produce a standard dynamic range (SDR) image that is sent to the printer. The digital video projector is then roughly positioned so its image field covers the print. Custom camera-based structured-light image registration software then automatically aligns the projected and printed images. A color calibration module then measures the print colors and determines the values to send to the projector to achieve the best possible reproduction of the original HDR image. This iCAM-based approach to HDR color reproduction goes substantially beyond prior work in terms of its colorimetric accuracy. With respect to intensity and dynamic range, because the print area is substantially smaller than a projector's typical field size, the maximum intensity in the combined image can be quite high, and the current display has a peak luminance around 2000 cd/m2 with a dynamic range greater than 20,000:1. While the print-based nature of this display does limit its usefulness for interactive studies, its low-cost, do-it-yourself design, and its ability to be calibrated should make it a valuable addition to the vision researcher's laboratory.

16.441 **The Combined Effect of Chromatic Contrast and Chromatic Assimilation Produced by a Purple Surround on an Achromatic Target**

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Chromatic assimilation and chromatic contrast are two different types of spatio-chromatic interactions, which are rarely observed simultaneously. These phenomena are normally considered mutually exclusive, as they shift the chromaticity of an "induced" region in opposite chromatic directions: away and toward the chromaticity of the surround, respectively. In our displays we observed a shift of chromaticity of a target achromatic field induced by a uniform purple surround in a direction in color space that can be interpreted as the combined effect of chromatic contrast and chromatic assimilation of the surround color. We measured this combined effect by varying stimulus size, stimulus eccentricity, and binocular disparity of our stimuli. Our results show that chromatic assimilation and chromatic induction do not always cancel each other and may lead to perceptual shifts in chromaticity in a direction in color space that does not coincide with the line formed by the color of the surround and its chromatic complement. For example, due to the impact of a purple surround, a region that would look gray without chromatic surround does not look green or purplish, but is perceived as blue if viewed from a certain distance. We explain the observed effects by the structure of receptive fields of the neurons that encode spatio-chromatic interactions and by combination of individual induction effects produced by inputs representing primary chromatic signals on the output of double-opponent neurons.

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16.442 **Variations in achromatic settings across the visual field**

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The stimulus spectrum that appears white shows little change between the fovea and near periphery, despite large changes in spectral sensitivity from differences in macular pigment screening (Beer et al JOV 2005; Webster and Leonard JOSA A 2008). This perceptual constancy could occur if color coding at different regions of the retina is normalized to the local average spectrum. However, local adaptation could instead lead to changes in the achromatic point across the visual field if the spectral characteristics of the world itself vary across space. Natural scenes in fact include significant spatial variations in chromaticity because of factors such as the spectral differences between earth and sky. We asked whether there might be corresponding differences in achromatic loci in upper and lower visual fields. Observers dark adapted and then viewed a 25 cd/m2 2-deg spot flashed repeatedly for 0.5 sec on and 3.5 sec off on a black background. The chromaticity of the spot was adjusted to appear achromatic by using a pair of buttons that varied chromaticities in terms of the CIE u'v' coordinates. Settings were repeated while observers fixated dim markers so that the spot fell at a range of eccentricities spanning +60 deg along the vertical meridian. Achromatic settings did not change systematically with location, and in particular did not show a blue to yellow-green trend consistent with outdoor scenes. This could indicate that observers are primarily adapted to environments with more stationary color statistics (e.g. indoor settings) or that achromatic loci are also calibrated by retinally non-local processes.

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16.443 **Are Gaussian spectra a viable perceptual assumption in color appearance?**

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Natural illuminant and reflectance spectra can generally be well approximated by a linear model with as few as three basis functions. Some models of color appearance further assume that the visual system constructs a linear representation of spectra by estimating the weights of these inferred functions. However, such models do not accommodate nonlinearities in color appearance such as the Abney effect. Previously, we showed that the hue of lights with Gaussian spectra remains constant over much of the spectrum as bandwidth changes, suggesting that the visual system might adopt an assumption like a Gaussian model of spectra so that hue is tied to a fixed inferred property of the stimulus such as the spectral centroid (Mizokami et al, 2006). This model is qualitatively consistent with measures of the Abney effect, and is also consistent with suggestions that natural spectra may in some cases be better described by Gaussian than linear models (MacLeod and Golz, 2003). Here, we examined to what extent this Gaussian inference provides a sufficient approximation of natural color signals. Spectra from available databases, hyperspectral images, and our own measurements were analyzed to test how well the curves could be fit by either a simple Gaussian with 3 parameters (amplitude, peak wavelength and standard deviation) vs. the first three PCA components of standard linear models. The spectra were coded from 400-700 nm in 10nm steps and were fit using the Matlab Optimization toolbox. Results shows that the Gaussian fits were essentially comparable to a linear model with the same degrees of freedom for both reflectance and illumination spectra, suggesting that the Gaussian model could provide a plausible perceptual assumption about stimulus spectra for a trichromatic visual system.

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16.444 **Colour constancy as measured by least dissimilar matching**

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Colour constancy is usually measured with the asymmetric colour matching technique. As an exact colour match between objects lit by different chromatic lights is impossible, we instructed our observers to establish the least dissimilar pair when studying colour constancy. Using such a technique, Logvinenko & Maloney (2006) found nearly perfect lightness constancy. The stimulus display consisted of two identical sets of 22 Munsell papers illuminated independently by neutral, yellow, blue, green and red lights. The lights produced approximately the same illuminance (50 lux). Their CIE 1931 chromaticity coordinates were (0.303, 0.351), (0.392, 0.410), (0.131, 0.150), (0.224, 0.667), and (0.635, 0.321). Four trichromatic observers participated in the experiment. Pointing out randomly a paper under one illumination, experimenter asked observer to indicate which paper under the other illumination appeared least dissimilar in colour. All measurements were repeated three times for each observer. When the least dissimilar match was the physically same paper we call it exact match. The proportion of exact matches was evaluated as a colour constancy index (CCI). When both the sets of papers were lit by the same light, the CCI was 0.92, 0.93, 0.84, 0.78, and 0.76 for the neutral, yellow, blue, green and red lights respectively. When one illumination was neutral and the other chromatic, the CCI was 0.80, 0.40, 0.56, and 0.32 for the yellow, blue, green and red lights respectively. Therefore, the simultaneous colour constancy was found to be much poorer. Yet, it was better than expected if one takes into account the illuminant induced colour stimulus shift as defined by Logvinenko (2009). Therefore, the visual system somehow overcomes the limitations on colour constancy imposed by the illuminant induced colour stimulus shift. References Logvinenko A. D. & Maloney L. T. (2006) Perception & Psychophysics, 68, 76-83. Logvinenko A. D. (2009) J. of Vision 9(11):5.

Acknowledgement: EPSRC

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16.445 **Why Does von Kries Law Hold?**

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von Kries law (1878) states that color adapation might be described by multiplicative gain controls within each class of cone receptor independently. This assumption has been widely used in various theories explaining color constancy phenomena under illuminant changes ever since Ives (1912). Several recent experimental work provide evidences supporting the idea that von Kries law indeed holds. One prominent example is the invariance of cone-excitation ratios observed by Foster and his colleagues (1994). Though it is widely accepted now, little work has been done to understand why von Kries law holds. Gerhard West and Michael H. Brill (1982) have stuided the necessary and sufficient conditions for von Kries chromatic adaptation. Their conclusion characterized the properties of illuminannt and surface reflectance spectral power distributions under fixed human cone sensitivity curve. However, it is more likely that the cone sensitivity curves evolve in the eviromental statistics such as illuminant and surface reflectance spectral distribution. James Dannemiller (1993) attributed von Kries law to the fact that approx. 95% the variance in these reflectance spectra is captured by the first principal component. However, we find that this might not be the case for sufrace reflectance spectral data set other than Krinov (1947) . Combining experimental simulation and theoretical analsysis, we find that the shape of cone sensitivities curves might be the major cause of von Kries law. In addition, our findings might provide a novel view for explaining why the cone sensitivity curves are as they are.

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16.446 **Individual differences in chromatic contrast adaptation**

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Pre-cortical color channels are tuned primarily to the SvsLM or LvsM cone-opponent (cardinal) axes, but appear elaborated in the cortex to form higher-order mechanisms tuned to both cardinal and intermediate directions. Psychophysical evidence for these mechanisms includes adaptation to temporal chromatic contrast. Adapting to any axis of color space selectively reduces perceived contrast along the adapting axis, implying channels that can be selectively tuned to this axis. Previous studies have found that the degree of selectivity for non-cardinal axes varies even for the small number of observers tested (Krauskopf et al., 1982; Webster & Mollon, 1994). Here we tested a larger sample of color-normal observers to explore individual differences in color contrast adaptation, to examine whether differences are larger for cardinal vs. noncardinal axes (e.g., because they reflect channels that arise at different visual levels). Observers adapted to a 2 Hz temporal modulation along the LvsM or SvsLM axis, or along 2 intermediate axes chosen to be midway between the cardinal axes. Test stimuli included 8 fixed-contrast chromaticities falling on either side of the 4 adapting axes. After an initial adaptation (2 min), 1-sec test pulses were interleaved with 4-sec top-ups in a 2° field above a central fixation cross, with the test colors matched by adjusting the color of a concurrent reference stimulus presented in a field below fixation. Changes in the perceived test chromaticities were fit with ellipses to estimate the selectivity of the adaptation for each of the 4 axes. The strength of adaptation varied widely across observers; all observers showed significant though reduced selectivity along non-cardinal axes. Inter-observer differences in these adaptation effects could reflect normal variation in the distribution of cortical color mechanisms and/or the adaptability of these mechanisms.

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16.447 **The duration of contingent color aftereffects for different directions in color space**

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The McCollough effect (ME) is a color aftereffect contingent on orientation. Though studied extensively, the basis for the effect and whether it reflects specialized processes remains poorly understood. ME's are conventionally induced by adapting to gratings that covary in brightness and color (e.g. both bright and red) and then testing on gratings that are achromatic (e.g. bright only). The hue shifts functionally resemble a form of tilt aftereffect within the color-luminance plane (e.g. so that bright bars appear rotated away from bright-red toward bright-green), and are known to have remarkably long persistence (e.g. Vul et al. JOV 2008). We compared the duration of these hue shifts to the shifts in both hue and lightness induced by comparable stimuli in other directions in the color-luminance plane (e.g. to the relative brightness changes induced in isoluminant gratings). Observers adapted to vertical and horizontal gratings with luminance and chromatic (LvsM) contrast paired in or out of phase, and then tracked the aftereffects in achromatic or isoluminant gratings with a matching task. Both types of test gratings show "tilts" away from the color-luminance direction of the adapting grating which are selective for orientation and which may therefore partly reflect common processes like contrast adaptation. However, the marked persistence of the aftereffects in achromatic stimuli suggests that additional processes - which may be specific to luminance edges - contribute to the hue shifts in the conventional ME, and could support a special role of processes like color spreading in the aftereffect (Broerse et al. Vision Research 1999). Differences in aftereffect duration in luminance and chromatic tests also argue against suggestions that the long persistence of the ME results only because the stimuli required to de-adapt are rarely encountered, and suggest instead that the persistence may reflect a special characteristic of the adaptation.

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16.448 **Cortical aftereffects of time-varying chromatic stimuli**

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Colored afterimages of steady fields are predominantly photoreceptor driven (Williams & MacLeod, 1979), but afterimages in other domains have implicated cortical loci. We demonstrate a new method to measure aftereffects of time-varying chromatic stimuli that can be used to probe properties of later color processes. If the colors of two halves of a disk start at the same point on a color-circle, and follow opposite paths for a half-cycle along the circumference so that they end at the same point, the two halves appear significantly different. This would be compatible with successive contrast from different adapting colors. If equal numbers of frames are subtracted progressively from the ends of the two animations, a point is reached where the two halves look identical to an observer, despite being physically distinct. Adaptation magnitude was estimated from the number of frames that had to be rewound for equalization. For excursions beginning and ending on the Δ(L-M) and Δ(S) cardinal axes, adaptation magnitude decreased from modulation frequencies of 0.5 to 2.0 Hz, both in phase and time. For half-cycle modulations along the color circles, the colors of the two halves go from the neutral point to opposite extreme points and back for one cardinal axis, and from the same extreme to the opposite extreme for the other axis. The adaptation effect of modulating solely along the cardinal axis with opposite directions was significantly less than the effect of the joint modulation along the color circle, especially at low frequencies, implicating neural interactions beyond the LGN. Adding the third harmonic at one-third power to the 0.5 Hz modulation gave a lower adaptation magnitude than subtracting it, by an amount larger than predicted from the sum of independent adaptations, indicating that excursion magnitude is more important than sharp transients.

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16.449 **Very-long-term chromatic adaptation and short-term chromatic adaptation: Are their influences cumulative?**

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Do very-long-term (VLT) and short-term chromatic adaptation have a cumulative influence on color vision? VLT adaptation results from exposure to an altered chromatic environment experienced over days or weeks. Color shifts from VLT adaptation are measured hours or days after leaving the altered environment. Short-term adaptation results from exposure for a few minutes or less, with color shifts measured within a few seconds or minutes after the adapting light is extinguished. Here, both types of adaptation were combined. Shifts in unique yellow caused by short-term chromatic adaptation can be ~10 times greater than for VLT adaptation. The specific question considered here is whether the color shift from VLT adaptation is cumulative with the far larger shift from short-term adaptation or, instead, does much stronger short-term adaptation eliminate the modest color shifts caused by VLT adaptation? All adaptation was to reddish-appearing long-wavelength light; shifts in unique yellow were measured. For VLT adaptation, the subject viewed for one hour daily a CRT monitor that displayed a moving red grating (Judd x = 0.60, y = 0.35, 22.4 cd/m2). Adaptation was repeated daily for 12 to 14 days. Unique yellow was measured before the start of each day's VLT adaptation, i.e., 22+ hours after the end of VLT adaptation on the previous day. The subject set an admixture of 540nm-plus-660nm light to appear equilibrium yellow at five luminance levels between 0.5 and 2.5 log trolands. For short-term adaptation, exposure to a 660 nm adapting light at 100 td was incorporated into the testing session for equilibrium yellow measurements. Shifts in unique yellow due to only short-term or to only VLT adaptation also were measured. The color shifts from VLT and short-term adaptation were cumulative, which is consistent with short-term and VLT chromatic adaptation acting independently.

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16.450 **The role of adaptation mechanisms at the mesopic range to achieve lightness constancy under glare conditions**

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Purpose: Previous results have shown the influence of glare on the brightness evaluation of a foveal test in the mesopic range depends on the test luminance as well as the surround luminance. In this work we perform new experiments in order to find which variable determines lightness constancy. Methods: Patches subtending 1.2 degrees placed on the center of a display of 7 x 9,5 degrees were shown binocularly to 3 subjects (25.7±2.9 years old) in a sequential way. In each trial, a comparison patch (Pc) before a standard patch (Pstd) were presented. Simultaneously to Pstd a transient peripheral glare source (10º temporal) was turned on. The task was to choice the brighter patch. The matching luminance (Lm) was obtained when both patches were equal in brightness. In a first experiment, the luminance values were: 4 cd/m2 for Pstd and 0.75, 1, 1.5, 2 and 3 cd/m2 for the surround. In a second experiment, the surround luminance was 0.001 cd/m2 and the values of Pstd were 0.3, 0.35, 0.4 and 0.45 cd/m2. The glare source illuminances were 60 and 30 lx measured between the two eyes. Results: We found lightness constancy in the first experiment but that was not the case in the second one, in which Lm was reduced. When the test and surround luminances have enough level to excite cones, a mechanism of adaptation maintains lightness constancy. But when the surround is in the scotopic range, the luminance veil over the scene saturates the rods and the cones adaptation takes a time in which produces a transient loss of lightness constancy.

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3D perception: Binocular and motion cues

Orchid Ballroom, Boards 451–460

Friday, May 7, 6:30 - 9:30 pm

16.451 **Quality in depth perception: the plastic effect**

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The qualitative superiority of depth perception under binocular viewing--the plastic effect (Ames, 1925; Schlosberg, 1941)--is generally regarded as an epiphenomenon (a quale) linked to binocular visual processing. This view finds some support in perceptual reports of depth quality when binocular vision is recovered in late adulthood (Barry, 2009). However, such qualitative vividness is also experienced under monocular and synoptic viewing of pictures (Ames, 1925; Schlosberg, 1941; Koenderink, 1998), suggesting that the story may be more complicated. We had naïve observers make qualitative judgments of depth and other perceptual attributes for real objects and pictorial images under a range of viewing conditions. Under monocular-aperture viewing, observers report the same effects as in binocular viewing of real scenes, saying that things "stick out", appear "more real and 3-dimensional", and that "the space between objects can be perceived". Observers also reported a heightened perception of material qualities (e.g. glossiness, color saturation) as well as a sharpening of the image. Curiously, such related effects have also been reported by individuals who have recovered stereopsis (Barry, 2009). More importantly, observers reported changes in perceived distance or scale consistent with an accommodation-based distance effect or micropsia in pictorial space. Surprisingly, observers did not report changes in perceived shape in these conditions. Parallel effects were observed for binocular viewing of pictorial images with simulated blur gradients; observers also report a heightened plastic effect accompanying changes in perceived distance. These observations neither support the idea that the plastic effect is a byproduct of binocular processing nor that it is determined by relative conflict among depth cues. Rather, they appear more consistent with the theory that the plastic effect is the perceptual presentation of the reliability of the brain's estimates of egocentrically scaled depth, which depend on the availability and reliability of distance information.

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16.452 **Combination of da Vinci stereopsis and Metelli's transparency in depth perception**

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The majority of natural scenes contains zones that are visible to one eye only. Past studies have shown that these monocular regions can be seen at a precise depth even though there are no binocular disparities that uniquely constrain its location in depth. In the so-called da Vinci stereopsis configuration, the monocular region is a vertical line placed next to a binocular rectangular occluder. The opacity of the occluder has been mentioned to be a necessary condition to obtain da Vinci stereopsis. However, this opacity constraint has never been empirically tested. In a first experiment, we tested whether there exists an interaction between classical stereopsis and perceptual transparency. Observers had to judge the depth ordering of two overlapping rectangles. The probability of seeing one surface in front of the other varied with the relative transmittance of the two rectangles. For each trial, a given disparity was added to one of the two surfaces, favoring one of the two to be seen in front. These two depth cues were varied independently. We found a significant interaction between the transmittance and the relative disparity of the rectangles suggesting that these two depth cues can be combined efficiently by the visual system. In the second experiment, we tested whether da Vinci stereopsis and perceptual transparency can interact using a classical da Vinci configuration in which the transparency of the occluder varied. We found that the monocular line was perceived according to the geometry of occlusion present in the scene even when the occluder was clearly transparent. Taken together, these results indicate that the mechanism responsible to place monocular regions in depth is not sensitive to the material properties of objects and da Vinci stereopsis is solved during the early stages of disparity processing.

16.453 **Shape Contrast: Where Does It End?**

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Visual surroundings can influence perception of 3D shape, as illustrated in 'shape contrast' biases where the perception of shape is biased in the direction opposite to the surroundings. Whereas this bias is very robust, little is known about the underlying mechanisms. In this study, we address the issue whether shape contrast biases are the result of local contrast enhancement or whether they are the result of a more global mechanism operating on an extended surround. Observers performed a sequential shape discrimination task on a hinged plane, which was defined by disparity. In the baseline condition, the central surface was presented in isolation but in the experimental conditions, surfaces were added on each side. To induce a shape contrast bias, flankers with different dihedral angle were added to the test and reference surface. These flankers were constant between surround conditions, but on each side we added four more surfaces ('extended surround') of which we varied the dihedral angle distribution. In a 'homogenous' condition, the flankers and extended surround were of constant dihedral angle, in a 'surround average' condition they were varied around the dihedral angle of the flankers and in a 'central average' condition the dihedral angle was varied around the angle of the central surface. Our results show that shape perception is influenced not only by the shape properties in the flanking surround but also by the mean of the distribution of shape properties in the extended surround. Thus, shape contrast is not locally determined and has to be understood from a global mechanism. We consider normalization of shape signals a likely candidate for such a mechanism.

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16.454 **Binocular shape vs. depth perception**

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It has been shown that binocular perception of depth intervals is both inaccurate and unreliable. On the other hand, binocular discrimination of depth order (called stereoacuity) is extremely reliable. Our recent psychophysical experiments showed that human binocular 3D shape recovery of symmetric polyhedra is also extremely reliable and accurate. These results suggest that binocular shape mechanism relies on binocular judgment of depth order, rather than of 3D distances. Our computational model provided a possible explanation of the underlying perceptual mechanisms by showing how a 3D symmetry constraint interacts with the depth order information to produce a 3D metric shape. The question arises as to whether the stereoacuity thresholds can actually account for the 3D shape recovery results. The study of Norman & Todd (1998) showed that stereoacuity thresholds are substantially elevated when the points, whose depth order is judged, are superimposed on the image of a smoothly curved surface. If these results generalize to the case of vertices of a symmetric polyhedron, will the elevated stereoacuity thresholds account for veridical 3D shape recovery? In order to answer this question we measured thresholds for depth order discrimination between two vertices of a polyhedron in the presence and in the absence of the line drawing of a polyhedron. The threshold was almost twice as big when the polyhedron was present, compared to when the two points were shown in isolation. These results were used to revise our model of binocular 3D shape recovery. We conclude by discussing the role of depth vs. shape information in 3D shape recovery.

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16.455 **Percept of shape distortion induced by binocular disparity and motion parallax**

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A flat surface lying in a frontal plane appears slanted in depth about a vertical axis when the image in one eye is horizontally magnified relative to the image in the other eye. The surface appears to slant away from the eye seeing the smaller image. Horizontal magnification disparity also produces shape distortion. Since the vertical angular size of the surface remains the same both with and without horizontal magnification of the image, the side that appears farther away appears larger. A rectangular figure with horizontal magnification disparity is therefore perceived as a horizontally tapered isosceles trapezoid slanted about a vertical axis. It seems that the apparent shape distortion induced by disparity has not been measured systematically although it is well established that the apparent slant approximates to the geometrical prediction. The aim here is to examine the apparent shape distortion induced by disparity. The test stimulus was a random-dot stereogram presented in a mirror stereoscope in a darkroom. The dots were depicted in a rectangular area. The stereoscopic image was a 100-mm-square at 500 mm ahead of the subject. Ten magnitudes of slant were tested: ±50, 40, 30, 20, and 10°. Subjects indicated the perceived slant of the test stimulus with an unseen paddle and then adjusted the taper of a trapezoid on a computer monitor to coincide with the apparent shape with buttons. The apparent slant and shape distortion from motion parallax were also investigated. Subjects monoularly viewed a single random-dot pattern displayed on a computer monitor while making side-to-side head movements. Stimulus translation and head movement were synchronized. For both disparity and motion parallax the perceived taper angle was smaller than prediction even though the perceived slant was almost veridical. While the predicted taper increases as slant increases, the perceived taper was immutably about 1°.

Acknowledgement: Japan Science and Technology Agency (JST)

16.456 **Integration time for the mechanisms serving the perception of depth from motion parallax**

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Our recent quantitative model for the perception of depth from motion parallax (MP), based on the dynamic geometry of MP, proposes that relative object depth (d) can be determined from fixation distance (f), retinal image motion ($d\theta/dt$), and pursuit eye movement ($d\alpha/dt$) with formula: $d/f = d\theta/d\alpha$ (Nawrot & Stroyan, 2009). Given the model's dynamics, it is important to know the integration time required by the visual system to recover $d\alpha$ and $d\theta$, and then estimate d. If the perception of depth from motion is sluggish, and needs to "build-up" over a period of observation, then the potential accuracy of the depth estimate suffers as the observer moves during the viewing period. A depth-phase discrimination task was used to determine the time necessary to perceive depth from MP. Observers remained stationary and viewed a briefly translating (4 deg/s) random-dot MP stimulus on a CRT (120 Hz) at 57 cm. The stimulus was 6.6 deg2, having 4000 2 min2 dots. Fixation on the translating stimulus was monitored with an ASL eye tracker. Stimulus duration was varied within an interleaved staircase procedure for leftward and rightward eye-movements. Depth-discrimination can be performed with presentations as brief as 16.6 msec, with only two stimulus frames providing both retinal image motion and the stimulus window motion for pursuit (mean range = 16.6–33.2 msec). This was found for conditions in which, prior to stimulus presentation, the eye was engaged in ongoing pursuit or the eye was stationary. A large (13 deg2) high-contrast masking stimulus (83 msec) disrupted depth-discrimination for stimulus presentations less than 60-80 msec in both pursuit and stationary conditions. We conclude that neural mechanisms serving depth from MP generate a depth estimate quickly, <90 msec. This interval might be linked to ocular-following response eye-movement latencies. Any additional sluggishness in MP might be due to head movement dynamics.

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16.457 **The Role of Temporal 'Priors' in the Perception of Depth-Order from Motion: A Priming Study**

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Computational studies suggest that the visual system uses its knowledge of the recent motion history of objects to help constrain the interpretation of depth-order from motion (DFM). However, it is unclear whether or how the visual system makes use of such information. We characterized the influence of prior temporal information on DFM perception using a priming experiment. Each stimulus consisted of a central strip of random dots moving in depth relative to a larger, outer reference surface, also comprised of random dots. Depending on the stimulus, the central surface appeared to be in the same, nearer or farther depth plane relative to the reference surface. During each trial, a prime stimulus and a target stimulus were presented sequentially for 100 and 50 ms, respectively. The two stimuli were separated by an inter-stimulus interval of 33, 66, 100, 133, or 166 ms, depending on the trial. Subjects reported the perceived depth-order of the target stimulus. We found that the depth-order of the prime stimulus had a significant influence on DFM perception (2-way ANOVA, depth-order of prime x SOA; $p < 0.05$ for both factors and their interaction). As expected, when both stimuli contained the same depth-order information, the perceived depth-order of the target stimulus was consistent with the depth-order expected from the depth-order information in the stimuli. When the target stimulus contained no depth-order information, but the prime stimulus did, subjects perceived the target stimulus to have the same depth-order as the prime, indicating that the prior depth-order information from the prime influenced the depth-order interpretation of the subsequent target stimulus. When the target stimulus supported the opposite DFM percept as the prime, the reported depth-order was intermediate between those expected from either stimulus alone. Together, our results characterize some key properties of temporal summation of DFM information.

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16.458 **Neural Mechanisms of Perception of Depth-Order from Motion: A Human fMRI Study**

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When one visual object moves behind another, it provides a compelling sense of which object is closer to the viewer and which object is farther in depth. This percept is referred to as depth-order from motion (DFM). The neural mechanisms of DFM are largely unclear, including the relative roles of the first-order (i.e., luminance-based) vs. the second-order (i.e.,non-luminance-based) motion processing mechanisms, and the relative contributions of the two know types of DFM cues, the accretion-deletion (AD) cue and the common motion (CM) cue. We performed a whole-brain fMRI scan using a mixed (i.e., events-within-blocks) design, which allowed us to compare the responses across blocks as well as across individual trials. Depending on the stimulus block, subjects were shown either stimuli that elicited depth-order percepts, or stimuli that did not. Stimuli that elicited the depth-order percept contained both types of motion and both types of DFM cues. During each trial of each stimulus block, subjects reported the perceived depth-order using a button press. We found significantly greater responses to depth-order stimuli relative to non-depth-order stimuli in several early retinotopic regions, including V1, V2, V3, V3A, and V4v. The response in V3A reliably reflected, on a trial-to-trial basis, whether the subjects perceived depth-order (logistic regression; group data, $N = 5$; $p < 0.05$). However, we were unable to find any region that was differentially responsive to near vs. far depth-order stimuli, or to the corresponding percepts. Importantly, neither V5/MT+ nor the kinetic occipital region (KO) showed significant differential responsiveness to the DFM stimuli across subjects ($p > 0.05$), although the responses in both regions showed a slight response suppression by the depth-order stimuli in some subjects. Together, these results identify specific brain regions may play an important role in DFM cue processing and mediate DFM perception.

Acknowledgement: Supported by Medical College of Georgia

16.459 **Transcranial magnetic stimulation improves rotation sensitivity for actively viewed structure from motion**

Lorella Battelli[1,2](lbattell@bidmc.harvard.edu), Giovanni Mancuso[1], Carlo Fantoni[1], Fulvio Domini[1,3]; [1]Center for Neuroscience and Cognitive Systems, Italian Institute of Technology, [2]Department of Neurology, Beth Israel Hospital, Harvard Medical School, [3]Department of Cognitive and Linguistic Sciences, Brown University

In previous experiments we measured observers' performance in a rotation-detection task during active vision of structure from motion (SfM) displays. Observers performed a lateral head shift while viewing either monocularly or binocularly the same optic flows consistent with either static or rotating random-dot planar surfaces. An Optotrack Certus system was used to update in real-time the optic flows as a function of observer's head position and orientation. Results showed that the addition of a null disparity field increased the likelihood of perceiving surface rotation causing reduced rotation sensitivity for the binocular relative to the monocular viewing condition. A possible hypothesis for this phenomenon is that the introduction of a null disparity field creates an inconsistency among the depth cues forcing the visual system to interpret the optic flow in a way consistent with disparity (rotating surface far from the point of view) rather than vergence information (static surface located at the level of the screen). In order to test this hypothesis we used low-frequency rTMS over the early visual cortex. Neurophysiological inactivation studies (Ponce et al., 2008) have found that visual areas V2/V3 are selective for the recovery of depth from binocular-disparity information. Two groups of subjects performed the same rotation detection task before and after rTMS or Sham-TMS delivered offline (10min, 1Hz) over V2/V3 targeting binocular disparity-sensitive neurons. Consistent with our hypothesis rTMS induced an improvement in the rotation sensitivity that was selective for binocular condition, while monocular performance remained intact. We conclude that low-frequency rTMS over V2/V3 inhibits binocular disparity-sensitive neurons allowing the visual system to interpret a binocularly viewed optic flow as consistent with retinal motion information and vergence regardless of disparity information.

16.460 **Surface Layout and Embodied Memory: Optic Flow and Image Structure as Interacting Components in Vision**

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Introduction: Optic flow and image-based vision are treated by the Two Visual Systems hypothesis (Milner and Goodale (1996)) as anatomically separate systems. We advocate conversely that optic flow and image structure are functional components of a unitary perceptual system. Optic flow provides powerful but temporary depth information; image structure is persistent but weak in specifying depth. When combined, optic flow informs image structure that provides embodied memory. Method: Two random-textured planes—a large rear plane containing targets seen through holes in a smaller front plane (holes without targets were distracters)—rotated rigidly to reveal depth structure; then the rear plane translated in one of 8 diagonal directions and stopped with targets occluded. Participants marked locations of hidden targets after some delay, during which they saw either the static image or a blank screen. In Experiment 1, delays were 5s, 10s or 15s with 2 to 15 targets and distracters, respectively, in three conditions: image structure only— holes were outlined but translation of plane was discontinuous; optic flow only—holes were not outlined but translation was continuous; and optic flow plus image structure. In Experiment 2, delays were 5s or 25s and numbers of targets and distracters were 9, 12, 15 or 18, respectively. Results: In Experiment 1, participants could not locate targets with only image structure and no optic flow. With only optic flow, participants correctly located up to 3 targets. With both, participants correctly located more than 60% of the 15 targets with 15s delay. In Experiment 2, mean numbers of targets correctly located were 8.0 without blank regardless of delay lengths; 7.7 with blank and 5s delay; and 7.0 with blank and 25s delay. Conclusion: Optic flow and image structure contribute functionally distinct properties to a single visual system. Optic flow yields layout and image structure preserves it.

Object recognition: Development and learning

Vista Ballroom, Boards 501–513

Friday, May 7, 6:30 - 9:30 pm

16.501 **Infant learning ability for recognizing artificially-produced 3D objects**

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Regardless of changes in viewpoint, observers can recognize objects from almost any direction. Experiencing objects from various viewpoints may enhance the development of this ability. Previous study has shown that 6- to 8-month old infants who were presented with sequentially rotated face images from profile to frontal view could identify the learned face (Nakato et al., 2005). Since faces are special objects for infants, it may be possible that such ability is limited to facial recognition. Here, we investigate the differences in infant learning ability for faces and objects. To investigate such 3D object recognition, we designed images which were well controlled in both their texture and color. Objects were created using three-dimensional graphic software (Shade 9 Professional; e-frontier, Inc., Japan, Poser 7; Smith Micro software, Inc., California). One hundred and twelve sequential images of each object were created by rotating an axis perpendicular to the visual axis connecting the viewer's eyes and the object from frontal view to plus-minus 60 deg. 3- to 6-month-old-infants participated in the present study, and a familiarization/novelty preference procedure was used to investigate infants' 3D object recognition. Infants were first familiarized with a face image (face image condition) or a shoe image (shoe image condition). During the familiarization phase, infants were repeatedly shown sequentially rotating images of a face or a shoe for 15 sec × 6 trials. After familiarization, we checked infants' novelty preference between these two conditions. In the test phase, infants were shown the familiarized face (or a shoe) and a novel face (or a shoe) side by side for 10 sec × 2 trials. Our preliminary results showed that the ability for face learning matures earlier than that for object leaning. This result suggests that the face is a special object for infants even in artificially-produced 3D object recognition.

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16.502 **The development of part-based and analytical object recognition in adolescence**

Elley Wakui[1](e.wakui@gold.ac.uk), Dean Petters[2], Jules Davidoff[1], Martin Juttner[2]; [1]Goldsmiths, University of London, [2]Aston University

Three experiments (familiar animals, familiar artefacts, newly learned but previously novel objects) investigated different developmental trajectories for part-based and analytical-based object processing between 7-16yrs. The 3-AFC task required selecting the correct appearance from individual part or part-relational manipulated versions. In all experiments, even the youngest children showed adult-like performance on part-changes. However, for animals and artefacts similar levels were only reached by 11-12yrs for relational changes. Interestingly, for novel objects relational- and part-change

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performance was equivalent throughout the age range. These results suggest an unexpected complex trajectory of analytical-based object recognition into adolescence.

16.503 **Adult Shape Preferences are Evident in Infancy**

Ori Amir[1](oamir@usc.edu), Rachel Wu[3], Irving Biederman[1,2]; [1]Psychology, University of Southern California, [2]Neuroscience, University of Southern California, [3]Psychology, Birkbeck, University of London

People and macaque IT cells are more sensitive to nonaccidental than metric differences (e.g., Biederman, et al., 2009; Kayaert, et al., 2003). For example, straight vs. curved contours (a nonaccidental difference) are more readily discriminated (and produce greater IT cell modulation) than two curved contours that differ in their degree of curvature (a metric difference). Similarly, parallel vs. nonparallel contours are more readily distinguished than two nonparallel contours that differ in their angle of convergence. Straight and parallel are singular values, zero curvature or convergence, respectively, as opposed to curvature or nonparallel, which can assume an infinite number of values. Are there spontaneous preferences for one or the other kind of value? And, if so, are these preferences manifested early in life. 5 mo. human infants and adults viewed a pair of geons arranged left and right on the screen. The geons differed in at least one nonaccidental, generalized cylinder property. For example, one geon could be a cylinder with a straight axis and the other a cylinder with a curved axis. Or one could have parallel sides (a cylinder or a brick) and the other nonparallel sides (a cone or a wedge). Both infants and adults showed a strong, significant, preference for initially fixating the geon with a nonsingular value, i.e., curved or nonparallel. Both groups of subjects also fixated longer on that initial value, although this effect was only reliable for the adults. This initial preference for nonsingular values, as well as search asymmetries which show pop out for nonsingular but not for singular values (Treisman & Gormican, 1988), may be a consequence of greater neural activation to such stimuli (and, possibly greater opioid release), as reflected in greater fMRI activation to the nonsingular values of these stimuli in the ventral pathway.

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16.504 **Visual recognition of filtered object in normal aging: A parvocellular impairment?**

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Normal aging of visual processing was investigated using localization and categorization of filtered pictures of real objects. Image filtering aimed at biasing processing toward magnocellular (low-pass), parvocellular (band-pass) or both (no filtering) pathways whereas the tasks served to dissociate between dorsal (localization) or ventral (categorization) pathways. Thirty young adults adults (m=22,6 ; α=1,2) and 23 old adults (m=60,1; α= 6,8) were asked to semantically categorize (animal vs. tools) or to localize (up vs. down) 120 stimuli that were presented onscreen for 200 ms in three different versions: a low-pass filtered (centered on 0 cpd, with SF up to 3.8 cpd), a band-pass filtered (centered 3.8 cpd, with SF from 1.9 cpd up to 7.7 cpd), and a control stimuli (non-filtered). The main results were the interactions between task, group and filter that were found on error and on RT (p=.07). Contrast analysis showed that, in the semantic categorization task, a decreased correct response rate and increased RT was observed for old adultsrelative to young adults, especially for the band-pass filtered objects. In the localization task, the age-related deficit was higher for band-pass filtered than for the others objects on RT, but was equivalent for band-pass filtered and for non filtered objects on error. Compared to young, older adults showed deteriorated performance specifically in the conditions that isolated band-pass information, whatever the pathways involved, either dorsal or ventral. Moreover, magnocellular and parvocellular interactions were found, when the task involved the dorsal pathway. Our results are consistent with those of Viggianno et al. (2005, Archives of gerontology and geriatrics) giving additional evidence for a parvocellular loss in early normal aging.

16.505 **Visual span as a sensory bottleneck in learning to read**

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The visual span is the number of letters, arranged horizontally as in text, that can be recognized without moving the eyes. It represents a sensory bottom-up bottleneck that limits reading speed (Legge et al., 2007). In adult fluent readers, the visual span equals the uncrowded span, the number of characters that are not crowded. Reading rate is proportional to the uncrowded span (Pelli and Tillman, 2008). But what about learning to read? Developmental growth of the visual span accounts for 35-52% of the reading speed variability in english speaking children (Kwon et al., 2007). Here we investigate whether this relationship applies to French speaking children and to dyslexics.

In two age-matched groups of 10 dyslexic and 38 learning-to-read children (from 3rd to 7th grade), we estimate the visual span and reading rate. As predicted by the hypothesis, we find that visual span size and reading speed both linearly increase with chronological age in normal reading children. Congruently with the Kwon et al.'s (2007) results, a significant part of the control participants' reading speed was accounted for by their visual span size. Dyslexics had small visual spans and slow reading rate. In nearly half (4 of 10) of the dyslexic sample, reading slowness is accounted for by the visual span shrinkage. For the remaining dyslexic participants, additional factors are required to explain their slow reading speed.

Kwon, M., et al. (2007). Developmental changes in the visual span for reading. Vision Research, 47(22), 2889-900.

Legge, G. E., et al. (2007). The case for the visual span as a sensory bottleneck in reading. Journal of Vision, 7(2), 1–15.

Pelli, D. G., & Tillman, K. (2008). The uncrowded window of object recognition. Nature Neuroscience, 11(10), 1129–35.

16.506 **Is there a functional overlap between the expert processing of characters from alphabetic and non-alphabetic writing systems?**

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Previous ERP and fMRI studies have shown that concurrent processing of units from alphabetic and non-alphabetic writing systems, such as Roman letters and Chinese characters, activate overlapping brain regions. It is unknown, however, whether different types of characters simply recruit separate yet nearby neural networks, or rather there are shared mechanisms for expert processing of characters independent of writing system. Here we study the functional overlap of expert character processing for different writing systems by examining the interference in a visual search task involving processing of multiple types of characters. Chinese-English bilinguals and English readers were asked to search for target Roman letters among images presented sequentially in a rapid serial visual presentation (RSVP) stream. The search for Roman letters occurred either in a sequence of Roman and Chinese distractors, or in a sequence of Roman and Pseudoletter distractors. Bilinguals performed worse than English readers during Roman letter search among Roman and Chinese characters, whereas there was no group difference in performance during Roman letter search among Roman and Pseudoletter distractors. In other words, the addition of Chinese distractors affected Roman letter search only for bilinguals. The existence of familiar distractors (Chinese characters for bilinguals) alone was insufficient to explain the finding. This can be shown in English readers, who performed similarly when searching for Pseudoletter targets among Pseudoletter and Roman (familiar) distractors compared with searching among Pseudoletter and Chinese (unfamiliar) distractors. Overall, we showed common expert processing mechanisms shared by characters in both alphabetic and non-alphabetic writing systems.

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16.507 **Not all spaces stretch alike: How the structure of morphspaces constrains the effect of category learning on shape perception**

Jonathan Folstein[1](jonathan.r.folstein@gmail.com), Isabel Gauthier[1], Thomas Palmeri[1]; [1]Department of Psychology, College of Arts and Science, Vanderbilt University

How does the way we experience and categorize the world affect the way we visually perceive the world? By some perspectives, visual representations provide input for categorization but are not significantly altered by categorization. Others argue that perception is required for categoriza-

tion but that categorization also alters visual perception. The latter view is supported by studies showing that visual features of categorized objects become more discriminable following category learning, but only if the features are useful or "diagnostic" for categorization. Evidence for this phenomenon is mixed, however. We investigate an explanation that has remained unexplored up to now: the structure of the morphspaces categorized by participants. Studies that do not find increases in discriminability often use "polar" morphspaces, with morph-parents lying at corners of the space, while studies with positive results use "dimensional" spaces, defined by orthogonal morphlines, each a dimension created by morphing two parents. Using the same four morph-parents, we created dimensional and polar morphspaces matched in mean pair-discriminability. Categorization caused a selective increase in discriminability along the diagnostic dimension of the dimensional space, but not the polar space. This suggests that polar morphspaces should be used if one wishes to avoid selective increases in perceptual discriminability caused by categorization but dimensional morphspaces should be used if one is interested in the effect of selective attention to object properties. In addition, our results suggest that previous fMRI and electrophysiological studies finding little effect of category learning in the visual system (as well as modest behavioral effects on perception) may have been limited by the use of polar spaces.

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16.508 **Eye movement patterns during object recognition are modulated by perceptual expertise and level of stimulus classification**

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In a previous study, Leek & Johnston (2008, Platform talk, Vision Science Society) showed that fixation patterns during three-dimensional object recognition show a preference for image regions containing local concave curvature minima at surface intersections. In this study we examined the extent to which fixation-based local shape analysis patterns are influenced by the perceptual expertise of the observer and the level of stimulus classification required by the task. The study was based on the paradigm developed by Wong, Palmeri & Gauthier (2009, Psychological Science, 20, 1108-1117.) in which observers are extensively trained to categorize sets of novel objects (Ziggerins) at either a basic or subordinate level of classification. The effects of training were measured by comparing performance between a pre- and post-test sequential shape matching task that required either basic- or subordinate-level judgements. In addition, we also recorded fixation patterns during the pre- and post-tests. Fixation data were analysed using the FROA methodology (Johnston & Leek, 2009, Journal of Eye Movement Research, 1 (3):5, 1-12). The results showed significant effects of training on shape matching RTs in the post-tests. In particular, Ss showed evidence of perceptual expertise at making basic and subordinate-level shape classification judgements. We also found that the acquisition of perceptual expertise resulted in changes in the local spatial distributions of fixational eye movement patterns observed in the pre- and post tests. This finding provides a clear link between fixation-based shape analysis patterns, perceptual expertise, and the level of shape classification being undertaken by the observer.

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16.509 **Knowledge influences perception: Evidence from the Ebbinghaus illusion**

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A fundamental question in cognitive science is the relation between knowledge and perception: does our knowledge of the world influence the way we see it? To help answer this question, we used the Ebbinghaus illusion, in which a circle looks larger when surrounded by smaller circles than when surrounded by larger ones. Unlike circles, coins – such as quarters or dimes – have a fixed size, and we predicted that such knowledge of object constancy would weaken the perceptual illusion. A hundred observers reported the apparent size of a quarter when surrounded by dimes, and when surrounded by one-dollar coins. The apparent size of the quarter was compared to the apparent size of a circle when surrounded by small circles, and when surrounded by big circles. Consistent with our hypothesis, the illusion was weakened for coins. We interpret this result to suggest that visual perception is influenced by semantic knowledge, such as the knowledge of coins as objects of invariant size.

16.510 **Benefits of a Hybrid Spatial/non-Spatial Neighborhood Function in SOM-based Visual Feature Learning**

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Neurally-inspired self-organizing maps typically use a symmetric spatial function such as a Gaussian to scale synaptic changes within the neighborhood surrounding a maximally stimulated node (Kohonen, 1984). This type of unsupervised learning scheme can work well to capture the structure of data sets lying in low-dimensional spaces, but is poorly suited to operate in a neural system, such as the neocortex, in which the neurons representing multiple distinct feature maps must be physically intermingled in the same block of tissue. This type of "multi-map" is crucial in the visual system because it allows multiple feature types to simultaneously analyze every point in the visual field. The physical interdigitation of different features types leads to the problem, however, that neurons can't "learn together" within neighborhoods defined by a purely spatial criterion, since neighboring neurons often represent very different image features. Co-training must therefore also depend on feature-similarity, that is, should occur in neurons that are not just close, but also like-activated. To explore these effects, we have studied SOM learning outcomes using (1) pure spatial, (2) pure featural, and (3) hybrid spatial-featural learning criteria. Preliminary results for a 2-dimensional data set (of L-junctions) embedded in a high-dimensional space of local oriented edges features show that the hybrid approach produces significantly better organized maps than do either pure spatial or non-spatial learning functions, where map quality is quantified in terms of smoothness and coverage of the original data set.

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16.511 **How do we recognize our own stuff? Expert vs. generic recognition of household items**

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Previous research on object recognition—as opposed to face recognition—has primarily focused on 'generic' objects (e.g. identifying an object as a car), in which different individuals are assumed to share the same basic knowledge about the target objects. However, we are all 'experts' with regard to a particular class of stimuli: the objects we see and use every day in our home or work environment. The current study aims to address how such 'expert' recognition compares with generic recognition of household objects. We compared performance for expert observers—in which the target objects came from the subject's own home, vs. generic observers— who were unfamiliar with the particular environment from which the objects were drawn. Recognition performance was measured using two paradigms: 'pixelation'— in which subjects progressively increased the resolution of the image of the object until they could recognize it and 'modified bubbles'—in which subjects had to progressively reveal the image of the object by removing square checks from an occluder obscuring it. In addition, we assessed the role of specific features (color, size, object type) across expert and generic observers. We found a large advantage for the expert observers overall as well as differences between expert and generic observers in the role of specific features.

16.512 **How do Task-dependent Attentional Demands Alter How Objects are Learned?**

Jeffrey Markowitz[1,2,3,4](jmarkow@cns.bu.edu), Yongqiang Cao[1,2,3,4], Stephen Grossberg[1,2,3,4]; [1]Department of Cognitive and Neural Systems, [2]Center for Adaptive Systems, [3]Center of Excellence for Learning in Education, Science, and Technology, [4]Boston University

We learn to recognize objects in the world in environments whose attentional demands vary greatly. How does such learning depend upon task-dependent attentional demands? Object recognition needs to be tolerant, or invariant, with respect to position, size, and object view changes. In monkeys and humans, a key area for recognition is the anterior inferotemporal cortex (ITa). Recent neurophysiological data show that ITa cells with high object selectivity often have low position tolerance. We propose a neural model whose cells learn to simulate this tradeoff, as well as ITa responses

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to image morphs, while explaining how invariant recognition properties may arise gradually due to processes across multiple cortical areas, including the cortical magnification factor, multiple receptive field sizes, and top-down attentive matching and learning properties that may be tuned by task requirements to attend to either concrete or abstract visual features. The model predicts that data from the tradeoff and image morph tasks emerge from different task-dependent levels of attentive vigilance in the animals performing them. Computer simulations predict how receptive field properties would change under different task-sensitive vigilance levels. The model also predicts how vigilance may be controlled by mismatches between top-down learned expectations and bottom-up perceptual inputs, leading to acetylcholine release in neocortical circuits and an increase in vigilance. These results emphasize the importance of top-down attentional mechanisms in object learning and recognition, and of the need to carefully monitor task demands in studies of perceptual and cognitive processing.

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16.513 **Discrimination training builds position tolerant object representations**

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Studies of perceptual learning have demonstrated that when observers are trained to discriminate low-level image features, such as orientation or contrast, in a single retinal position, performance improvements are specific to the trained stimuli and position. However, it is unknown whether perceptual learning of objects is similarly specific to both the trained stimuli and position. If perceptual learning of objects occurs at lower-level stages of visual processing it may display position sensitivity. However, if learning of objects occurs in higher-level visual regions, which show decreased retinotopic sensitivity, learning effects may generalize across retinal positions. We investigated whether learning to discriminate among novel objects in a single retinal position improves performance in the trained position, untrained positions, or in cases where the objects to be discriminated appear in two separate in positions (swap). 14 observers were trained with feedback to discriminate among 24 exemplars from a single category of novel objects, each of which was shown in one of two possible retinal positions over the course of 5 days (8640 total exposures per observer). After training, observers' discrimination performance significantly increased (mean d' increase = 1.1±0.12 SEM) for the trained but not untrained objects. Training improvements were not significantly different across the trained positions, untrained positions, or swap conditions. Generalization across positions occurred despite the fact that a given object was only observed in one retinal position during training. 17 additional observers participated in an identical experiment but were not given feedback during training. Learning improvements were smaller without feedback (mean d' increase = 0.70±0.13 SEM), but resulted in the same category-specific, position-general profile. Our results suggest that discrimination training on objects is mediated by high-level visual regions with large receptive fields, and that building position invariant representations of objects does not necessitate experience with these objects in many retinal positions.

Acknowledgement: NEI R01 EY019279-01A1

Face perception: Development

Vista Ballroom, Boards 514–527

Friday, May 7, 6:30 - 9:30 pm

16.514 **Revisiting upright and inverted face recognition in 6 to 12-year-old children and adults**

Adelaide de Heering[1,2](adeheer@mcmaster.ca), Bruno Rossion[2], Daphne Maurer[1]; [1]McMaster University, Hamilton, Ontario, Canada, [2]Université Catholique de Louvain, Belgium

Adults are experts at recognizing faces. However there is still controversy about how this ability develops with age, with some arguing for adultlike processing by 4-6 years of age (Crookes & McKone, 2009) while others maintaining that this ability undergoes protracted development (Monldoch et al., 2002). Here we tested 108 6- to 12-year-old children and 36 young adults with a digitized version of the Benton Face Recognition Test (Benton et al., 1983), which is known to be a sensitive tool for assessing face recognition abilities (Busigny & Rossion, in press). Participants had to identify 3 faces among 6 alternatives that matched the target face despite changes in viewpoint and lightning. The faces were projected upright and upside-down in separate blocks, with order counterbalanced across participants. Children's correct response times did not improve with age, for either upright or inverted faces, but were significantly slower than those of adults for both conditions. This pattern is consistent with known increases with age in attention and information processing. Accuracy improved between 6 and 12 and significantly more for upright than inverted faces, leading to a larger face inversion effect in older children. Inverted face recognition improved slowly until late childhood whereas the improvement for upright faces was largest before versus after 8 years of age, with a further enhancement by young adulthood. Together, the results indicate that during childhood face processing becomes increasingly tuned to upright faces, likely as a result of increasing experience.

16.515 **Eyes on the target: A comparison of fine-grained sensitivity to triadic gaze between 8-year-olds and adults**

Mark Vida[1](vidamd@mcmaster.ca), Daphne Maurer[1]; [1]Department of Psychology, Neuroscience & Behaviour, McMaster University

Adults are able to determine which object in the environment someone is looking at with high precision (triadic gaze). By age 6, children can detect large (10°) differences in triadic gaze (Doherty et al., 2009). Here, we developed a child-friendly procedure to compare sensitivity to small horizontal differences in triadic gaze between 8-year-olds and adults (n = 18/group). Participants sat in front of a computer monitor on which they saw faces fixating a series of points (separated by 1.6°) that were physically marked on a board halfway between them and the monitor. The task was to indicate whether each face appeared to be looking to the left or right of one of three target points (center, 6.4° left or 6.4° right). All participants were at least 75% correct on a practice block completed before each experimental block. Adults were highly sensitive to deviations from the central target, with a mean error of 0.83° (calculated from the .25 and .75 points on the fitted psychometric curves). 8-year-olds were not as sensitive (M error = 2.05°, $p < .0001$). When the targets were peripheral, participants overestimated the degree to which the face was looking toward the periphery (e.g., judging the face to be looking to the left of the left target), with a larger error in children (M = 2.26°) than in adults (M = 0.91°, $p < .05$). Relative to 8-year-olds, 10-year-olds (n = 10 tested to date) appear to show a more adult-like pattern characterized by a steeper slope and a more adult-like asymptote. These results indicate for the first time that by age 8, children can detect small differences in triadic gaze, but that sensitivity is not yet as refined as it will become in adulthood.

Acknowledgement: Canadian Natural Sciences and Engineering Research Council (NSERC)

16.516 **Psychophysics of face processing in childhood: A developmental perspective**

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Developmental prosopagnosia is an impaired ability to recognize familiar faces which is present at an early age. To better understand this condition, we examined the development of face processing abilities in normal children. Methods: Seven and ten-year-old children completed three tasks. Short-Term-Memory-Span for Faces: Participants were presented with a target face and then asked to select that face from a line-up of three faces. This test used a staircase method to determine the maximum number of faces that could be successfully recognized by the child. Perceptual Similarities: A target face was presented and children were asked to sort 6 faces based on their similarity to a target face, a task with minimal memory demands. Attractiveness: Children ordered 8 female faces from most attractive to least attractive. Results: 1. Significant improvement with age in memory span for faces. Average span went from 1.78 in 7-year-old children to 2.09 in 10-year-old children. ($p=0.018$) 2. Significant increase in ability to judge the similarity between faces with age. ($p<0.001$) 3. Little improvement in attractiveness judgments over the age range studied. 4. A regression analysis examining the contributions of age, memory span, and similarities on working memory performance suggests that performance on the similarity task was the strongest predictor of memory for faces while age contributes less variance to the prediction. 5. Judgments of attractiveness correlated little with performance of the two other tests and with age. Discussion: These results suggest that memory for faces and judgments of the similarity of faces share common perceptual process while judgments of attractiveness require attention to properties that are not required for the identification of an individual face.

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16.517 Children's Face Coding is Norm-Based rather than Exemplar-based: Evidence From Face Identity Aftereffects

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Children perform more poorly than adults on tests of face identification yet the source of their difficulty is controversial, with recent evidence pointing to general cognitive immaturity rather than differences in the use of specialized face-coding mechanisms such as holistic coding. However, not all aspects of children's face coding are well studied and relatively little is known about children's face-space. Immaturity in face-space is therefore a potential source of children's face identification difficulties. We used face identity aftereffects to investigate children's face-space. Previous studies have shown that 8 year-olds experience face identity aftereffects and their aftereffects do not differ quantitatively from adults'. In the present study we tested younger children and found that face identity aftereffects were present as early as 4-5 years-of-age and did not change quantitatively between 5 and 8 years-of-age. However, children's aftereffects, including those of 8 year-olds, were larger than adults' suggesting that children's face-space may not be mature by 8 years-of-age. We then conducted additional tests to determine whether a major qualitative change in how faces are represented in face-space could occur between 8 years-of-age and adulthood. Specifically we investigated whether children's face identity aftereffects, like those of adults, reflect norm-based coding or instead result from exemplar-based coding. These tests showed that children's face-space coding is norm-based because (1) children's face identity aftereffects were larger for adaptors far from the norm than for adaptors closer to the norm, (2) children's aftereffects were larger for opposite adapt-test pairs than non-opposite pairs equated for perceptual similarity and (3) children perceive faces close to the average as "neutral" for identity. We conclude that there is no evidence of a qualitative change from exemplar to norm-based coding between 8 years and adulthood. Children's larger aftereffects may reflect other immaturities in children's face-space such as more flexible norms.

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16.518 Adaptation effect for facial identity in infants

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By using the fMRI-adaptation technique, recent studies have demonstrated that the face specific region of fusiform face area (FFA) and the superior temporal sulcus (STS) show the adaptation effect for facial identity; a reduced activation to repeated presentation of identical face compared to presentation of different facial images (e.g., Andrews & Ewbank, 2004). In the present study, we used NIRS to examined whether a similar facial identity adaptation effects are shown in infants. By using Near-infrared spectroscopy (NIRS), we compared the hemodynamic responses of infants during the presentation of an identical face and the presentation of different faces. Based on our previous studies investigating face-related neural activation to faces by using NIRS (Otsuka et al., 2007; Nakato et al., 2009; Honda et al., 2009), we focused on the bilateral temporal regions. We hypothesized that infants would show the decreased brain activity during the repeated presentation of the same face compared to the presentation of the different faces. The responses were compared to the activation in the baseline period in which we presented various images of vegetables. The results were as follows: (1) the infants' brain activities in the channels surrounding the T5 and T6 regions increased during the observation of different faces compared to the baseline, suggesting that brain activity in infants' STS can be measured, (2) the repeated presentation of identical face lead to a significant reduction in the oxy-Hb concentrations compared to the presentation of different faces. These results suggested that the infants' STS showed the adaptation effect for facial identity. Our findings are consistent with the previous fMRI studies showing the adaptation effect in face recognition in adults' STS.

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16.519 Infants' neural responses to facial expressions using Near-Infrared Spectroscopy

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Facial expressions play an important role in social communication during infancy. 3-month-olds can discriminate between happy and anger faces (Barrera & Maurer, 1981), and 7-month-olds have the ability to categorize happy facial expressions, but not fearful ones (Ludemann & Nelson, 1988).

Neuroimaging studies in adults revealed that the superior temporal sulcus (STS) was implicated in the processing of facial expressions (Haxby et al, 2000). Our previous near-infrared spectroscopy (NIRS) study demonstrated that the right STS was mainly activated in the perception of faces in infants (Nakato et al, 2009). However, infants' brain regions involved in perceiving facial expressions has not been investigated.

To examine whether STS was responsible for the perception of facial expressions in infants, we used NIRS to measure the neural activation in STS when infants looked at happy and angry faces. Twelve 6- and 7-month-old infants viewed five happy and five angry female faces passively. The measurement area was located in the bilateral temporal area which was centered at T5 and T6 according to the International 10-20 system of EEG.

Our findings indicated that the time-course of the average changes in oxy-Hb concentrations showed a distinct pattern of the hemodynamic response between happy and angry faces. The hemodynamic response increased gradually when infants looked at happy faces. In contrast, the hemodynamic response peaked quickly when infants looked at angry faces. Following this peak, the hemodynamic response decreased until the stimuli disappeared.

Moreover, we found that the right temporal area of infants' brain was significantly activated against the baseline when infants looked at angry faces, while the left temporal area was activated for happy faces. These findings suggest hemispheric differences in STS when processing positive and negative facial expressions in infants.

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16.520 Infants' brain activity in perceiving facial movement of point-light display

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Adult observers quickly identify the specific actions performed by the invisible actor from the points of lights attached to the actor's head and major joints. Even infants are already sensitive to biological motion and prefer it depicted by the dynamic point-light display (Arterberry & Bornstein 2001). To detect biological motion such as whole body movements and facial movements, neuroimaging studies demonstrated involvement of occipitotemporal cortex including superior temporal sulcus (STS) (Lloyed-Fox et al., 2009). In the present study, we applied the point-light display technique and examined infants' brain activity while watching facial biological motion in the point-light display by using near-infrared spectroscopy (NIRS). Dynamic facial point-light displays (FPD) were made from video recordings. As in Doi et al. (2008), about 80 luminous markers were scattered pseudo-randomly over the surface of the actors' face. Three actors

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performed the surprised expression in the dark room and were videotaped. In the experiment, we measured hemodynamic responses by using NIRS. We hypothesized that infants would show differential neural activity for upright and inverted FPD. The responses were compared to the baseline activation during the presentation of individual still images those were frames extracted from the dynamic FPD. We found that the concentration of oxy-Hb and total-Hb increased in right lateral area during the presentation of the upright FPD compared to the baseline period. The results suggested that (1) the brain activity while watching the facial movement in point-light display would develop by 6-8-months of age, (2) processing of the facial biological motion related to the right lateral area.

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16.521 Age-contingent face aftereffects depend on age of the observer

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Following repeated exposure to faces with contracted (or expanded) internal features, faces previously perceived as normal appear distorted in the opposite direction. These face aftereffects suggest that face-coding mechanisms adapt rapidly to changes in the configuration of the face. Past work with young adults has suggested that distinct coding mechanisms respond to faces that differ in orientation, gender, race, and eye gaze direction. The first aim of the present work was to determine whether coding of faces from different age categories (young and older adults) shows similar selectivity. Given evidence for age-related changes in face recognition, emotional expression recognition and configural information processing, we also tested aftereffects in older adults. Before and after an adaptation phase, participants rated the normality of morphed distorted faces ranging from 50% contracted through normal to 50% expanded. These test faces depicted young (18-32 years) and older (64+ years) individuals matched for distinctiveness and presented in equal numbers. In the adaptation phase, participants viewed either young or older faces with 60% contracted features. The size of the adapt and test faces was varied. For young participants (18-23 years), aftereffects occurred in all conditions but were significantly reduced when the age of the adapting face and test faces differed. These findings suggest that dissociable neural populations code young and older faces. For older adults (60-83 years), a different pattern of aftereffects was observed. When older adults were adapted to older faces, a significant aftereffect occurred with older but not young test faces, consistent with the age-contingent aftereffects observed with young adults. However, after adapting to young faces, older adults showed significant aftereffects of equal magnitude for young and older test faces. These findings suggest that changes in the perceptual or neural mechanisms that code faces take place as a function of the aging process.

16.522 Exploring the perceptual spaces of faces, cars, and birds in children and adults

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To date, much of the developmental research concerning age-related changes in face processing has focused on the type of information and the specific strategies utilized by children during face recognition. Other aspects of facial recognition, such as the principles governing organization of individual face exemplars and other objects in perceptual memory, have been less extensively investigated. The present study explores the organization of face, bird, and car objects in perceptual memory using a morphing paradigm. Children ages five-six, seven-eight, nine-ten, and eleven-twelve, and adults were shown a series of morphs created with equal contributions from typical and atypical face, bird, and car parent images. Participants were asked to judge whether each 50/50 morph more strongly resembled the typical or the atypical parent image from which it was created. Children in all age groups and adults demonstrated a systematic atypicality bias for faces and birds: the 50/50 face (bird) morph was judged as appearing more similar to the atypical parent face (bird) than the typical parent face (bird). Interestingly, the magnitude of the atypicality bias remained robust and stable across all age groups, indicating an absence of age-related differences. No reliable atypicality bias emerged for the car category. Collectively, these findings establish that by the age of five, children are sensitive to the structure and density of face and bird probes, and are capable of encoding and organizing face, bird, and car exemplars into a perceptual space that is strikingly similar to that of an adult's. These results suggest that category organization, for both children and adults, follows a distance-density principle (Krumhansl, 1978) where the perceived similarity between any two category exemplars is attributed to both their relative distance and the density of neighboring exemplars in the perceptual space.

16.523 Sad or Afraid? Body Posture Influences Children's and Adults' Perception of Emotional Facial Displays

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Adults' perception of facial displays of emotion is influenced by context (body posture; background scene), especially when the facial expressions are ambiguous (Van den Stock et al., 2007) and the emotion displayed in the context is similar to that displayed in the face (Aviezer et al., 2008). We investigated how context influences children's perception of rapidly presented emotional expressions. Adults and 8-year-old children (n=16 per group) made two-alternative forced-choice judgments about sad and fearful facial expressions. Each facial expression was posed by 4 models (2 males) and presented with both congruent and incongruent body postures that were either aligned or misaligned with the face. Participants were instructed to ignore the body. In the aligned condition, accuracy was higher when face and body were congruent versus incongruent, $p < .001$, with a larger effect in children (M difference = .314) than in adults (M difference = .125). In the misaligned condition, the effect of congruency was small and did not differ between adults (M = .05) and children (M = .07). These results suggest that body posture may have a larger influence on 8-year-olds' than adults' perception of emotional expressions, at least when holistic processing is facilitated by alignment. However, adults were more accurate (M = .93) than children (M = .69) on control trials in which isolated faces were presented. Thus, larger context effects for children may be related to task difficulty. In follow-up studies we are testing adult participants with subtle facial expressions (e.g., 70% sad, 40% sad) and child and adult participants with happy and sad facial expressions—expressions to which sensitivity develops early and that differ in both valence and intensity, unlike sad and fear which differ only in intensity. Collectively these results will provide novel insights about how context influences children's sensitivity to facial expressions.

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16.524 The fear factor: Attentional capture by fearful faces in adolescence

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Teenagers are generally more vulnerable to emotional distractions than adults, which may partly explain relatively poorer decision-making in this population. We have previously shown that performance on a flanker task is relatively mature by mid-adolescence for letter stimuli but not for emotional face stimuli. This follow-up study investigated how attention to a central affective face is modified by the presence of both affectively-opposite and affectively-neutral flanker stimuli in adolescents and adults. Since fMRI data suggest that repeated presentation of fearful faces results in neural habituation of the amygdala, changes in attentional capture by fearful faces over time were also investigated. Results showed that reaction time (RT) increased when the emotional expressions of flanker stimuli were incompatible with that of the target, for happy targets only. Identification of a central happy target was significantly slower when it was flanked by fearful faces than when flanked by happy faces, for both adults and adolescents. Furthermore, adolescents experienced significantly greater interference by fearful flankers than adults. In contrast, happy face flankers produced little change in RT for fearful targets for both adults and adolescents. Affectively-neutral flankers produced significantly increased RT for happy compared to fearful face targets in adults. This trend was not significant in adolescents, which may be due to difficulties in processing neutral faces. Adolescents experienced significantly more attentional capture by fearful faces in the first half of the experiment than adults, but their responses were adult-like by the second half of the experiment. Our data suggest that fearful faces capture attention more effectively than happy faces and adolescents are initially more vulnerable to this effect than adults. However, with repeated exposure this difference quickly diminishes. Increased sensitivity to fearful faces in adolescents is likely due to immature top-down processing that fails to adequately over-ride more bottom-up, affectively-driven processes.

16.525 **The effects of aging and stimulus duration on face identification accuracy with differing viewpoints**

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Habak, Wilkinson and Wilson (2008, Vision Res, 48(1), 9-15) reported that face identification accuracy was lower in older subjects than younger subjects, especially for faces presented at different viewpoints. In addition, they found that identification accuracy for faces presented in different viewpoints improved in younger subjects, but not older subjects, as stimulus duration increased from 500 to 1000 ms. This result led Habak et al. to propose that the accumulation of information used to refine neural representations saturates earlier in the older visual system than in the younger visual system. However, Habak et al. used artificially constructed stimuli that differed in outer contour and hair in addition to the geometry of internal features, and may not have been discriminated on the basis of facial features per se. We therefore investigated the effect of stimulus duration in older (n=8) and younger (n=8) observers using pictures of faces that differed in viewpoint but had identical outer contours and no hair, forcing subjects to base identification on internal facial features. Observers viewed a high-contrast target face for 250ms, 500ms, 1000ms, or 2000ms followed by a 10-face choice response. Faces in the response window were presented in fronto-parallel view; target faces were presented at one of several oblique viewpoints. A repeated measures ANOVA revealed significant main effects of age ($p<0.001$) and duration ($p<0.0001$), but the age x duration interaction was not significant ($p=0.28$). Moreover, contrary to Habak et al, we found significant linear trends in both younger ($p<0.05$) and older ($p<0.001$) observers, and performance did not reach an asymptote in either group, even with durations up to 2000 ms. Thus, although older observers performed worse than younger observers, both groups accumulated stimulus information across time at similar rates, calling into question the neural saturation hypothesis as a general explanation of age-related face perception deficits.

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16.526 **Differential development of the ventral visual cortex extends through adolescence**

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The ventral temporal cortex (VTC) in humans includes functionally defined regions that preferentially respond to objects, faces and places. Recent developmental studies suggest that the face selective region in the fusiform gyrus (‘fusiform face area’, FFA) undergoes a prolonged development involving substantial increases in its volume after age 7. However, the endpoint of this development is unknown. Here we used functional magnetic resonance imaging (fMRI) to examine the development of face-, object- and place-selective responses in the VTC of adolescents (12 – 16 year olds, n = 14) and adults (18 – 40 year olds, n = 11). Subjects underwent fMRI in a 3T scanner (3x3x3 mm voxels), while viewing images of faces, objects, scenes and scrambled images, presented in pseudo-random ordered blocks and performing a 1-back task. Outside the scanner subjects participated in a recognition memory task for faces, objects and places. We found that the volume of face-selective activations in the right fusiform gyrus (i.e. right FFA) and right inferior occipital gyrus was substantially larger in adults than in adolescents, and was postively correlated with age. This development was associated with higher response amplitudes and selectivity for faces in these face-selective regions and increased differentiation of the distributed response patterns to faces versus non-face stimuli across the VTC. Furthermore, right FFA size was correlated with face recognition memory, but not with recognition memory of objects or places. In contrast, the volume of object- and place-selective cortical regions or their response amplitudes did not change across the age-groups. Thus, we found a striking and prolonged development of face-selectivity across the VTC during adolescence. These findings have important implications for theories of VTC’s development and its functional specialization.

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16.527 **Plasticity of face recognition in early childhood disappears in adolescence and adulthood**

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Introduction. Anecdotally, Caucasians raised with no Asian contact sometimes report they cannot reliably recognise Asian faces no matter how hard they try, and no matter how much experience they obtain with Asian colleagues as adults. There is also formal evidence – from studies of perceptual narrowing in infancy (eg., Pascalis et al, 2002) and adults’ ability to learn infant faces (Macchi Cassia et al., 2009) – to suggest contact at an early age may be crucial to maintain, or allow adult reactivation of, the ability to individuate all face types. But, just how “early” must exposure be? Language learning studies imply perceptual narrowing for nonexperienced languages in infancy is followed by a relatively lengthy period of retained plasticity that extends throughout primary school. Here, we test whether face recognition follows a similar course. Methods. Testing Caucasian adults, we used the unusual demographics and immigration history of Australia to dissociate effects of contact at different developmental stages: as babies, at primary school, at high school, and as adults. We measured both the ‘other-race’ effect on memory (difference between own-race and other-race faces) and the ‘other-ethnicity’ effect (difference between British-heritage Caucasian faces typical in Australia, and American Caucasian faces from the Harvard Face Database). Tasks were the Cambridge Face Memory Test and Chinese-face and Australian/British face variants. Subjects reported multiple contact variables (e.g., percentage of nonBritish Caucasians in their classes). Results. Contact in adulthood or at high school showed no correlations with either the other-race or other-ethnicity effects. Contact as a baby/toddler and in primary school each correlated with the other-ethnicity effect. (Currently, we have too little variation in early Asian exposure to address the equivalent question for the other-race effect.) Conclusion. Plasticity of face recognition is present in early childhood but disappears in adolescence and adulthood.

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Attention: Reward, motivation, emotion

Vista Ballroom, Boards 528–541

Friday, May 7, 6:30 - 9:30 pm

16.528 **Reward has a larger impact on visual search in people with reward-seeking personalities**

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Reward-related midbrain dopamine is thought to guide animal behavior, motivating approach towards objects associated with reward and away from objects unlikely to be beneficial. We have recently conducted a series of experiments that suggest the dopamine system implements a similar principle in the deployment of covert attention in humans. This work shows that participants automatically attend to an object characterized by features recently associated with monetary reward. We call this reward priming. Using event-related potentials, we have demonstrated that the strength of reward priming in a given subject is predicted by the magnitude of neural response to positive feedback in anterior cingulate cortex (ACC), a brain area known to be a part of the dopamine reinforcement circuit. Those subjects who show a strong ACC response to reward are also those who show a strong bias to select reward-conditioned stimuli. This has led us to suggest that reward priming may be determined by reward-seeking or reward-sensitivity personality traits; some participants may attribute positive feedback with greater motivational valence, resulting in a stronger bias to select reward-conditioned stimuli. Here we present results that confirm this hypothesis. We had participants complete a personality inventory, the BIS/BAS scale, prior to completing a visual search task designed to measure reward priming. High scores on a reward-seeking subscale of the BIS/BAS strongly and reliably predicted the magnitude of the subsequent reward priming effect. These results both link trait reward-seeking to the dopamine reward circuit, and ACC specifically, and illustrate the important role reward plays in attentional control.

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16.529 Attention ignores rewards when feature-reward mappings are uncertain

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Recent investigations have shown that externally-adjudicated rewards can modulate selection processes both within and between trials. In particular, when participants recently received a reward or a penalty (on the previous trial) or can expect to receive a reward or a penalty in the current trial (based on learned reward-feature contingencies), rewards can strongly guide attention, biasing selection mechanisms towards highly-rewarded information and away from penalty-inducing information. These effects are observed after participants have had extensive experience with the task and with the reward-feature contingencies (how much each feature is typically worth). Here, we investigated whether reward-based effects on attention can be induced on a trial-by-trial basis (i.e., without a consistent association between a level of reward and a specific visual feature). We used the Distractor Previewing Effect, an inter-trial bias of selective attention that is observed in oddball-search tasks: participants are slower to select an oddball target when its defining feature was shared by all distractors on a preceding target-absent trial, and are faster when distractors share a feature with the distractors on a preceding target-absent trial. Previously, we have shown that learned rewards strongly modulate the DPE. When penalties are associated with the color of distractors on a target-absent trial, the ensuing DPE is exaggerated, whereas when high levels of rewards are associated with the color of distractors on the target-absent trial, the ensuing DPE is reversed, showing now an attentional preference to select normally inhibited information. Furthermore, we observed strong within-trial biases such that items defined by rewarded features were preferentially selected, and items defined by penalized features were efficiently rejected. Our current results show that these reward-induced modulations of attention are totally absent when reward levels are randomly assigned to features on trial-by-trial basis. Under conditions of reward-uncertainty, attention ignores rewards, presumably because previous rewarding experiences fail to predict future rewards.

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16.530 The role of motivational value in competition for attentional resources

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Value associations are acquired for visual stimuli through interaction with them, which can subsequently predict both the resulting value of interaction (i.e., in terms of reward or punishment) and the likelihood of obtaining that outcome should they be encountered again. We have previously shown evidence that visual stimuli are processed in a value-specific manner, where expected value is determined by both valence and motivational salience. Under conditions of constrained attention (e.g., presentation during an attentional blink, AB), recognition of value-laden stimuli is determined by their associated valence. More specifically, a reward-associated stimulus presented for recognition as a second target (T2) in a rapid serial visual presentation (RSVP) of non-valued stimuli escapes the AB; a loss-associated stimulus does not. Thus, when attention is limited visual recognition appears to be biased in favor of reward-associated stimuli. Here we asked whether this reward bias in visual recognition persists when value-laden stimuli are in direct competition for attentional resources. To test this, we first had participants engage in a simple choice task where they gained or lost money with high or low probability in response to choosing specific visual stimuli. We then measured recognition of these learned stimuli in a dual RSVP stream AB task, where T2 response required the recognition of two value-laden stimuli presented simultaneously under conditions of limited attention. Preliminary evidence suggests that reward-associated stimuli are preferentially processed over other valenced stimuli; however, performance is also modulated by motivational salience.

16.531 Reward speeds up response inhibition, but only when it is unpredictable

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We often must inhibit response to one visual stimulus upon seeing another. We asked whether people could inhibit responses in less time when it is more important to do so by offering different levels of reward—points that were later converted into monetary bonuses—for successful inhibition. In our experiments, participants made rapid manual responses to dots appearing on either side of the computer screen. We tested their inhibitory abilities by presenting a square "stop signal" shortly after the dot onset in some trials, indicating that participants must cancel their response to receive reward. We measured the efficiency of response inhibition by estimating the time required for participants to react to the stop signal and cancel their response, namely their stop-signal reaction time (SSRT). In experiment 1, we separated trials with high and low rewards for stopping into different blocks. We found that participants' SSRTs did not vary with the reward for stopping, although participants were significantly slower when responding to the dots in high reward blocks, suggesting that they waited longer in anticipation of potential stop signals in those blocks. We then looked to reduce this anticipation by associating high and low stop rewards with different dot locations and presenting trials with different stop rewards in random order. The unpredictable ordering of reward eliminated the difference between response times to dots in high and low reward locations, and now participants were significantly faster to inhibit their response when reward is high than when reward is low. Our findings suggest that at least in the domain of inhibiting responses to visual stimuli, anticipation of higher reward interferes with more automatic mechanisms we have for improving performance in response to reward.

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16.532 Saccadic reaction times in response to rewards of varying magnitude and probability

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Decision-making has often been studied by asking observers to choose between two movements (e.g., a saccade to a target on the left or right of fixation). Choosing a movement with the highest expected value is adaptive, in that it maximizes reward over time. Saccadic reaction time (SRT) is used as a conventional index of movement preparation in such tasks. In the current study, latencies to initiate a saccade to a red target dot presented to the left or right of fixation were measured. Reward manipulations consisted of varying the magnitude of the reward, as well as the probability of receiving the reward, following a correct eye movement to the left or right target. Results show that higher expected reward leads to lower saccadic reaction times (SRT) to the target, taken to imply better saccadic preparation, and supporting previous findings by Milstein & Dorris (2007).

16.533 Effects of hunger and body mass index on attentional capture by high and low calorie food images: An eye-tracking study

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Reaction time indices of attentional biases toward food and food-related stimuli have been shown to vary with changes in motivational state (i.e., hunger) and variations in body mass index (BMI). The current study used eye-tracking methodology to examine how attentional biases towards different food images are moderated by hunger and BMI. Twenty-six women (15 normal BMI, 11 overweight or obese; 13 sated, 13 hungry) viewed pairs of images of high-calorie sweet, high-calorie salty, and low-calorie foods while eye movements were monitored. Proportions of initial fixations to the different food types were used as an index of attentional capture and pupil diameter as an index of emotional arousal. Results revealed a significant interaction between food type and BMI: the overweight group had a greater proportion of first fixations on low-calorie food images relative to the normal weight group (who had a tendency to fixate first on high-calorie salty images). These results are consistent with reaction time data showing more positive implicit attitudes to high-calorie salty foods (e.g., pizza, burger; Czyzewska & Graham, 2007). In addition, there was a significant food type by hunger interaction: the hungry group made more initial fixations to high-calorie salty foods (relative to low-calorie foods), suggesting that hunger temporarily enhances attentional capture by high-calorie salty foods. Furthermore, the effects of BMI and hunger on attentional capture to these foods are statistically separable. In contrast, pupil diameters did not change as a result of hunger: mean pupil diameter was larger overall for the overweight group, but this main effect was mitigated by an interaction between BMI and food type wherein pupil diameters were largest to high-calorie salty foods. Overall, these results suggest that hunger and BMI have separate effects on attentional capture to food images that increase the salience of high-calorie salty foods.

16.534 **Exploring the relationship between anxiety and processing capacity for threat detection**

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Cognitive models suggest that anxiety is associated with the presence of a highly sensitised threat detection mechanism which, once activated, leads to the automatic allocation and focusing of attention on the source of threat (review by Bar-Haim, Lamy, Pergamin, Bakermans-Kranenburg & Ijzendoorn, 2007). Previous studies have only ever considered the detection of singleton threat targets in anxiety. The threat detection system should also be configured to rapidly detect signs of impending danger in situations where there is a possibility of multiple threats. Given multiple threats, it is unclear whether a more advantageous strategy for threat detection in anxious individuals is to localise and focus attention on one threat stimulus or to distribute attention widely (see Eysenck, Derakshan, Santos & Calvo, 2007). To address this theoretical question, we conducted a reaction time redundant signals study in which participants were asked to indicate the presence or absence of an angry or happy target face in displays containing no targets, one target or two targets. In all conditions, the task was to detect the presence of at least one target. We used measures of processing capacity (e.g., capacity coefficient, Miller and Grice inequalities; see Wenger & Townsend, 2000) to assess whether, at all time points, the fastest RTs in the redundant target condition (e.g., two target condition) could be predicted from the fastest RTs in the single target conditions. Eye-movements were also measured during the study. Significant correlations showed that anxiety was associated with increased processing capacity for threatening faces but only at early time points in target detection. The results also demonstrated that significantly fewer eye-movements were made to targets when anxiety was high. The data are consistent with anxiety influencing threat detection via a broadly tuned attentional mechanism.

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16.535 **Value associations make irrelevant stimuli especially distracting**

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Learning and experience lead us to associate reward or punishment value with specific visual objects. Value associations, especially reward associations, are thought to activate dopaminergic systems that may in turn support enhanced attention to such objects. Here we asked whether value associations (reward or punishment) learned in one context could make stimuli especially distracting when irrelevant in other contexts. To explore this possibility, we use a two-phase experimental procedure. First, participants learned to associate different face stimuli with winning, losing, or having no outcome in a simple choice game. Later, a typical 'flanker' attention task (with no possibility of winning or losing points) was conducted using the pre-conditioned stimuli or novel stimuli as distractors. Five faces were presented and the task was to categorize the gender of the middle (target) face as quickly as possible. In this task, attentional distraction by flanking stimuli is indexed as a slowing in mean response time (RT) to judge the central target relative to a baseline condition. Here, the target was always a novel face; the baseline was measured using novel faces as flankers (gender congruent or incongruent), and the experimental conditions used the preconditioned faces as flankers. We found that RTs were significantly slower than baseline (regardless of gender congruity) when flankers had been preconditioned with rewards or punishers but not when preconditioned with no outcome. This effect was especially robust for stimuli that had been optimal choices in the choice game, regardless of their association with reward versus punishment. These findings indicate preconditioned value associations play an important role on visual selection processes.

16.536 **Interaction effects of emotion and attention on contrast sensitivity correlate with measures of anxiety**

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Background: Last year at VSS we showed that faces effectively cue attention, improving contrast sensitivity at a cued location, and impairing sensitivity at an uncued location, compared to distributed cues; however, facial expression had no impact. Some have suggested that anxiety modulates the effects of emotion and attention on performance (e.g., Bar-Haim et al., 2007), which led us to look at individual differences in trait anxiety. Here we investigate whether anxiety influences the interaction of emotion and attention on contrast sensitivity.

Method: Non-predictive precues directed exogenous (involuntary) attention to a visual task stimulus. Precues were faces with either neutral or fearful expressions and were presented to the left, right, or both sides (8° eccentricity) of central fixation. On each trial, a target (tilted Gabor) was displayed on one (random) side and a distracter (vertical Gabor) on the other (1.5cpd, 3° Gabors; 4° eccentricity). Attention was thus randomly cued toward the target (valid cue), distracter (invalid cue), or distributed over both locations. Observers discriminated target orientation with contrast-varying stimuli, and completed self-reported measures of anxiety (PANAS: Watson, Clark & Tellegen, 1988; STAI: Spielberger et al., 1983).

Results: We found that emotion significantly interacted with attention in a manner that reflected trait anxiety. Consistent with previous research, distributed-fear cues significantly improved performance compared to distributed-neutral cues. Although valid- and invalid-fear cues did not consistently modulate sensitivity across observers, individual differences in anxiety significantly correlated with this interaction of emotion and attention. The emotion effect (fear minus neutral sensitivity) was negatively correlated with anxiety for valid cues but positively correlated for invalid cues. These results suggest that for observers with increased anxiety the fear cue impairs processing of the nearby stimulus. These findings will be discussed in the context of an ongoing debate regarding the relation of anxiety and attention.

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16.537 **Evaluation of attentional biases towards thin bodies**

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Background: The aim of this research is to understand how people distribute their visual attention across scenes containing people. Previous studies have indicated that women with eating disorder symptoms (high body dissatisfaction) selectively attend to images of thin female bodies. With increasing numbers of men experiencing body dissatisfaction (BD), we examined whether men also selectively attend to thin bodies, whether this attentional bias depends upon the gender of observed body, and whether this bias is a function of observer BD, weight, and/or gender. Method: Male and female participants completed the Body Shape Questionnaire-34 to measure their level of BD. They then completed a dot-probe task in which they first saw a fixation followed by two bodies of the same gender (one thin, one overweight) presented simultaneously one above the other. After 500 ms, the bodies disappeared from the display and an arrow appeared in the previous location of one of the bodies. With a key press, participants reported whether the arrow pointed to the left or right. Reaction times were recorded to determine whether observers had directed their attentional resources towards the thin or heavy body type. Trials were blocked by figure gender. Results: There was a significant interaction between subject gender, figure gender, and figure body type, $F(1,35)$-5.52, p=.025. No main effects were significant. Conclusions: Female observers spontaneously direct their attentional resources to thin female bodies and to overweight male bodies. Male observers selectively attend to thin male bodies and distribute their attention equally across all female bodies. It has been proposed that selective attention to thin bodies maintains high levels of body dissatisfaction. If so, the current results suggest that both men and women exhibit similar relationships between attentional biases and body dissatisfaction.

16.538 **Suppressing sex and money: Response inhibition leads to devaluation of motivationally salient visual stimuli**

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Stimuli that are ignored or otherwise inhibited during the course of a visual task typically receive more negative evaluations than stimuli that are the targets of attention or a behavioural response. This distractor devaluation effect occurs, not only for stimuli that are otherwise affectively neutral, but also for images that are clearly positive or negative in valence (Fenske et al.,VSS, 2009). This suggests that inhibition may elicit negative affect for task-irrelevant items, regardless of their a priori affective status. Here we examine whether similar effects occur for motivationally salient stimuli--images of men and women that vary in sexual attractiveness (Exp. 1) and abstract patterns associated with monetary loss or gain (Exp. 2)-- presented as 'Go' or 'No-go' items in a response-inhibition task. Affective evaluations obtained after the Go/No-go task revealed higher ratings, overall, for images depicting individuals of the sex matching the participants' prestated preference than for images depicting their non-preferred sex. Higher ratings were also obtained for gain-associated patterns than for loss-associated patterns. Importantly, the magnitude of inhibition-related devaluation, manifested as a reduction in ratings for 'No-go' items to which a response was withheld compared to 'Go' items to which a response was made, was similar for all images regardless of their prior motivational status. These findings raise the possibility that attentional and behavioural inhibition trigger an avoidance response that can modify the reward value associated with a visual object. Findings are discussed in terms of potential applications of cognitive tasks for modulating the pathologically-high salience of stimuli associated with motivational disorders (e.g., drug-associated cues in addiction).

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16.539 **Arac attack! Natural images of spiders and snakes in a response priming paradigm**

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People with spider or snake phobia might process phobia-related images more rapidly than neutral ones. We report a series of experiments to investigate the influence of aversive (spiders and snakes) and non-aversive (flowers and mushrooms) natural pictures on response times in phobic and non-phobic participants. In each experimental trial, one prime and target, chosen randomly from one of the four stimulus categories, were presented in rapid sequence, and participants performed speeded keypress responses to classify the targets. 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). Targets acted as backward masks for preceding primes. Results in non-phobic participants showed strong and reliable priming effects in both conditions but larger effects in the animal-nonanimal task. We will compare these results with those of phobic participants to disentangle effects of image processing speed with those of attentional biases.

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16.540 **Endogenous Attention Control "Chokes under Pressure"**

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Choking under pressure is a well-documented phenomenon. Previous studies have suggested that pressure compromises performance by creating mental distractions that compete for and reduce working memory capacity required for skill execution (Beilock, 2008). We hypothesized that pressure may also compromise the central executive control system, typically in charge of goal maintenance and endogenous control of action. Here, we tested this latter prediction and examined whether pressure would impact observers' ability to endogenously control attention. Participants were asked to complete a series of alternating math and attention tasks. The attention task was an endogenous cueing task: a colored dot was presented briefly at fixation and the color of the dot was 80% predictive of the location of an upcoming target. Three different SOAs between cue and target were used (200, 600 and 1000ms). The math task was included to make sure participants were sensitive to the pressure manipulation. Halfway through the experiment, we introduced the pressure manipulation, so that performance on the first half could be taken as a benchmark of normal performance and compared to performance under pressure (within subjects). We manipulated pressure by telling our participants: that they would be videotaped; that they had an opportunity to double their money if they and a randomly-paired partner could both improve their performance by 20%; and that their partner had already successfully improved their own performance (so all responsibility laid with the participant). However, none of this was true and participants always earned twice the advertised money. Consistent with our hypothesis, preliminary analysis showed that pressure did impact endogenous attention control: while cueing effects were still observed at the shorter SOAs, participants seemed unable to maintain attention at the cued location at the long SOA condition, even though in the first half of the experiment they had no problem doing so.

16.541 **Disguising Losses as Wins in Multi-line Video Slot Machines**

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In contrast to traditional mechanical reel slot machines, on video slot machines one can wager on 15 lines or more per spin. When a player spins and wins feedback is provided by attention-grabbing, salient visual information. Certain symbols flash, counters tally the amount won, and the symbols accounting for the win are highlighted. When players spin and lose no feedback is given. When players wager on multiple lines, however, many of their "wins" are actually less than the spin wager. We refer to these outcomes as "losses disguised as wins" or LDWs. To assess the physiological consequences of wins, LDWs and losses we had players play a real multi-line slot machine. We used heart-rate deceleration to gauge the perceptual intake of the visual information following wins, LDWs, and losses and used skin conductance responses (SCRs) to measure player's arousal for these outcomes. For 39 players, average heart-rate decelerations were significantly greater following wins than either LDWs or losses. We interpret these deceleration effects in terms of perceptual intake of the presented reinforcers – there are simply more flashing, highlighted symbols following real wins than LDWs or losses. For arousal, the average SCRs of 37 players were equivalent for wins and LDWs – with both values being significantly larger than for losses. That is despite losing money on LDWs, participants' somatic reactions to LDWs were the same as when they won. Since arousal is arguably the most significant reinforcer in slot machine play, the finding that LDWs and real wins are equally arousing suggests that playing multiple lines on slot machines may heighten arousal and possibly increase the risk of developing gambling problems.

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Memory: Capacity and resolution of working and short-term memory

Vista Ballroom, Boards 542–556

Friday, May 7, 6:30 - 9:30 pm

16.542 **Which Features of an Object are Stored in Visual Working Memory across a Saccade? Evidence from Visual Search**

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Before a saccade, attention shifts covertly to the saccade target object, allowing the consolidation of target features into VWM and the retention of those features across the saccade. Such transsaccadic memory is critical for establishing object correspondence and perceptual continuity across eye movements. In the present study, we contrasted two hypotheses regarding feature encoding and retention in transsaccadic VWM. First, encoding into VWM might be limited to the features of an object that led to its selection as the saccade target. For example, when searching for a round object, the relevant property for saccade target selection (shape) might be preferentially encoded and retained in transsaccadic VWM. Second, encoding into VWM might be object-based in the sense that all features the target are retained across the saccade, including features that were irrelevant to its selection. In the present study, observers searched for a shape singleton (disk) among distractors (squares) in a circular array. Each shape had a particular color that was incidental to the search task. Participants executed a saccade to the disk, and during the saccade, the array rotated so that the eyes landed between the target disk and an adjacent distractor square. Participants were instructed to correct gaze to the target disk. On key trials, the target and distractor swapped colors during the initial saccade. This change in the color of the target caused significant interference with gaze correction, despite the fact that color was incidental to the task. Similar results were obtained even when participants were given strong incentive to avoid encoding the target color. Thus, participants appear to have minimal control over the object features encoded into transsaccadic VWM. All features of the saccade target, including task-irrelevant features, are encoded, maintained across the eye movement, and consulted when the visual system locates the target after the saccade.

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16.543 **Proximity Grouping in Visual Working Memory**

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The ability to group information into "chunks" is a well know phenomenon in verbal working memory paradigms. However, the effects of chunking in the visual memory domain is not as well understood. Here, we investigate the effects of visual chunking on working memory capacity by utilizing gestalt principles to bias subjects to group individual items into larger, virtual objects. Previously, we have examined the effects of grouping in Kanizsa figures and demonstrated a reduction in working memory load for elements comprising illusory triangles compared to individual "pac-men". Here, we investigate the effect of proximity in generating virtual objects. In Experiment 1 Subjects were presented with randomly spaced groups of 6 dots: 1 group of 6 dots, 2 groups of 3 dots, or 3 groups of 2 dots. Subjects performed a location change detection task on a single item probe after a brief delay, indicating whether the probe was in the same or different location as the sample. ERPs were also recorded during the experiment. In particular, we examined the contralateral delay activity, which is an ERP component sensitive to the number of items held in memory during the delay activity of a visual working memory task. By examining the amplitude of this activity we were able to further determine whether these grouping principles facilitated efficient allocation of memory capacity towards the "chunked" objects or whether the number of maintained representations in memory was set by the number of elements within the figure.

Change detection performance was greater in grouped conditions compared to individual presentation conditions. In addition, ERP activity indexing online working memory load was greater for higher numbers of elements compared to grouped figures containing the same number of elements. The implications of working memory grouping mechanisms for category learning will also be discussed.

16.544 **Visual short term memory serves as a gateway to long term memory**

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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 this study, we took a different approach to test this model. 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. It is well known that individuals substantially and reliably vary in their STM capacity. Here we tested whether individuals with a high STM capacity, and thus a "larger gate", were better able to successfully store and retrieve information from LTM than their low capacity counterparts. To do this, we tested LTM recognition performance for novel and repeated arrays of simple objects that were originally presented as part of a STM change detection task. Across several experiments, we found that an individual's STM capacity strongly predicted his or her success on both incidental and intentional LTM recognition tasks (r's = .47~.78). These results support the proposal that the effective size of the individual's STM gate determines how much information from a display will be successfully stored in LTM.

16.545 **Can Observers Trade Resolution for Capacity in Visual 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 asked whether the resolution and capacity of stored representations in VWM is under top-down strategic control. That is, can VWM store more coarse-grained representations or fewer fine-grained representations depending on task demands? To address this question, we used a short-term color recall task in which observers attempted to retain several colors in VWM over a 1- second retention interval and then reported one of them by clicking on a color wheel (Zhang & Luck, 2008, Nature). In one condition, the colors varied continuously across the color wheel, encouraging the retention of precise color information. In a second condition, the color wheel was divided into 9 or 15 homogeneous color wedges, reducing the degree of precision necessary to perform the task. The flexible resource hypothesis predicts that VWM should store fewer colors with higher resolution in the continuous color wheel condition but more colors with lower resolution in the discrete color wheel condition. In contrast, the fixed resolution hypothesis predicts that VWM resolution and capacity must remain constant across conditions. We found that VWM resolution and capacity remained constant across conditions, supporting the fixed resolution slot hypothesis. Follow-up experiments using other methods of manipulating the need to maintain precise representations also found no evidence that subjects could increase the number of items in VWM by storing them with less precision.

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16.546 **The Optimal Allocation of Visual Working Memory: Quantifying the Relationship Between Memory Capacity and Encoding Precision**

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Visual working memory is central to nearly all human activities. Given its importance, it is perhaps surprising that the capacity of visual working memory is severely limited. A long history of research has sought to identify the nature of this limit, with the primary theoretical division concerning whether this capacity is a continuous resource, or a number of discrete "slots". In an effort to resolve this debate, Bays and Husain (2008) have examined how the precision of information encoded in visual working memory changes as a function of the number of features that are stored, with the finding that storing even two features can degrade memory precision compared with the case of storing just a single feature. While this relationship has been characterized using a power-law model (Bays & Husain, 2008), or a modified discrete slot model (Cowan & Rouder, 2009), we have instead applied a principled theoretical framework to explain the relationship between allocated memory resources and the resulting fidelity of the encoded information. In particular, results from a branch of information theory known as rate–distortion theory (Shannon & Weaver, 1949), dictate the optimal precision with which any information can be transmitted as a function of the capacity of the system, measured in bits. Importantly, this upper limit on performance must hold regardless of whether human visual working memory is biologically instantiated as discrete slots, a continuous pool of resources, or any other encoding scheme. It is shown that results from rate–distortion theory not only provide a principled theoretical basis for describing capacity limits in visual working memory, but are also able to provide a remarkable quantitative fit to empirical results of previous experiments (Bays & Husain, 2008). These findings form the basis for the development of a computational model of the optimal allocation of visual working memory.

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 See page 3 for Abstract Numbering System

16.547 Interactions between motion perception and visual working memory

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Question: Are working memory representations biased by new visual inputs?

Method: Observers were instructed first to view a random dot motion display (100% coherence) and, then, to remember its direction of motion during a two-second retention interval. While holding that direction of motion in visual working memory, observers viewed second motion display (10%~15% in coherence) and indicated whether it was counter-clock wise or clock wise with respect to a reference line presented at the edge of the display (2AFC task). The difference in motion direction between these two motion displays was independently varied from -20° to +20°. After performing the direction judgment task, observers reported the remembered direction of motion by adjusting a clock needle to the memorized direction. This judgment provided a measure of memory precision, indexed as the difference between the actual direction of the first motion display and the memorized direction.

Result: The remembered direction of motion was systematically biased toward the direction of motion shown during the intervening perceptual-discrimination task.

Discussion: These findings demonstrate that new perceptual inputs affect visual working memory representations. This general experimental paradigm opens avenues to investigate how perception influences working memory representations and, for that matter, how working memory representations influence ongoing perception.

16.548 Crossmodal Working Memory Load: Perceptual and Conceptual Contributions of Image Characteristics

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What can crossmodal associations reveal about working memory capacity for complex objects? Forming these associations starts before baby first shakes a rattle and continues past Grandma's first cellphone purchase. To examine the contributions of perceptual and conceptual characteristics of images to WM for novel visual-auditory associations, we assessed crossmodal change-detection accuracy (Gilman & Ware, 2009) for associations between animal sounds and four image types: grayscale shapes, color shapes, grayscale drawings (Rossion & Pourtois, 2004), and color photographs. Following Alvarez & Cavanagh (2004), image information load was measured by comparing time costs for adding more images of the same type to a search array. Participants' average search times (N=22) were all under 20ms/item, comparable only to the two fastest image classes—colored squares and letters—tested by Alvarez and Cavanagh (2004). Meaningfulness of the image types was assessed using word association counts, with each image prompting on average four associations; representational images garnered .7 more associations than shapes, and full-color images received approximately .2 more associations than grayscale ones. Similar results were obtained for associational variety. Crossmodal change-detection accuracy was higher for associations between color images (representational or abstract) and unrelated animal sounds than for those using grayscale images. However, response bias was lower for crossmodal associations with representational images (color photos or grayscale drawings) than for those with color or grayscale shapes. This difference parallels recognition memory findings of lower bias for more-distinct visual (Sekuler & Kahana, 2007) and auditory (Visscher, Kaplan, Kahana, & Sekuler, 2007) stimuli—stimuli designed to avoid conceptual associations. Visual search cost for the present image types varied linearly with participants' measured working memory capacity for crossmodal associations ($r2=.971$, $F(1,2)=66.99$, $p=.015$); the proportion of variance explained is comparable to that found in the visual precedent. These crossmodal WM dynamics are compatible with information-theoretic WM models, showing sensitivity to unimodal perceptual and conceptual characteristics affecting the discriminability of stimuli to be associated.

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16.549 Visual Working Memory Capacity in Retinotopic Cortex: Number, Resolution, and Population Receptive Fields

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Introduction: Visual working memory (VWM) capacity has been shown to be limited by the number of items one can hold in memory and the resolution at which those items are represented. The number limit appears to be subserved by cortex in inferior interparietal sulcus (IPS), while the resolution limit seems to be subserved by superior IPS and part of the lateral occipital complex (LOC). Visual field maps have recently been discovered in IPS and LOC, and some or all of the regions involved in VWM capacity limits may lie in these visual field maps, which may have functional consequences for VWM capacity limits. Methods: We measured angular and eccentric retinotopic organization and population receptive fields across visual cortex using fMRI. Retinotopic stimuli consisted of black and white, drifting checkerboards 11° in radius comprising wedges, rings, and/or bars. A change detection task with set sizes 1, 2, 4 or 8 was performed using fMRI, with locations of stimuli controlled such that they were in the shape of a ring or wedge, to directly measure angular and eccentric VWM organization. The stimuli consist of colored squares (6 possible colors) or shaded cubes (controlled for spatial frequency, in 6 colors with 6 shading patterns, with low-similarity changes between colors and high-similarity changes between shading patterns) that subtend roughly 1° of visual angle. Results/Discussion: We present the location of functionally defined regions underlying VWM capacity limits and whether some or all fall into visual field maps. The change detection tasks replicate previous studies showing that we maintain just as many complex objects as simple objects, but at limited resolution. We present the first measurements of population receptive fields in IPS visual field maps, and analyze the number limit and mnemonic resolution for simple and complex objects as a function of population receptive fields.

16.550 An investigation of the precision and capacity of human visual working memory

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How does the visual system maintain an active representation of a visual scene after it can no longer access that information directly? Two key theories dominate the current understanding of how the brain deals with the challenges of maintaining information from its rich visual surroundings. Slot models predict that up to 3-4 discrete items can be simultaneously maintained in working memory. By contrast, resource models assume a limited capacity that can be flexibly distributed to remember a few items very well, or to store many items with less precision. Our study evaluates these models by measuring the precision and capacity of visual working memory for orientations. We used orientation because this continuously varying feature can be precisely represented by the human visual system. Subjects were briefly presented with 1-6 randomly oriented gratings; after a 3-second delay subjects were cued to report the orientation of one of the gratings by method-of-adjustment. This design allows the dissociation of two components of visual short-term memory performance: precision of a remembered item and likelihood of forgetting (Zhang & Luck, 2008). Rigorous psychophysical testing indicated that each of our subjects was able to accurately maintain a representation of orientation across set sizes (5-20° SD). Precision of this memory declined steadily when subjects had to remember more items, which is consistent with the resource model. However, not all our results were inconsistent with the slot model. The likelihood of forgetting sharply increased when more items had to be remembered, indicating the difficulty of maintaining over 4 items in memory. Finally, we found only a weak effect of distracter orientation on target response, contrary to some recent reports (Bays et al. 2009). Our results suggest that people can maintain more than 4 visual items simultaneously, albeit with some loss of precision and a greater likelihood of forgetting.

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16.551 The capacity limit of the visual working memory of the macaque monkey

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Behavior can be guided by visual working memory as well as vision. For example, visual exploratory behavior is most efficient if subjects can accurately retain items they have previously fixated. This visual working memory capacity is limited; human studies have estimated the visual working memory capacity as 3 items on average, with values as low as 1.5 in some individuals. To date, no study has determined the capacity limit in animals and as such, no animal model has been established to investigate the neural basis of the capacity of visual working memory. We employed an adaptation of the sequential color-change detection task used in human studies to determine the visual working memory capacity in the macaque monkey (see supplementary figure 1). Each trial began with the presentation of a fixation spot on a blank screen. The monkey was required to fixate on this central fixation spot before a memory array was presented. The memory array consisted of a set of two to five highly discriminable colored stimuli, presented for 500ms. The memory array, except for the fixation spot, was removed for a retention interval of 1000ms, during which the monkey was required to maintain fixation. The test array was then presented with one of the stimuli having changed color. The monkey was required to indicate this change by making a single saccadic eye movement to its location. Consistent with the use of mnemonic processes, the performance decreased with increasing set size (see supplementary figure 2). Using the relationship between performance and set size, monkey visual working memory capacity was at least 2 memoranda, a value within the range of human capacity estimates. This similarity between the monkey and human visual working memory capacity suggests a shared common neural process, which can now be investigated with invasive techniques.

16.552 Variations in mnemonic resolution across set sizes support discrete resource models of capacity in working memory

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Discrete resource models propose that WM capacity is determined by a small number of discrete "slots" that share a limited pool of resources. By contrast, flexible resource models posit a single resource pool that can be allocated across an unlimited number of items. To test these models, we measured mnemonic resolution for orientation as a function of set size (1-8). Using a mixture model consistent with discrete resource models (Zhang and Luck, 2008), we estimated number (Pmem) and resolution (SD) as a function of set size. To test the flexible resource model, we fitted a single Gaussian distribution to the distribution of recall errors to operationalize WM capacity. Although both models predict worse mnemonic resolution for larger set sizes, the discrete resource model predicts that resolution should reach an asymptote when capacity has been achieved because items that are not stored should not affect the precision of the stored representations. In line with this hypothesis, the group data revealed a clear asymptote in resolution at set size 4. Critically, we also found that observers with fewer "slots" reached asymptote at smaller set sizes, leading to a strong correlation between individual slot estimates and the set size at which mnemonic resolution reached asymptote. By contrast, capacity estimates based on the assumptions of the flexible resource model were significantly worse at predicting resolution as a function of set size. Thus, discrete resource models provide superior predictive validity for understanding the relationship between resolution and set size in visual WM.

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16.553 Developmental evidence for a capacity-resolution tradeoff in working memory

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A recent debate in the study of visual short-term memory (VSTM) asks whether capacity is better characterized as limited by the number of items stored (Luck & Vogel, 1997), the total information load of the items (Alvarez & Cavanagh, 2004; Xu & Chun 2006), or by a hybrid of these (Gao, Li, Liang, Chen, Yin & Shen, 2009; Zhang & Luck, 2008). Here we extend the scope of this capacity-resolution debate by studying infants and by using a working memory rather than a VSTM task. We asked whether the resolution of infants' object representations decreases as infants remember larger numbers of objects. We presented 18-month-olds with arrays of 1-3 toys that were then hidden in a box. Infants were allowed to search for and retrieve all of the hidden objects, and we measured their subsequent searching. On some trials infants retrieved exactly those objects they saw hidden (e.g., brush and car hidden; brush and car retrieved), and as a result then searched very little (because the box was expected empty). On other trials, one or more of the retrieved objects secretly switched identity (e.g., brush and car hidden; duck and car retrieved). On these trials the number of retrieved objects was always correct, but if infants remembered the identity of the initially hidden objects they should detect a mis-match and continue searching for the missing objects. In three experiments we found that infants' ability to detect this kind of identity switch decreased as the number of hidden objects increased. These studies expand the capacity-resolution debate in two ways: First, they provide evidence of a tradeoff in infants, suggesting that capacity and resolution interact from early in the lifespan. Second, they extend existing results to a longer timescale, suggesting that capacity and resolution trade off beyond VSTM, in memory more broadly.

16.554 The Effect of Minimizing Visual Memory and Attention Load in Basic Mathematical Tasks

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How might minimizing visual working memory and attention load affect students' ability to perform basic mathematical tasks? Recent work (Schneps et al, 2007) suggests a potential trade-off between central and peripheral visual abilities: "While the central field appears well suited for tasks such as visual search, the periphery is optimized for rapid processing over broad regions. People vary in their abilities to make use of information in the center versus the periphery, and we propose that this bias leads to a trade-off between abilities for sequential search versus contemporaneous comparisons." We focus here on two pencil-and-paper algorithms for finding multi-digit products: the familiar standard algorithm (S), which places large demands on visual working memory and visual attention; and an older algorithm (Treviso, 1478). In the latter (T), an elegant spatial layout guides visual attention, and at the same time minimizes demands for visual memory. While algorithm S makes strong use of central (hence sequential) processing, the alternative algorithm T makes effective use of its spatial (therefore more pre-attentive, less sequential) layout. We report results from two experiments in progress, to compare the performance of post-secondary students on these algorithms in two learner populations: typical STEM undergraduates, and STEM undergraduates whose executive functions are believed to be impaired (specifically, those with dyslexia). In the first experiment, fifteen students from each population are tested on accuracy of performance on multi-digit products, comparing methods S and T. In the second experiment, students from each population again perform multi-digit products as above, but in this experiment their eye and hand motions are simultaneously tracked, to assess task dynamics. Results are analyzed statistically, for comparisons within and across both learner populations.

Acknowledgement: NSF HRD-0930962

16.555 How low can you go? An investigation of working memory span and change detection

Bonnie L. Angelone[1](angelone@rowan.edu), Nikkole Wilson[1], Victoria Osborne[1], Zachary Leonardo[1]; [1]Department of Psychology, College of Liberal Arts and Sciences, Rowan University

Change detection performance is often impaired due to limits in visual memory and attention. Therefore, individual differences in visual memory and attentional abilities may impact change detection performance. Extensive research has examined the impact of factors related to the external stimulus on change detection performance. For example, changes to objects that are more important to scene context are detected faster than objects of lesser importance. Also, several studies have shown that type of task, type of change, scene complexity, meaningfulness, salience, and change probability play a role in change detection performance. Although not as extensively examined, research has also investigated the role of internal personal factors. For example, individuals with increased attentional breadth (tested using Functional Field of View) demonstrate better change detection performance. In addition, individuals immersed in cultures with more holistic world views show a benefit for certain types of changes compared to their counterparts from more individualistic cultures. Finally, previously at VSS we showed that visual memory for locations accounted for a significant amount of the variance in change detection performance, while field independence/dependence and perceptual speed did not. The current project investigated the effect of working memory span on naturalistic scene change detection. Participants completed the Automated Operation Span Task (AOSPAN) and a change detection task for both type and token changes. Research suggests that individuals with high working memory

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span do not always excel at other tasks; they may not show a benefit until the task becomes more attentionally demanding. As such, high working memory span individuals may only outperform low span individuals for type changes and not token changes.

16.556 **Beyond magical numbers: towards a noise-based account of visual-short term memory limitations**

Wei Ji Ma[1](wjma@bcm.edu), Wen-Chuang Chou[1]; [1]Department of Neuroscience, Baylor College of Medicine

Visual short-term memory (VSTM) performance decreases with set size, but the origins of this effect are disputed. Some attribute it to a limit on the number of items that can be memorized (the "magical number 4", e.g. Cowan, 2001), others to internal noise that increases with set size (e.g. Wilken and Ma, 2004). We present new experiments and a neural model to distinguish these theories. Observers viewed widely spaced colored discs at fixed eccentricity for 100 ms. After a 1-second delay, one location was marked and the observer reported the color of the disc that had been at that location (the target) by either clicking on a color wheel or scrolling through all colors using arrow keys. A limited-capacity model predicts: 1) an observer's capacity, K, is independent of response modality; 2) when set size N satisfies N≤K, the target color is always reported; 3) any instance of not reporting the target color is due to random guessing; 4) when reporting the target color, response variance is independent of N. Instead, we find that: 1) observers' capacity is 36% higher in the scrolling than in the color wheel paradigm; 2) when N≤K, subjects do not always report the target color; 3) when subjects do not report the target color, they often report the color of another item, consistently with Bays and Husain (2009); 4) response variance increases continuously with N. We confirmed these findings in a two-alternative forced-choice experiment in which subjects indicated for a given test color, which of two marked locations contained that color. Our findings can be explained by a simple neural network characterized by spatial averaging and divisive normalization, without an item limit. We argue that VSTM must be reconceptualized in terms of noise and uncertainty, and that its limitations are likely tied to attentional ones.

Saturday Morning Talks

Attention: Interactions with eye and hand movement

Saturday, May 8, 8:15 - 10:00 am
Talk Session, Royal Ballroom 1-3
Moderator: Amelia Hunt

21.11, *8:15 am*

Remapping of an unseen stimulus

Amelia Hunt[1](a.hunt@abdn.ac.uk), Kay Ritchie[1], Lawrence Weiskrantz[2], Arash Sahraie[1]; [1]School of Psychology, University of Aberdeen, [2]Department of Experimental Psychology, Oxford University

When the eyes move, the visual world shifts across the retina. In visual cortex, this means information represented by one population of neurons will suddenly be represented by another population, sometimes transferring from one hemisphere to another. Saccadic remapping is the predictive response of neurons that has been shown to precede the retinotopic shift of stimuli caused by an eye movement. We examined whether conscious perception of a visual stimulus and an intact V1 are prerequisite to remapping stimuli into expected coordinates. Stimuli below the threshold for detection were presented in the blind field of patient DB, who has left homonymous hemianopia after surgical removal of the right striate cortex. Using a two-alternative forced-response procedure, DB performed at chance level (~50%) when asked to detect a target presented within his blind field while fixating on a fixation cross. However, when he executed a saccade that would bring the visual target into his intact field, his accuracy improved to 89%, even though the stimulus was removed at saccade onset, and never entered his sighted field. Despite the increase in sensitivity, DB reported no conscious awareness of the stimulus. Saccades of equal size and eccentricity that would not bring the stimulus into his sighted field did not elevate detection. The results suggest that the intact visual hemifield may have predictively responded to a stimulus in the blind field, even though that stimulus was neither detected nor consciously perceived. This predictive response improved detection, but did not lead to explicit awareness.

21.12, *8:30 am*

Non-retinotopic cueing of visual spatial attention

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Attentional capture by an exogenous spatial-cue is generally believed to be mediated by retinotopic mechanisms. Using a Ternus-Pikler display, we show that attentional capture occurs in non-retinotopic coordinates. In a first frame, three squares were presented for 200ms followed by a 70ms ISI and a second frame containing the same three squares shifted laterally by one position. Observers perceived three squares moving laterally as a group. Within the central square of the first frame, a cue was flashed either at the center (neutral cue) or at a peripheral position (retinotopically neutral cue, non-retinotopically 100% valid cue). In the central square of the second frame, a conjunction search display was presented. Subjects had to search for a red tilted bar (target) and indicate its tilt direction. Relative to the surrounding squares, the peripheral position of the cue in the first frame corresponded to the peripheral position of the target in the second frame. On the other hand, because the central square moved, retinotopic positions of the cues were different from those of the search items. A retinotopic account of attention predicts no difference in performance between central and peripheral cue as both cues recruit attention at a location where the target is not presented. In contrast to this prediction, we found faster reaction times for peripherally versus centrally cued trials, indicating that the peripheral cue acts in non-retinotopic coordinates in summoning attention to the target location. These results provide strong evidence for a non-retinotopic component in spatial visual attention.

Acknowledgement: Swiss National Fund

21.13, *8:45 am*

Predictive updating of attention to saccade targets

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We examined the allocation of attention in a two-step-saccade task, probing several locations in space at different times following the onset of the central cue indicating the locations of the two targets. We found the expected advantage in detection performance at both the first and second saccade target locations increasing from around 150 msec before the first saccade, with a slight delay for the appearance of the advantage at the second saccade target. More interestingly, we also found an advantage at the remapped locations for the second target (and of the first as evaluated in a separate experiment), emerging just 75 msec before the saccade. These locations correspond to the positions the two saccade targets will have on the retina following the saccade but, prior to the saccade when these benefits are seen, they do not correspond to the saccade target locations in either retinotopic or spatiotopic coordinates. These results suggest that location pointers to saccade targets are updated by a predictive remapping process working in a retinotopic frame of reference, allowing attention to be allocated to the upcoming target location in advance of the saccade landing, lending behavioral support to the now classic physiological finding that many cells in retinotopically organized brain areas pre-activate in anticipation of stimuli that will be landing in their receptive fields.

Acknowledgement: This research was supported by a Chaire d'Excellence grant to Patrick Cavanagh.

21.14, *9:00 am*

Toward an interactive race model of double-step saccades

Claudia Wilimzig[1](claudia.b.wilimzig@vanderbilt.edu), Thomas Palmeri[1,2], Gordon Logan[1,2], Jeffrey Schall[1,2,3]; [1]Vanderbilt University, Department of Psychology, [2]Vanderbilt University, Center for Integrative and Cognitive Neuroscience, [3]Vanderbilt Vision Research Center

Performance of saccade double-step and search-step tasks can be understood as the outcome of a race between GO processes initiating the alternative saccades and a STOP process (Camalier et al. 2007 Vision Res) paralleling the race model of stop signal task performance (Logan & Cowan 1984 Psych Rev). The models require stochastic independence of the finishing times of the racing processes. However, the control of movement initiation is accomplished by networks of neurons that interact through mutual inhibition. An interactive race model demonstrated how late, potent inhibition of a STOP unit on a GO unit can reproduce stop signal task performance with patterns of activation that resemble actual neural discharges (Boucher et al. 2007 Psych Rev). We are extending this interactive race architecture to account for double-step performance in which a second saccade is produced to the final target location after canceling the first saccade to the original target location. Alternative architectures have been explored. In a GO-STOP-GO architecture a separate STOP unit inhibits the GO unit producing the first saccade and allows the GO unit producing the second saccade to complete. In a GO-GO architecture the second GO unit both inhibits the first GO unit and initiates the saccade to the final target location.

The models were fit to the probability of compensating for the target step and the response times of compensated saccades as well as noncompensated followed by corrective saccades. The quality of fits of the GO-STOP-GO architecture was contrasted with that of the GO-GO architecture. Also, the form of the activation of the GO and STOP units was compared to the patterns of neural activity in FEF of monkeys performing the search step and double-step task (Murthy et al. 2009 J Neurophysiol). The results illustrate how stochastic cognitive models can be related to neural processes to understand how choice responses are initiated, interrupted and corrected.

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21.15, *9:15 am*

Information at hand is detected better in change detection

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Recent studies have suggested an altered visual processing for objects that are near the hands; visual search rates were slower when an observer's hands were near the display, which was interpreted as a result of a detailed evaluation of objects. Slower reaction times, however, can also arise from a number of inhibitory processes and therefore do not warrant the claim of a detailed visual analysis. Here we present two experiments that use a change detection paradigm to test this claim. While performing a change detection task, observers placed their hands either vertically or horizontally on the frame of the display, or away from the display. When their hands were on the display, change detection performance was more accurate and they held more items in visual short term memory. Both vertical and horizontal hand positions were facilitative, but vertically-placed hands elicited a robust enhancement that was resistant to task difficulty. Gains in hit rate were equal in magnitude across all regions, regardless of distances from the hands, suggesting that the extensive analysis is non-specific in nature. Together, our accuracy data provide concrete evidence for an enhanced visual analysis of objects near the hands.

21.16, *9:30 am*

The role of feedback to foveal cortex in peripheral perception: A TMS study

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Recent neuroimaging evidence suggests that visual inputs arising beyond the fovea can be 'fed back' to foveal retinotopic cortex, building a new representation of extra-foveal events. Williams et al. (2008) presented novel objects in diagonally opposing parts of the peripheral visual field, while participants fixated centrally. The task was to determine if the objects were identical or different, and the objects on each trial could be from one of three different categories. Using fMRI and multi-pattern voxel pattern analysis, they found significant discrimination performance in the foveal confluence – the region of cortex representing central vision, where no objects were presented. Critically, this pattern was not dependent on the location of the objects suggesting it is due to feedback from higher areas that are position-invariant. Thus, contrary to the traditional view of early visual cortex being strictly retinotopic in the mapping of visual space, here is evidence of object-specific information about objects in the periphery being fed back to foveal cortex. However, the designation of such encoding as feedback depends entirely on its neural timecourse and behavioural significance, both of which are unknown. Here, we used a similar task and applied transcranial magnetic stimulation (TMS) to the posterior termination of the calcarine sulcus (the foveal site), and an occipital control region in line with a more peripheral calcarine representation (the non-foveal site). On each trial, a double-pulse of TMS was applied at one of seven possible times relative to target onset (–150 to +500 ms), at either a low or high intensity (40% or 120% motor threshold). Late (350-400ms) disruption of foveal visual cortex impaired the ability to perceptually discriminate objects in the periphery. This shows that delayed foveal processing is crucial for extra-foveal perception, and highlight the pivotal role of 'constructive' feedback in human vision.

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21.17, *9:45 am*

Guidance of gaze based on color saliency in monkeys with unilateral lesion of primary visual cortex

Masatoshi Yoshida[1,2](myoshi@nips.ac.jp), Laurent Itti[3,4], David Berg[3,4], Takuro Ikeda[1,5], Rikako Kato[1,5], Kana Takaura[1,2], Tadashi Isa[1,2,5]; [1]Department of Developmental Physiology, National Institute for Physiological Sciences (Okazaki, JAPAN), [2]School of Life Science, The Graduate University for Advanced Studies (Hayama, JAPAN), [3]Computer Science Department, University of Southern California (Los Angeles, California), [4]Neuroscience Graduate Program, University of Southern California (Los Angeles, California), [5]CREST, JST (Kawaguchi, Japan)

In the accompanying paper (Itti et.al.), we investigated residual visually-guided behavior in monkeys after unilateral ablation of primary visual cortex (V1), to unravel the contributions of V1 to salience computation. We analyzed eye movements of monkeys watching video stimuli and a computational model of saliency-based, bottom-up attention quantified the monkeys' propensity to attend to salient targets. All monkeys were attracted towards salient stimuli, significantly above chance, for saccades directed both into normal and affected hemifields. We also quantified the contribution of visual attributes (intensity, color, motion and so on) to the saliency-based eye movements and obtained evidence that the monkeys' guidance of gaze was influenced by color saliency. Here we directly examined residual visuomotor processing based on color saliency with color discrimination tasks. In two monkeys after unilateral ablation of V1, the isoluminant, chromatic stimuli was presented in one of the two positions in their affected hemifield. The monkeys were rewarded by making saccade to the target. The CRT monitor (Mitsubishi DZ21) was used for stimulus presentation and was calibrated with a colorimeter (PR650). The stimuli were defined by the DKL color space, that is, the luminance axis, the L-M axis and the S-(L+M) axis. In both monkeys, the correct ratio was significantly above chance for stimuli with the L-M component and the S-(L+M) component. Control experiments were done to exclude the possibility that a small luminance difference from background may contribute to the above-chance performance. When a small positive or negative luminance difference (<5%) was added to the chromatic stimuli, the correct ratio was not decreased. On the other hand, the correct ratio was near the chance level when the achromatic stimuli with the same luminance difference were used. Our results suggest that unilateral ablation of V1 does not abolish the computation of color saliency.

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Saturday AM

Memory: Working and short-term memory

Saturday, May 8, 8:15 - 10:00 am

Talk Session, Royal Ballroom 4-5

Moderator: Wei Ji Ma

21.21, *8:15 am*

Hierarchical Encoding in Visual Working Memory

Timothy F. Brady[1](tfbrady@mit.edu), Joshua B. Tenenbaum[1]; [1]Department of Brain and Cognitive Sciences, Massachusetts Institute of Technology

When remembering a real-world scene, people encode both detailed information about specific objects and higher-order information like the overall gist of the scene. However, existing formal models of visual working memory capacity (e.g., Cowan's K) generally assume that people encode individual items but do not represent the higher-order structure of the display.

We present a probabilistic model of VWM that generalizes Cowan's K to encode not only specific items from a display, but also higher-order information. While higher-order information can take many forms, we begin with a simple summary representation: how likely neighboring items are to be the same color. In Experiment 1, we test this model on displays of randomly chosen colored dots (Luck & Vogel, 1997). In Experiment 2, we generalize the model to displays where the dots are purposefully arranged in patterns. In both experiments, 75 observers detected changes in each individual display, which allowed us to calculate d' for a particular change in a particular display (range: d'=0.8-3.8). Results show that observers are highly consistent about which changes are easy or difficult to detect, even in standard colored dot displays (split-half correlations=0.60-0.76). Furthermore, the correlation between observers d' and the model d' is r=0.45 (p<0.01) in the randomly generated displays and r=0.72 (p<0.001) in the patterned displays, suggesting the model's simple summary representation captures which changes people are likely to detect. By contrast, the simpler model of change detection typically used in calculations of VWM capacity does not predict any reliable differences in difficulty between displays.

We conclude that even in simple VWM displays items are not represented independently, and that models of VWM need to be expanded to take into account this non-independence between items before we can usefully make predictions about observers' memory capacity in real-world scenes.

Acknowledgement: NSF Graduate Research Fellowship to TFB.

21.22, *8:30 am*

Working Memory for Spatial Relations Among Object Parts

Pamela E. Glosson[1](glosson2@uiuc.edu), John E. Hummel[1]; [1]University of Illinois, Urbana Champaign

It is broadly agreed that the capacity of working memory (WM) is 4±1 items. In the vision literature these items are objects (i.e., bound collections of object features), whereas in higher cognition they are role bindings. The distinction between these accounts becomes clearer in the context of the spatial relations among an object's parts: If parts are items then the WM capacity required to store the spatial relations among an object's parts should scale with the number, n, of parts (i.e., load = n); but if part-relation bindings are items, then WM load should scale as r*n2, where r is the number of relations to be remembered. An intermediate account, according to which relational roles can be "stacked" on object parts, predicts that load should scale simply as n2. We ran an experiment investigating WM for spatial relations among object parts, orthogonally varying both the number of parts composing and object and the number of relations the subject was required to remember. The results clearly support the intermediate model, which accounts for 85% of the variance in Ss accuracy. The higher cognitive model accounts for only 71% and the "parts as objects" model accounts for 0%. Visual WM load thus appears to scale with n2 with no additional cost imposed for additional relations.

Acknowledgement: AFOSR Grant # FA9550-07-1-0147

21.23, *8:45 am*

The limitations of spatial visual short-term memory

Patrick Wilken[1](pwilken@gmail.com), Ronald van den Berg[2], Jochen Braun[3], Wei Ji Ma[2]; [1]Berlin School of Mind and Brain, Humboldt-Universität zu Berlin, Germany, [2]Baylor College of Medicine, One Baylor Plaza, Houston TX 77030, USA, [3]Cognitive Biology Lab, University of Magdeburg, Germany

We present a novel experimental paradigm examining the effects of set size on the encoding of spatial location in visual short-term memory (VSTM). The nature of the structure of VSTM has recently been the subject of intense debate. One group of researchers (e.g. Zhang and Luck, 2008) have argued that changes in performance as a function of set size reflect limits in the number of items that can be encoded in VSTM. In contrast, we along with others (Wilken and Ma, 2004; Bays and Husain, 2008) argue that VSTM performance is limited by internal noise, which itself grows with set size. In our experiment, observers viewed randomly positioned Gaussian "blobs", presented for 100 ms. After a 1000 ms ISI, a second display was shown that was identical to the first except that one blob was missing. The observer's task was to report the memorized location of this "missing" (target) blob. Logically, reports could fall into two categories: (1) those based on a noisy internal representation of the true location of the target; and (2) those in which no information about the target location was used. Accordingly, we fitted a mixture model consisting of a target-centered, bivariate Gaussian and a second, approximately uniform distribution centered on the fixation point. The proportion of responses that were assigned to the first distribution decreased as a function of set size, though significantly more slowly than would be predicted by a "4-item" slot model (e.g., Cowan, 2001). Importantly, we found that the precision of spatial localization decreased monotonically as a function of set size, independent of eccentricity. These results are consistent with a model of spatial VSTM in which responses are limited by a continuous resource that is distributed across all items.

21.24, *9:00 am*

The Primary Visual Cortex as a Modality-Independent 'Screen' for Working Memory

Lora Likova[1](lora@ski.org); [1]Smith-Kettlewell Eye Research Institute

INTRODUCTION: Increasing evidence suggests that the function of the early visual areas is not restricted to sensory processing. Recently, Harrison & Tong (2009) have shown that areas V1-4 play a role in the maintenance of visual information in visual working memory. This result, however, leaves open the question of whether these areas can also support non-visual working memory, and if so what are the implications for the underlying functional architecture. METHODS: We addressed these questions in an fMRI drawing paradigm with blindfolded subjects in a Siemens 3T scanner. Four experimental conditions, separated by 20sec intervals, were run: Tactile Exploration - line-images (faces and objects) were explored with one hand and remembered to guide a future drawing task; Drawing - subjects had to draw the image remembered from a tactile template presented 20 seconds earlier to the non-drawing hand; Scribbling - a control task of pure hand movements with no image structure or memory component; Copying - drawing the image, but with concurrent access to the tactile template, minimizing demands on memory. The drawing trajectory was recorded with a custom MRI-compatible system, incorporating a fiber-optic stylus. RESULTS AND CONCLUSIONS: Of the occipital areas, only V1 was significantly activated in any condition, implying direct top-down feedback from high-level cortex beyond the occipital lobe. Tactile Exploration activated foveal V1 only, as if it were representing the local focus of attention during the exploration. In contrast, tactile-memory-guided Drawing while blindfolded activated full peripheral V1, as if responding to a large-scale visual representation. Frontal, parietal and inferotemporal activations specific to the memory-guided condition provide a basis for extensive top-down involvement in the V1 memory maintenance. The overall pattern of results suggests that V1 can operate as the conscious 'visualization screen' for working memory, even when evoked by non-visual sensory and complex memory guided tasks.

Acknowledgement: NSF # 0846230

21.25, *9:15 am*

Decoding individual natural scene representations during perception and imagery

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Previous neuroimaging results indicate that reflective processes such as working memory and mental imagery can increase activity in category-selective extrastriate (CSE) cortical areas whose preferred category is that of the item held in mind. Recent classification studies also show that some CSE areas demonstrate exemplar-specific activity during perception for items of the preferred category, and that early visual cortex contains information about simple stimuli (e.g., oriented gratings) held in working memory. The aim of the present study was to determine to what extent item-specific information about complex natural scenes is represented in different human cortical areas (both in early visual cortex and several scene-selective extrastriate areas) during both perception and visual mental imagery. We used a multi-voxel classification analysis of moderately high-resolution fMRI data and found item-specific scene information represented in multiple areas including middle occipital gyrus (MOG), parahippocampal place area (PPA), retrosplenial cortex (RSC), and precuneus/intraparietal sulcus (PCu/IPS). Furthermore, item-specific information from perceiving scenes was partially re-instantiated during mental imagery of the same scenes. In addition, we examined voxels in the fusiform face area (FFA) and found that, despite the area's preference for face stimuli, item-specific scene information was represented there as well. These results suggest that 1) item-specific natural scene information is carried in both scene- and face-selective extrastriate areas during perception and 2) activity induced in CSE areas by reflective tasks such as mental imagery does carry information relevant to maintaining the specific representation in question.

Acknowledgement: National Institute on Aging, National Science Foundation

21.26, *9:30 am*

Visual working memory information in foveal retinotopic cortex during the delay

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Several studies have implicated early retinotopic cortex in the storage of low-level visual information in working memory over a delay. An intuitive interpretation of these findings is that visual working memory for visual features reflects a continuation of activity (whether synaptic or spiking activity) in the neural populations that originally responded to the stimulus perceptually. Here we propose and test a more radical hypothesis, based on our recent discovery of a novel form of feedback in the visual system (Williams et al., 2008): that visual working memory information is represented in foveal retinotopic cortex, no matter where in the visual field the stimulus was first presented. In order to test this hypothesis, we used fMRI and pattern classification methods to examine whether the foveal area contains information about objects presented in the periphery during a working memory delay. During each trial, a single memory sample (drawn from one of two categories of novel 3D objects) was briefly presented in a peripheral location, followed by a 14s delay period. A probe appeared subsequently, followed by another 14s interval, and subjects reported whether it was identical to or different from the memory sample. The results show that the pattern of fMRI responses in the foveal cortex, where no stimulus was presented, contains position-invariant information about the category of objects presented in a peripheral location during the delay period, but not during the inter-trial interval when no stimulus is held in memory. Furthermore, over the course of the delay period, object information decreases at the location in retinotopic cortex corresponding to the stimulus location, whereas it increases at the foveal region, suggesting a transfer of visual information from the stimulus location to foveal cortex. These findings indicate that working memory information arises in foveal retinotopic cortex regardless of where the stimulus is presented.

Acknowledgement: EY13455

21.27, *9:45 am*

Cortical anatomy relates to individual differences in dissociable aspects of attention and visual working memory capacity

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Attention and working memory are important aspects of visual cognition, for which brain networks and individual differences have been studied extensively with functional neuroimaging. Here we instead related behavioural measures of these functions to brain anatomy . We studied 39 healthy adult participants who performed five tasks : the Attentional Network Test (ANT) , two separate measures of visual working memory precision, a measure of visual working memory capacity, and a test of filtering efficiency. A principal component analysis on behavioural measures yielded three main components: precision of visual working memory; executive function that loaded with filtering inefficiency; and working memory capacity that loaded with attentional measures. Each participant also underwent structural MRI scanning. Voxel Based Morphometry analyses revealed that gray matter density in basal ganglia, anterior intraparietal sulcus, middle frontal gyrus and visual cortex were positively correlated with precision of visual working memory; executive function with gray matter density in precentral gyrus; and visual working memory capacity with gray matter density in middle frontal gyrus and frontal eye field. A negative correlation was found between gray matter density in the mid-cingulate gyrus and visual working memory precision. These findings identify separable contributory components to visual working memory and attention, both behaviourally and in the structural anatomy of the human brain

Multisensory processing

Saturday, May 8, 11:00 - 12:30 pm
Talk Session, Royal Ballroom 1-3
Moderator: Paola Binda

22.11, *11:00 am*

Touch disambiguates rivalrous perception at early stages of visual analysis

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Signals arising from different sensory modalities are integrated into a coherent percept of the external world. Here we tested whether the integration of haptic and visual signals can occur at an early level of analysis by investigating the effect of touch on binocular rivalry. Visual stimuli were orthogonal (vertical or horizontal) Gabor Patches (spatial frequency: 3.5 cpd or 5 cycles/cm, patch size: 1.5 deg, contrast: 45%), presented foveally against a grey background (7.8 cdm-2) and displayed alternatively to the two eyes through Ferro-Magnetic Shutter goggles (driven at the monitor frame rate, 120 Hz). At random intervals subjects explored briefly (~3 s) a haptic stimulus (sinusoidal milled Plexiglas, 5 cycles/cm) oriented vertically or horizontally. The task was to report the perceived orientation of the visual stimulus. We measured the probability of switching perception during haptic stimulation and during periods of visual-only stimulation of comparable duration. When the orientation of the haptic stimulus was orthogonal to the dominant visual percept, perception switched towards the haptic orientation; the probability of a switch was significantly higher than during visual-only stimulation. Similarly, when the haptic orientation was parallel to the dominant visual percept, maintenance of that percept was significantly more probable. We repeated the experiment varying the spatial frequency of the visual (1.3 and 3 cycles/cm) and the haptic stimuli (1.3, 2, 3 and 4 cycles/cm) and we showed that the effect is spatial-frequency tuned, occurring only when visuo-haptic spatial frequencies coincided. Our results indicate that a visual stimulus, rendered invisible by binocular rivalry suppression, can nonetheless revert to consciousness when boosted by a concomitant haptic signal of congruent orientation and spatial frequency. Given that suppression is thought to occur early in visual analysis, our results suggest that haptic signals modulate early visual processing.

Acknowledgement: Italian Ministry of Universities & EC projects MEMORY and STANIB

22.12, *11:15 am*

The common 2-3Hz limit of binding synchronous signals across different sensory attributes reveals a slow universal temporal binding process

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The human brain processes different aspects of the surrounding environment through multiple sensory modalities (e.g., vision, audition, touch), and each modality can be subdivided into multiple attribute-specific channels (e.g., color, motion, form). When the brain re-binds sensory signals across different channels, temporal coincidence, along with spatial coincidence, provides a critical binding clue. It however remains unknown whether neural mechanisms for binding synchronous attributes are specific to each attribute combination, or universal and central. In a series of human psychophysical experiments, we examined how combinations of visual, auditory, and tactile attributes affect the temporal binding of attribute-value combinations. Observers discriminated the phase relationship of the two repetitive sequences. Each sequence was an alternation of two attribute values (e.g., red/green, high/low pitches, left/right finger vibrations). The alternation was always synchronized between the two sequences, but the paring of attribute values was changed between the two phase conditions (in-phase or 180-deg out-of-phase). We measured the upper temporal-frequency limit to perform this binding discrimination task. The results indicated that the temporal limits of cross-attribute binding were relatively low in comparison with those of within-attribute binding. Furthermore, they were surprisingly similar (2-3 Hz) for any combination of visual, auditory and tactile attributes. The cross-attribute binding limits remained low and invariant even when we increased the stimulus intensity or adjusted the relative timing of the two sequences. They are unlikely to reflect the limits for judging synchrony, since the temporal limits of a comparable cross-attribute synchrony task (Fujisaki & Nishida, 2005; 2009) were higher and more variable with the modality combination (4-9 Hz). These findings suggest that cross-attribute temporal binding is mediated by a slow central process universal to any attribute combinations. We conjecture that 'what' and 'when' properties of a single event are once separately processed, and then combined in this slow central universal process.

22.13, *11:30 am*

Dynamic Grapheme-Color Synesthesia

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In grapheme-color synesthesia, observers perceive colors that are associated with letters and numbers. We tested the dynamic properties of this phenomenon by exposing two synesthetes to characters that rotate smoothly, that morph into other characters, that disappear abruptly, or that have colors either consistent or inconsistent with the corresponding synesthetic color. First we tested our observers for color identifications on all letters of the alphabet, numbers up to 12, and roman numerals. Two tests more than 48 hours apart were in 100% agreement, showing that our subjects were true synesthetes. Peripheral crowding eliminated synesthetic color,

Saturday AM

so our synesthetes were both associators, not projectors. Rotating letters at 36deg/sec changed their synesthetic colors abruptly as letter identification changed or failed. Rotated characters, in a constant-width sans-serif font, were N, M, T, A, H, S, K and X, and the number 9. These characters were chosen to have varying symmetries and varying letter transformations under rotation; rotating M, for example, produced a W 180deg and an E at 270deg with the corresponding changes in synesthetic color. Morphing letters also changed color together with a change in letter identification, for example P to R with growth of the diagonal line element. The transformations were E-F, P-R, and I-J. Abrupt disappearance of a colored character on a white background yielded a negative color afterimage, but maintenance of the same synesthetic color. Our synesthetes could maintain both physical and synesthetic color in the same character, without conflict. Neon color spreading in one observer occurred for physical but not synesthetic color, in the enclosed regions of the number 8. These results show close linking of synesthetic color with character identity rather than image properties, in contrast to physical color.

22.14, *11:45 am*

Influence of asynchrony on the perception of visual-haptic compliance

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Compliance of deformable materials is perceived through signals about resistive force and displacement. During visual-haptic interactions, visual and proprioceptive signals about material displacement are combined over time with the force signal. Here we asked whether multisensory compliance perception is affected by the timing of signals by introducing an asynchrony between the participant's movement (sensed proprioceptively) and force information or visual information. Visual-proprioceptive asynchronies are obtained by making participants see a delayed video of their haptic interaction with an object rather than the real interaction. Force-proprioceptive asynchronies are instead obtained by making participants compress a virtual object with their hand and sense the resistive force generated by a force feedback device.

Results indicate that force-proprioceptive asynchronies can significantly alter the perception of object stiffness. Moreover, we find that perceived compliance changes also as a function of the delay of visual information. These effects of asynchrony on perceived compliance would not be present if all force-displacement information would be utilized equally over time, as both delays generate a bias in compliance which is opposite in the compression and release phases of the interaction. To explain these findings we hypothesized instead that information during object compression is weighted more than information obtained during object release and that visual and proprioceptive information about the hand position are used for compliance perception depending on the relative reliability of the estimate obtained. We confirm these hypotheses by showing that sensitivity to compliance is much higher during object compression and that degradation of visual and proprioceptive information can modify the weights assigned to the two sources. Moreover, by analyzing participants' movements and feedback forces we show that the two hypothesized factors (compression-release and visual-proprioceptive reliability) can account for the change in perceived compliance due to force-proprioceptive and force-displacement asynchronies.

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22.15, *12:00 pm*

Visual perception of motion produced solely by kinesthesia

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We all experience repeated, reliable pairings of self-generated movements that result in visual sensations. Simply wave your hand in front of your open eyes and you will invariably perceive visual motion. Given this consistent pairing of kinesthetic and visual sensations, is it possible that experiencing only one of the paired sensations could give rise to the other? We tested this possibility in three groups of blindfolded volunteers. People in Group A slowly waved their own hand in front of their face, those in Group B waved a cutout of a hand in front of their face, and Group C had the experimenter wave his hand in front of participants' blindfold. Participants rated resulting visual experience on a six-point scale ranging from "no visual experience" to "I perceive an outline of a moving hand." Importantly, participants were given two successive test trials, and deceptive instructions explicitly led them to expect no visual sensation on one of the two trials. This created a bias against our proposed hypothesis. Nevertheless, people in Group A reported substantially higher visual ratings than those in Group C (main effect of group: $F(2, 85)=5.72$, $p=0.005$; planned t-test: $t(55)=3.37$, $p=0.001$). Ratings from Group B were between those from Groups A and C. Importantly, Group A participants who reported perceiving visual motion did so on both trials ($t(27)=0.76$, $p=0.46$) despite expecting no visual sensation on one of the trials. Preliminary data suggest that this illusory visual motion perception may be stronger when a dominant hand is used.

In conclusion, we show that self-generated movements are sufficient to yield visual sensations when executed in a way that typically results in the reliable pairing of vision and kinesthesia. We are currently exploring whether illusory visual motion is stronger in expert musicians, who have had years of training on intricate hand motions.

22.16, *12:15 pm*

Efficient visual search from synchronized auditory signals requires transient audiovisual events

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A prevailing view is that audiovisual integration requires temporally coincident signals. Here we demonstrate that audiovisual temporal coincidence alone (i.e., synchrony) does not necessarily lead to audiovisual binding. In visual search experiments, subjects found a modulating visual target vastly more efficiently when it was paired with a synchronous auditory signal. By manipulating the shape of temporal modulation (sine-wave vs. square-wave vs. difference-wave; harmonic sine-wave synthesis; gradient of onset/offset ramps) we show that abrupt audiovisual events are required for this search efficiency to occur, and that sinusoidal audiovisual modulations do not support efficient search. Thus, temporal alignment will only lead to audiovisual integration if the changes in the component signals are both synchronized and transient. We propose that transient signals are necessary in synchrony-driven binding to avoid spurious integration when unrelated signals occur close together in time.

Motion: Perception

Saturday, May 8, 11:00 - 12:45 pm
Talk Session, Royal Ballroom 4-5
Moderator: Scott Stevenson

22.21, *11:00 am*

The vestibular frame for visual perception of head rotation.

Albert V. van den Berg[1,2](a.v.vandenberg@uu.nl), David Arnoldussen[2], Jeroen Goossens[2]; [1]Functional Neurobiology, Helmholtz Institute, Utrecht University, The Netherlands, [2]Dept. Biophysics, Donders Institute for Brain Cognition and Behaviour, Centre for Neuroscience, Radboud University Nijmegen Medical Centre

The visual flow provides the brain with important information about the changing orientation of eye, head, and body and the direction of movement. The visual flow related to translation and rotation of the eye is processed in extra-striate areas in combination with an extra-retinal signal like eye-in-head movement. Previously we have shown that the putative human homologue of monkey area MST includes a subregion with BOLD signals that represent the (simulated) rotation of the subject's head. Here we investigate the 3D organisation of this capacity. We simulated forward motion through a 3D cloud of dots along a sinusoidal trajectory. Thus, the gaze line rotated relative to the environment about an axis perpendicular to the plane of the trajectory. As in our previous study we decoupled the retinal rotation (as determined by the gaze rotation) from the simulated head rotation about the same axis, by combining identical gaze rotation with different eye pursuit conditions. We varied the axis of rotation between vertical and various axes in the horizontal plane of the head. Using wide-field (120 deg diameter) presentation of such stimuli to 6 subjects and, recording BOLD signals at 1.0 mm resolution (Siemens 3T), we observed distinct locations within human pMST for the vertical axis and for two horizontal axes aligned with the posterior and anterior canals of the vestibular system. These subregions were characterised by BOLD signals that varied in proportion to the simulated speed of rotation of the head and no modulation by the gaze rotation. The same two areas related to the horizontal vestibular axes were activated by simulated head pitch. These data indicate that the processing of visual flow and eye-in-head movement signals to represent head rotation is arranged in a vestibular frame of reference. We present perceptual evidence to probe this notion further.

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22.22, *11:15 am*

Suppression of retinal image motion due to fixation jitter is directionally biased

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Background: Although relative motion thresholds are just a few seconds of arc for adjacent targets (McKee et al. 1990), the overall image motion due to fixation jitter is typically not perceived. An internal copy of the efferent eye movement commands influence motion perception for larger eye movement, but may not have the precision required to correct for fixation jitter. Alternatively, overall retinal image motion may be sensed by early visual mechanisms and then suppressed in perception (Murakami & Cavanagh 1998). Here we ask whether fixation jitter motion suppression is sensitive to the relative direction of eye and retinal image motion. Methods: We decoupled retinal image motion from eye motion using a modified stabilized image technique. An AOSLO with target stabilization was used for both eye tracking and target presentation. Eye motion was recorded and fed back into target position in real time (~4 ms delay) so that the target moved with the eye (conventional stabilization, gain = 1), with the eye but faster (gain = 2 to 4), opposite the eye (gain = -1 to -4), or in a different direction at various gains. Subjects used a matching procedure to set a conventionally viewed jittering target (flat velocity spectrum) to have the same apparent average excursion as the modified stabilized target. Each appeared in unstabilized square 2-degree frames. Results: Gain and direction had a strong effect on perceived motion of the target. Conventionally stabilized targets faded rapidly, as expected. Higher positive gain motion resulted in greater perceived motion, again as expected. Surprisingly, all motions that were in the opposite direction of eye motion (negative gains) appeared as stationary or only very slightly moving. Conclusions: Suppression of retinal image motion due to fixation eye movements includes information about the current eye motion direction, as well as the stimulus motion direction.

Acknowledgement: Supported by NSF AST-9876783 through the UC Santa Cruz Center for Adaptive Optics

22.23, *11:30 am*

Comparing the static and flicker MAEs with a cancellation technique in adaptation stimuli

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[Purpose] After the exposure to superimposed sinusoidal gratings with different spatial frequencies moving in the opposite directions, the motion aftereffect (MAE) of the high spatial frequency grating was seen with a static test while that of the low spatial frequency was seen with a flicker test. We interpreted the MAEs by assuming the slow and fast motion systems, showing difference in temporal frequency selectivity of MAE durations (Shioiri and Matsumiya, 2009). The purpose of the study is to confirm the assumption using a technique that can estimate contrast sensitivity of the systems with MAE. The technique varied contrast of either of the two superimposed gratings in adaptation to find the condition where no MAE was perceived. With varying temporal frequency of either grating, temporal tuning of each motion system was estimated. [Experiment] The spatial frequencies of the gratings were 0.53 c/deg and 2.1 c/deg. After 5 s of adaptation, the observer judged MAE direction in the stationary or the flicker (4 Hz) stimulus. Dependently on the response, the contrast of one of the gratings changed so that the MAE would be weaker. The contrast with no MAE was obtained with a stair case procedure. This provides the equivalent contrast of the grating to the fixed one of the other. Temporal frequency of the 2.1 c/deg (or 0.53 c/deg) grating was varied between 0.63 and 20 Hz in adaptation when the static (or flicker) test was used to investigate the MAE strength of the slow (or fast) motion system. [Results] The static and flicker MAEs showed different dependency of temporal frequency: the static MAE duration peaked at lower temporal frequency than the flicker MAE as has been shown with the MAE duration measurements. This indicates that the dependency of contrast sensitivity on temporal frequency is different between the two motion systems.

Acknowledgement: KAKENHI(B) 18330153

22.24, *11:45 am*

The neural correlates of motion streaks: an fMRI study

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Aim: Due to temporal integration in the visual system, a fast-moving object can generate a static, oriented trace (a ‘motion streak’). These are generally not seen, but might be used to judge direction of motion more accurately (Geisler, 1999). Psychophysics and single-unit studies support this hypothesis, but no physiological evidence from the human brain has yet been provided. Here we use functional magnetic resonance imaging combined with standard univariate as well as multivariate pattern classification techniques to investigate the neural correlates of motion streaks. Method: Observers viewed fast (‘streaky’) or slow-moving dot fields, moving at either 45 or 135 degrees, or static, oriented patterns (filtered noise) at the same orientations, while performing a fixation task in the scanner (3T, high-res sequence, 1.5 x 1.5 x 1.5mm, 32 slices, TR= 3.2s). 10 sessions, each with 6 blocks per session (randomized block design) gave 10 blocks for each stimulus type. Results: Initial univariate group analysis in SPM5 showed greater activation in early cortical areas (V1, V2 and V3) when comparing fast to slow motion, but no increased activation in V5/MT+; the pattern of activity was similar to that seen when comparing static, oriented conditions to fixation rest. A multivariate pattern classifier trained on brain activity evoked by static, oriented patterns could successfully generalize to decoding brain activity evoked by fast but not slow motion sessions. These results suggest that static, oriented “streak” information is indeed present in human early visual cortex when viewing fast motion.

Acknowledgement: Australian Federation of University Women University of Sydney Wellcome Trust

22.25, *12:00 pm*

Perception of motion from the combination of temporal luminance ramping and spatial luminance gradients

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It has been shown previously that illusory motion is seen when local temporal ramp after-effects are viewed slightly out of register with a static display of light or dark regions (Anstis, 1990, Perception, 19, 301-306). In the research presented here we investigated the apparent motion produced by after-effects such as these. In a first experiment observers adapted to a radial pattern of ramping lightening or darkening regions, which were replaced by static luminance gradients. The combination of temporally ramping luminance after-effects and physically present luminance gradients induced clear rotational motion. The speed of this rotation was measured in a binary choice task. The speed of rotation was very regularly related to the magnitude of the luminance gradient, shallower gradients resulted in faster rates of rotation, but the ramping rate during adaptation had no effect on the speed of perceived rotation. In a second experiment we adapted observers to a radially interleaved spatially separated pattern of static spatial luminance gradients and temporal luminance ramps. After adaptation we presented observers with a static uniformly mid-grey circle. Although this test pattern contained no physical luminance change, either spatially or temporally, observers perceived radial expanding or contracting motion, which was dependant on the direction of the temporal luminance ramping during adaptation. This suggests that temporal ramp after-effects and spatial gradient after-effects were spatially integrated to produce illusory motion. Overall our results point to a precise integration of temporal luminance ramping and spatial luminance gradients in the computation of image motion, whether these are physically present or in the form of perceptual after-effects.

Acknowledgement: BBSRC

22.26, *12:15 pm*

Position-variant perception of a novel ambiguous motion field

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Observers can extract the translational motion of Gabor arrays (static Gaussian-windowed drifting sine gratings) when the velocities of the individual Gabors are consistent with a global solution (Amano et al., 2009; doi:10.1167/9.3.4). The ambiguity in the motion of the Gabors (aperture problem) is overcome by pooling over space and orientation. We have shown that observers can perform a similar disambiguation for rotating and expanding stimuli where a large-field pooling algorithm for computing global translation would be uninformative (Rider and Johnston, 2008, ECVP). Models of global complex motion encoding typically involve three stages: local motion extraction, pooling to provide unambiguous 2D estimates of local motion and a third stage that uses these estimates to calculate the global complex motion percept. We developed a novel stimulus that is theoretically ambiguous at all three stages. The orientations of an array of Gabors are chosen to be orthogonal to their position vector relative to the centre of the array and hence form concentric ring patterns. The drift speeds are then set to be consistent with a rigid translation, but this means the arrays are also consistent with an infinite number of rotations. Subjects were shown these arrays in a number of positions in the visual field and adjusted the motion of a surrounding array of plaid patches to match the perceived motion of the Gabor array. We found that the stimuli were perceived as translating, rotating clockwise or rotating anticlockwise depending on their position in the visual field, although conventional models predict translation only. We propose an explanation in which local 1D motion estimates are used directly in computing the global rotation without being locally disambiguated. This implies a novel mechanism for the aperture problem solution that uses global rotation templates.

Acknowledgement: Supported by the EPSRC and BBSRC.

22.27, *12:30 pm*

Perceptual grouping of ambiguous motion

Stuart Anstis[1](sanstis@ucsd.edu); [1]Dept of Psychology, UC San Diego

Introduction. What are the rules of common fate? How are spots that move in different directions grouped perceptually? Method. A pair of spots, separated by 2°, rotate about their common centre at 1 rps. Four such pairs spin in synchrony at the corners of an imaginary square of side 8°. Results. On first viewing, observers report four spinning pairs (Local motion), but after 5—20s the percept suddenly changes to two overlapping 8° squares circling around (Global motion). Thereafter, global motion tends to predominate. Factors that increase local motion include: Gazing straight at a spinner. Proximity – putting the two spots in a spinner closer together. Orientation – replacing the spots within a spinner by two radial or tangential dashes (as if painted on an invisible disk). Luminance – making each spot-pair a different grey. Increasing the number of spots in each spinner from 2 up to 3 or 4. Factors that increase global motion include: Viewing spinners in peripheral vision. Moving the two spots in a spinner further apart. Orientation – replacing the spots with two floating lines that remain horizontal (or vertical) as they spin. Luminance polarity – on a grey surround, four spots defining an 8° square (one spot from each pair) are black, the remaining spots are white. Increasing the number of spinners from 4 to 8. Conclusions. It is a more parsimonious perceptual hypothesis to group the data from the motion array into only two objects (squares) moving globally, rather than into four objects (spinners) moving locally.

Acknowledgement: UCSD Senate

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Saturday Morning Posters

Spatial vision: Image statistics and texture

Royal Ballroom 6-8, Boards 301–312

Saturday, May 8, 8:30 - 12:30 pm

23.301 The Role of Higher-Order Statistics in Naturalistic Texture Segmentation: Modelling Psychophysical Data

Elizabeth Arsenault[1](elizabeth.arsenault@mail.mcgill.ca), Curtis Baker[1]; [1]McGill Vision Research

Some texture boundaries are easier to segment than others, and characterizing these discrepancies is an important step in understanding the neural mechanisms of texture segmentation. Previously we demonstrated (Baker et al., VSS 2008) that contrast boundary segmentation thresholds in natural textures decrease when the higher-order statistics are removed by phase scrambling. We also demonstrated (Arsenault et al., VSS 2009) that naturalistic synthetic textures are subject to this phase-scrambling effect, and were able to determine that some higher-order statistics are more important than others. Here we sought to examine the extent to which a standard two-stage (filter-rectify-filter) model can account for the observed psychophysical data. Stimuli were naturalistic textures extracted from high-resolution monochrome photographs of natural scenes. Mean luminance and RMS contrast were fixed. A half-disc contrast modulation was applied to each texture to create a left- or right-oblique boundary. The first stage of the model consisted of a bank of Gabor spatial filters in a range of orientations and spatial frequencies. Each texture was convolved with this filter bank, subjected to a power-law nonlinearity, pooled, and passed through left- and right-oblique second-stage filters. The model simulated trial-by-trial results by making a 2AFC decision on the boundary orientation based on the second stage filter response magnitudes with additive noise. As in the psychophysical experiment, modulation-depth thresholds were obtained for two conditions: phase-scrambled and intact. The model is capable of producing results qualitatively similar to those measured in human observers: phase scrambling improves segmentation thresholds. This improvement can occur over a range of noise levels, power-law exponents (both compressive and expansive) and model architectures (both early and late pooling). These results suggest that a two-stage model, like human observers, can be sensitive to higher-order image statistics.

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23.302 Distance dependent contextual interactions in natural images

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Long-range horizontal connections in V1 (Bosking et.al. 1997) are thought to mediate the facilitating effects of aligned contour elements in the extra-classical surrounds of V1 cells, and to contribute to contour integration at the perceptual level (Kapadia et.al. 1995). To better understand the nature of these nonlinear classical-extraclassical modulation effects, we have analyzed the statistics of object contours in natural images (from the Corel database) labeled by human subjects. We gathered joint statistics of multiple Gabor-like oriented edge detectors at varying spatial separations in natural images both on and off contours, and characterized the changes in the contour probability function P(contour | edge cues) as we varied the spatial separation and arrangement of the edge cues. We observed clear differences in the form of the contour probability function when the contributory edge elements were closely spaced within the classical receptive field, which led to symmetric AND-like interactions between edge cues, compared to the more asymmetric “contextual” interactions seen between flanker and central cues at greater spatial separations.

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23.303 Natural scenes statistics and visual saliency

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Visual saliency is the perceptual quality that makes some items in visual scenes stand out from their immediate contexts. Visual saliency plays important roles in natural vision in that saliency can direct eye movement, deploy attention, and facilitate object detection and scene understanding.

Natural visual scenes consist of objects of various physical properties that are arranged in three dimensional space in a variety of ways. When projected onto the retina, visual scenes entail highly structured statistics, occurring over the full range natural variation in the world. Thus, a given visual feature could appear in many different ways and in a variety of contexts in natural scenes. Dealing effectively with these enormous variations in visual feature and their contexts is a paramount requirement for routinely successful behaviors. Thus, for visual saliency to have any biological utility for natural vision, it has to tie to the statistics of natural variations of visual features and the statistics of co-occurrences of natural contexts. Therefore, we propose to explore and test a novel, broad hypothesis that visual saliency is based on efficient neural representations of the probability distributions (PDs) of visual variables in specific contexts in natural scenes, referred to as context-mediated PDs in natural scenes.

We first develop efficient representations of context-mediated PDs of a range of basic visual variables in natural scenes. We derive these PDs from the Netherland database of natural scenes and the McGill dataset of natural color images using independent component analysis. We then derive a measure of visual saliency based on context-mediated PDs in natural scenes. Experimental results show that visual saliency derived in this way predicts a wide range of perceptual observations related to texture perception, pop-out, saliency-based attention, and visual search in natural scenes.

23.304 Classification Images for Search in Natural Images

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Purpose: Previous studies have proposed estimation procedures for classification images in white and correlated noise (Abbey & Eckstein 2006). Here, we investigate methods to estimate classification images (linear template) for search of targets embedded in natural images. Methods: Observers searched for an additive Gaussian luminance target in one of four locations (4 alternative forced choice) within 3000 calibrated natural scenes (van Hateren & van der Schaaf, 1998). We compute classification images using various methods including genetic algorithms (GA; Castella et al., 2007), support vector machines (SVM; Jakel et al., 2009) and weighted averaging of prewhitened noise fields (Abbey & Eckstein, 2002). All methods relied on a limited set of Gabor basis functions. We compare human classification images to optimal linear templates also estimated using GA and SVM. Results: GA and SVM methods result in similar estimates of the optimal linear templates. Average observer performance was higher than the estimated human classification images and optimal linear templates. For all three observers, the estimated linear templates were similar to the target but contain inhibitory surroundings. Conclusions: We extend previous classification image methods to search for a target embedded in natural scenes and explore computational procedures for reliable estimation. The presence of inhibitory surrounds in human classification images reflects a strategy to optimize detection of targets in natural scenes. The superior human performance relative to the optimal linear template suggests that humans are able to use additional higher-order information to detect targets in natural scenes.

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23.305 Implementing a maximum-entropy parameterization of texture space

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Visual textures are an important tool for studying many aspects of perception, including local feature extraction, segmentation, and perception of surface properties. Visual textures are defined by their statistics. Image statistics include the luminance histogram, the power spectrum, and higher-order analogs, and thus, constitute a very large number of parameters. This richness enables construction of visual stimuli that can be used to discriminate among candidate models. However, it also presents a challenge, because image statistics are not only high-dimensional, but also, have complex algebraic interrelationships. To approach this problem, we use maximum-entropy extension. The basic idea is that a texture can be defined by specifying only a small number of image statistics explicitly. The unspecified statistics are then determined implicitly, by creating textures that are as random as possible, but still satisfy the constraints of the explicitly-specified statistics (Zhu et al., 1998). We implement this idea for binary homogeneous textures, focusing on local image statistics. 10 parameters are required to determine the probabilities of the 16 possible 2x2 blocks. Via maximum-entropy extension, these parameters comprehensively describe all homogeneous binary textures with purely local structure, along with the long-range structure that the local organization necessarily implies. We develop algorithms to generate texture examples in all 45 coordinate planes of the space. In most planes, an iterative "glider" rule suffices, but in some, a novel Metropolis (1953) algorithm is required. We show how the Metropolis algorithm can be used to project naturalistic textures into the texture space, thus extracting their local structure. Perceptually, each plane of this space is characterized by salient and distinctive visual structure. We present isodiscrimination contours in several of these planes. While ideal-observer contours are circular, human isodiscrimination contours are strongly elliptical, and may be tilted with respect to the coordinate axes.

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23.306 Frequency content of the retinal stimulus during active fixation

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Under natural viewing conditions, the retinal input depends not only on the external scene but also on the observer's behavior. During fixation, the luminance modulations caused by small, involuntary eye movements profoundly influence the spatiotemporal stimulus on the retina. In this study, we examined the frequency content of the retinal stimulus during the normal instability of visual fixation. Eye movements were recorded while subjects freely viewed grayscale natural images. On the basis of the recorded traces we reconstructed the spatiotemporal retinal input experienced by the observers, i.e. the movie resulting from scanning the image according to subjects' eye movements. We then selected periods of fixation and estimated the power spectrum of such input. The results of this analysis show that, outside of the zero temporal frequency plane, the spatiotemporal spectrum of the retinal stimulus during fixational instability is space-time separable. That is, the spatial distribution of power was similarly organized on every nonzero temporal frequency plane, while the total amount of power at any given temporal frequency was entirely determined by the power spectrum of eye movements. The luminance modulations caused by fixational instability had the effect of flattening the 1/f2 power spectrum of natural images. That is, at every nonzero temporal frequency, the amount of power present at different spatial frequencies was approximately constant. This effect occurred only when viewing images with a scale-invariant power spectrum, like natural images, and was lost when the trajectories of eye movements were artificially enlarged. It is often argued that the shapes of neuronal receptive fields in the early visual system act to reduce the redundancy of input signals. Our results show that, during normal fixation on natural stimuli, the visual input which drives neurons sensitive to temporal modulations is already decorrelated in space.

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23.307 Sampling Efficiencies for Spatial Regularity

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Observers performed a 2AFC (temporal) discrimination in which they had to decide which of two arrays of dots had the greater amount of spatial regularity in their spacing. The 11 dots in each array were arranged on a notional circle of radius R, centred on the fixation point. The actual eccentricity of each dot in the array was sampled independently from a uniform distribution over the interval [R-P-C(x), R+P+C(x)], where P was a pedestal common to both arrays, C(ref) was zero for the "reference" array, and C(test) was determined on each trial by a QUEST staircase designed to converge on the 84% correct discrimination point. Two-dimensional perturbations of dot positions on an a 11 x 11 rectangular grid were also investigated. As in a previously reported study of orientation variance [Morgan et al, 2008], data formed a 'dipper' function, having a minimum (best discrimination) at a non-zero pedestal value, and were well fit by a two-parameter model, in which one parameter represents the intrinsic (in this case, positional) noise, and the other parameter represents sampling efficiency. The latter varied between 4/11 and 6/11 in different observers and conditions. Sampling efficiencies of less than 4/11 could be ruled-out with high confidence. Sampling efficiencies were lower for the rectangular arrays ~ (8/121), suggesting a limit on the absolute number of samples. Adding a second source of variance, by randomising the contrast polarity of the dots, which the observer was instructed to ignore, made performance worse by increasing intrinisic noise, with little if any effect on sampling efficiency. The same was true of adding irrelevant tangential perturbations in dot position. We conclude that there is some degree of obligatory confusion between different sources of variance, as in previous studies of colour camouflage [Morgan et al, 1992].

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23.308 Noise reveals what gets averaged in "size averaging"

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Observers are adept at estimating texture statistics such as mean element-orientation, a process that can be modeled using population coding of responses from orientation-selective neurons in V1. Here we consider how observers average the size of objects, given that (a) the neural substrate for object-size is less clear, and (b) limitations of previous paradigms used to explore size-averaging have sparked debate as to whether observers can average size at all.

We used a noise paradigm: observers reported which of two sets of 16 Gabor elements had the greater mean element-size in the presence of different levels of element-size variability. We randomized the spacing of the Gabors (thus minimizing any cue from element-"coverage") and both the contrast and orientation of elements (minimizing any cue from global statistics). In the first condition (scale averaging) the envelope-size and carrier spatial frequency (SF) of elements co-varied, so that all elements were scaled/rotated versions of one another. Under these conditions observers averaged ~50% of the elements, effectively estimating the scale of each with a precision (σ) of ~25%. This unequivocally indicates that observers can average element-scale. Fixing carrier spatial frequency (SF) forces observers to use envelopes (size averaging) and produced near-identical performance. Fixing envelope size forces subjects to use carrier-SF (SF-averaging) and produced moderately poorer performance. Thus observers must, at least in part, be using envelope size when scale-averaging. Critically, adding independent noise to the SF and the envelopes of elements substantially increases the number of elements that are averaged, indicating that observers can exploit independent statistical properties of both the envelope-size and SF of elements to make perceptual discriminations. We consider it likely that cues from feature (e.g. edge) density drive both these and a range of related tasks (e.g. judgment of number and density).

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23.309 Dimensions of preattentive visual sensitivity in human color space

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This study used texture discrimination tasks to investigate preattentive visual sensitivity to equiluminant chromatic variations. Specifically, we looked for evidence of "half-cardinal-axis" mechanisms in DKL space - i.e., mechanisms sensitive exclusively to variations between neutral gray and each of the red and green poles of the L-M axis and the blue and yellow poles of the S-(L+M) axis. Observers strove to discriminate spatially random mixtures of colors called scrambles. A given scramble is characterized by its color histogram. The preattentive sensitivity space of a set C of colors is the space of histogram differences people can discriminate given a brief display. The dimensionality of this space gives the number of preattentive mechanisms sensitive to C variations. In these experiments, briefly presented stimuli comprised alternating bars of scramble differing in histogram, and observers had to judge bar pattern orientation. We used a new method called "iterated seed-expansion" to obtain a basis of the sensitivity space for each of 6 different sets of colors: a set drawn from each of the half-DKL-cardinal-axes in the equiluminant plane and also from each of the full L-M and S-(L+M) cardinal axes. For each of these sets C, the sensitivity space proved to be two-dimensional, with one basis element showing linear and the other parabolic sensitivity for the colors in C. This suggests that associated with each full-cardinal-axis is one linear mechanism L and one second-order mechanism S derived from the L output. Our results support the idea that for any element x in the scramble, S(x) is proportional to the squared difference between L(x) and the mean L-output in the neighborhood of x. These same two mechanisms suffice to account for discrimination of half-axis scrambles; thus, we find no evidence for separate half-axis mechanisms.

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23.310 **Lateral Occipital cortex responsive to correlation structure of natural images**

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The distribution of features around any location in natural images adheres to the Weibull distribution (Geusebroek & Smeulders, 2005), which is a family of distribution deforming from normal to a power-law distribution with 2 free parameters, beta and gamma. The gamma parameter from the Weibull distribution indicates whether the data has a more power-low or more normal distribution. We recently showed that the brain is capable of estimating the beta and gamma value of a scene by summarizing the X and Y cell populations of the LGN (Scholte et al., 2009) and that this explains 85% of the variance in the early ERP. Here we investigate to what degree the brain is sensitive to differences in the global correlation (gamma) of a scene by presenting subjects with a wide range of natural images while measuring BOLD-MRI.

Covariance analysis of the single-trial BOLD-MRI data with the gamma parameter showed that only the lateral occipital cortex (LO), and no other areas, responds stronger to low gamma values (corresponding to images with a power-law distribution) than high gamma values (corresponding to images with a normal distribution). The analysis of the covariance matrix of the voxel-pattern cross-correlated single-trial data further revealed that responses to images containing clear objects are more similar in their spatial structure than images that do not contain objects. This data is consisted with a wide range of literature over object perception and area LO (Grill-Spector et al., 2001) and extend our understanding of object recognition by showing that the global correlation structure of a scene is (part of) the diagnostics that are used by the brain to detect objects.

23.311 **Adaptation effects that gain strength over 8 hour induction periods**

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Depriving adult subjects of visual stimulation at a narrow range of orientations increases sensitivity to the deprived orientation. Here we measured the growth of this effect as a function of adaptation duration. Subjects were deprived of vertical energy for 1, 4, or 8 hours, viewing the world through an "altered reality" system. The system was comprised of a head mounted video camera that fed into an image-processing laptop computer that in turn drove a head-mounted display (HMD). Vertical energy was removed from the video in real time using a simple mask in the Fourier domain. Viewing the filtered video, subjects were able to interact with the world while being deprived of vertical visual input. Prior to and following deprivation, we measured perceived orientation of sinusoidal gratings, using a version of the tilt aftereffect. Subjects viewed a plaid made from two 45 deg gratings, which perceptually resembled a blurred square checkerboard. When the grating components were symmetrically tilted away from 45 degrees, the checks appeared rectangular. Subjects adjusted the tilt of the components from a random initial angle until the checks appeared square, which revealed the physical orientations that appeared to be 45 deg. Subjects adapted to deprivation: Following deprivation, they set the components tilted away from 45 degrees towards horizontal, indicating that they perceived 45 degree gratings tilted towards vertical. Eight hours of adaptation produced reliably larger and longer-lasting effects than four or one hours. The shift in apparent orientation towards vertical suggests that deprivation increased the gain of neurons selective to the deprived orientation. The fact that this effect continues to strengthen over eight hours suggests that relatively low level mechanisms of adaptation can operate over long time scales, which may allow them to contribute to long-term plasticity in the visual system, such as adaptation to retinal disease.

23.312 **The limited availability of brain resources determines the structure of early visual processing**

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The visual system summarizes complex scenes to extract meaningful features (Barlow, 1959; Marr 1976) by using image primitives (edges, bars), encoded physiologically by specific configuration of receptive fields (Hubel & Wiesel, 1962).

This work follows a pattern-filtering approach, based on the principle of most efficient information coding under real-world physical limitations (Punzi & Del Viva VSS-2006; Del Viva & Punzi VSS-2008). The model, applied to black and white images, predicts from very general principles the structure of visual filters that closely resemble well-known receptive fields, and identifies salient features, such as edges and lines, providing highly compressed "primal sketches" of visual scenes

Here we perform a psychophysical study of the effectiveness of the sketches provided by this pattern-filtering model in allowing human observers to discriminate between pairs of similar natural images. As a control, we compare results with alternative sketches with the same information content, derived from a similar procedure, but not keeping into account the needs for optimal usage of computing resources.

The performance was measured by the task of identifying natural images corresponding to briefly presented sketches (<50 ms.), with a 2AFC procedure.

Our results show that performance obtained with sketches provided by our model is as good as that obtained from fully detailed original images, while the alternative sketches of equivalent information content are much less effective.

These results provide support for the correctness of the model in predicting the salient features that human subjects use to identify visual scenes, supporting the idea that computing power limitations are a crucial factor in determining the way we perceive the world.

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Attention: Eye movements

Royal Ballroom 6-8, Boards 313–327

Saturday, May 8, 8:30 - 12:30 pm

23.313 **There's plenty of time in the bottom: the time spent before a saccade is generated is a complex interplay of competing saliency and decision**

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Saturday AM

Various models were proposed for the interplay between subcortical and cortical mechanisms and bottom-up and top-down mechanisms in driving our saccades rapidly to targets in the environment. One such model is the "linear approach to threshold at ergodic rate" (LATER) model (Carpenter & Williams, 1995). In this work we show evidence based on experimental data for this mechanism being involved in our eye movements. We used eye-tracking data from subjects viewing natural scenes in free and task-dependant viewing (Cerf, Frady, & Koch, 2009) to test bottom-up and top-down based attention allocation to high-level objects. Separating the distributions of saccades according to their latencies† provides mean of identifying different populations types of saccades. We identified 3 sets of population: very early saccades (60ms), which can be looked at as correction saccades to an over/under-shoot of a target, early saccades (~80-100ms), and regular saccades. Using attractive stimuli such as faces and text we were able to test the latency by which these saccades are initiated towards a target, and identify the attention mechanisms which drive us to look at attractive targets at each stage of our viewing. We used the saccadic latencies to estimate the brain regions which are involved in driving our eyes, under each condition†. We quantified the interplay of subcortical and cortical structures in generating rapid, accurate saccades to images. We show a separate, cortical source of bottom-up saliency to objects within a visual scene which disappears within a few fixations, and modification of the decision signal by top-down influences. We propose that these observations reflect a common cortical pathway which represents a utility signal which modulates the process of saccadic decision. In addition we propose a parallel subcortical pathway capable of generating rapid, accurate saccades to salient targets under the control of cortical structures.

† See attached PDF for illustration

Acknowledgement: Mathers foundation, DARPA

23.314 **Modulation of saccade latencies by hand action coding**

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Previous studies indicated that saccade latencies are affected by the spatial compatibility between the target position on the screen and the position of a static hand. Further, the modulation of saccade latencies depended on the delay between fixation point offset and target onset. With a 0-ms delay, saccades were slower toward a target close than opposite to the hand location (eye-hand proximity interference), while the opposite pattern was found for a 1000-ms delay (eye-hand proximity facilitation). Time-consuming competition for attentional processes between eye and hand were evoked to account for these results. In the present study, we opposed a code occupation hypothesis (COH) to this attentional explanation. According to COH, once a code is bound to a current action, all other access to this code will be temporarily delayed. We varied the target location with respect to the hand. The hand was laid at a fixed location on the left or right and the target was presented at different eccentricities to the left or right of the screen center. The results indicated that the saccadic modulation did not depend on the spatial proximity between the hand and the target. Rather, similar eye-hand interference (0-ms delay) and facilitation (1000-ms) were found for all targets sharing the same hemi-space as the hand. In agreement with the code occupation hypothesis, the saccadic modulation in the presence of a static hand depended on whether the saccade shared or not the hand-related action code.

23.315 **Attention during pauses between successive saccades: Task interference vs. modulation of contrast-gain**

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Perceptual performance is better at the target of a saccade than other locations (e.g., Gersch et al., 2009). To better understand pre-saccadic attention shifts, we studied perceptual discrimination across different stimulus contrasts during pauses between successive saccades.

Displays contained 4 outline squares (1.4° on a side) located at the corners of an imaginary square. Sequences of saccades were made in a V-shaped path from one corner square, to center, to another corner square. When the eye reached the center, perceptual targets (oriented letter T's) appeared inside each eccentric square. The orientation of a randomly-selected T was reported after scanning was completed. Orientation discrimination was poor (<75% correct) at all test locations other than the saccadic goal, even at the highest contrast. These performance losses could be due to selective decay of visual memory (Gersch et al., 2008).

Selective memory was not the only factor, however, because results were similar in a second experiment in which a single perceptual target (right or left tilted Gabor; +/- 22.5o) was presented in each trial. Durations of pauses between saccades were prolonged when the Gabor was detected at a location other than the saccadic goal, reflecting an attempt to improve perceptual discrimination by delaying the saccade. This strategy succeeded when perceptual reports were required on most (80%) of the trials. When reports were required in only 20% of trials, performance at non-goal locations fell across the contrast range, reaching an asymptotic level of only 85% correct at 60% contrast.

These results extend findings that pre-saccadic attention is selectively allocated to the target of a saccade. The new findings show that non-goal locations suffer by more than a simple reduction in effective contrast gain. Instead, pre-saccadic modulation of attention reflects the interference between the effective stimuli for the saccadic and perceptual tasks.

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23.316 **Evidence for the predictive remapping of visual attention**

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When attending an object in visual space, the perception of the object remains stable despite frequent eye movements. It is assumed that visual stability is due to the process of remapping, in which retinotopically organized maps are updated to compensate for the retinal shifts caused by eye movements. Remapping is predictive when it starts before the actual saccade. Until now, most evidence for predictive remapping has been obtained in single cell studies involving monkeys. In the present study, human observers made a saccade to a location in space. Just before executing the saccade, a brief irrelevant onset was presented somewhere in the visual field to summon exogenous attention. After executing the saccade, a probe stimulus (a titled line-segment) appeared at one of four locations (spatiotopic, retinotopic and two control locations). Participants made a speeded keypress response to indicate the orientation of the probe. We show that immediately following a saccade, attention has partly shifted with the saccade. Importantly, we show that remapping is predictive and affects the locus of attention prior to saccade execution: before the saccade was executed, there was attentional facilitation at the location which, after the saccade, would retinotopically match the attended location. Subsequent experiments show that it did not matter whether spatiotopic and retinotopic locations were presented in the same or in different quadrants of the visual field and whether manual or saccadic responses were made towards the probe. We conclude that exogenous visual attention is only partly remapped. Immediately following a saccade, attention is allocated at two locations: the original locus of attention and the location which retinotopically matches the original locus of attention. Importantly, we also show that remapping is predictive causing the locus of attention to shift in the direction of the saccade prior to its execution.

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23.317 **Temporal dynamics of remapping captured by peri-saccadic motion trace**

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Whenever an eye movement is made, several visual areas (e.g., LIP, FEF, CS) help maintain visual stability by shifting the activation for currently attended targets to the locations these targets will have after a saccade. The temporal dynamics of this anticipatory activation, known as remapping, can be visualized with a continuous motion stimulus that begins before and ends after the saccade. We asked participants to make horizontal saccades following the fixation point as it jumped 15 deg to the left or to the right. A red square moved vertically at 50 deg/sec covering 25 deg midway between the first and second fixation point locations. The motion began 50 msec before the fixation point shifted and about 200 msec before the saccade onset. Even though the motion of the red square was vertical, participants reported that it appeared separated in two pieces, with the second part being displaced in the direction of the saccade. Using this procedure, we first evaluate the amount of displacement of the second part of the motion

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trace compared to the first part. Then we used this amount to null the effect and find the moment at which this error of remapping occurred. The magnitude of the trace offset around the time of the saccade was about 15-20% of the saccade amplitude, and this offset appeared in a temporal window about 30 msec to 70 msec after the saccade onset. The displacement of the pre-saccadic relative to post-saccadic motion trace suggests that the remapping overcompensates for the saccade vector. Moreover, the visibility of the pre-saccadic trace after the saccade is a novel demonstration of spatiotopic visual persistence; visual because monitor persistence would not show a break between the pre- and post-saccadic portions of the trace.

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23.318 **Spatial localization during fixation does not depend on an extraretinal drift signal**

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We are normally unaware of the eye movements which, during visual fixation, keep the retinal image continually in motion. How does the visual system disregard the retinal motion caused by these movements to achieve visual stability? According to extraretinal theories, stability is attained by means of motor/proprioceptive signals; according to retinal theories, eye motion is, instead, inferred directly from the spatiotemporal stimulus on the retina. In this study, we focus on the retinal motion caused by ocular drift. We have previously shown that motion detection does not rely on possible extraretinal drift signals. Here, we investigated whether this is true also for spatial localization. In a 2AFC experiment, subjects reported which one of two dots briefly displayed at distinct times during ocular drift was at the same spatial location of a reference presented at the beginning of each trial. One of the two dots was displayed at the same spatial (monitor) position of the reference, whereas the other was at the same retinal position. Stimuli were displayed in complete darkness. If an extraretinal signal is used, subjects should be able to correctly identify the dot at the same monitor position of the reference. Moreover, discrimination performance should increase with the extent of drift, as the extraretinal signal would also increase. Subjects systematically reported that the dot at the same retinal position of the reference was the one at the same spatial location. Furthermore, the probability of this error increased, rather than decreased, with the size of ocular drift. These results strongly support the predictions of retinal theories. Like motion detection, also spatial localization does not depend on an extraretinal drift signal, but relies instead on the spatiotemporal image on the retina to discard the retinal motion caused by ocular drift.

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23.319 **Differential involvement of the oculomotor system in covert visual search and covert endogenous cueing**

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The relationship of spatial attention to eye movements has been controversial. Some theories propose a close relationship, while others view these systems as completely independent. In a recent study using a cueing task we proposed that this controversy can be resolved by distinguishing between the maintenance and shifting components of attention (Belopolsky & Theeuwes, 2009; Psy Science). Specifically, we proposed that shifting covert attention is always associated with preparation of saccade, while maintaining attention at a location can be dissociated from saccade preparation. The current study tests the boundary conditions of this proposal. Experiment 1 used a visual search task in which repeated serial shifts of attention were required in order to find the target. The identity of the target indicated whether an eye movement towards the target or a non-target location had to be made. The results indicated that saccades were initiated faster towards the location where covert attention was shifted. Experiment 2 used endogenous cueing manipulating the SOA between the cue and the appearance of the target. The results showed suppression of saccade in the direction of the covert attention shift even at the shortest SOA. The findings suggest that shifts of attention during covert visual search are associated with activation of an oculomotor program, while shifts of attention during covert endogenous cueing are associated with suppression of an oculomotor program. This suggests that distinction between endogenous and exogenous covert shifts of attention is important when relationship between attention and eye movements is investigated. We propose that only during pure endogenous covert shifts of attention can the oculomotor system be suppressed. In addition and consistent with previous findings (Wolfe, Alvarez & Horowitz, 2000), our results implicate that shifts of attention during covert visual search are not purely endogenous.

Acknowledgement: Netherlands Organization for Scientific Research (NWO)

23.320 **Gaze Patterns and Visual Salience in Change Detection of Natural Scenes**

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Most change blindness studies suggest that attention is necessary to detect a change in a scene. Recent research also suggests that visual attention is guided in part by bottom-up visual salience of the regions in a scene. In this study, we used an image processing algorithm for measuring the visual salience of different regions in a visual scene, and measured participants' ability to detect changes in high and low salience regions of the scenes with a flicker paradigm. The stimuli were 28 digital photographs of natural outdoor scenes. Itti's saliency map algorithm was used to select one high saliency and one low saliency region in each image; color or presence/absence changes were applied to both regions. Participants completed 56 trials; one low and one high salience trial with each image. We also used a Tobii 2150 eye tracking system for measuring eye movement. Preliminary results indicate: 1) Participants detected changes made to high salience regions (M = 6,855 ms) faster than those made to low salience regions (M = 10,397 ms); 2) Participants fixated high visual salience changed regions (first fixation onset M = 2,812 ms) sooner than low visual salience changed regions (M = 4,339 ms); 3) The total time fixating changed regions was similar in the two conditions (Mhigh = 915 ms and Mlow = 1073 ms); and 4) Participants were more likely to require more than one fixation within the region of change to detect the change in the low saliency condition. An analysis of the eye movement data will allow us to further investigate individual differences in scene perception and change detection.

23.321 **Does eye vergence dissociate between covert and overt attention?**

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The neural mechanisms of attention are closely related to oculomotor control of saccadic eye movements and vergence eye movements. Visual covert attention is a mechanism for mentally scanning the visual field to enhance the sensory signal. This shift in covert attention is linked to eye movement circuitry that prepares a saccadic eye movement to a particular location. Overt attention is believed to direct the saccade towards that location. Currently, it is unclear whether and how covert and overt attention influences vergence responses. To test this idea, we used a visual task in which subjects focused on a central fixation spot surrounded by an array of 8 letters. After one second of fixation one of the letters flashed. After additional fixation period an identical or a different letter briefly appeared at the fixation spot. The observer responded by making a saccade towards the flashed letter in the case it was the same as the central letter. Otherwise the observer remained its gaze at the fixation spot. In addition a button press was requested. Our findings show that eye vergence changes during the task. During the initial period, where covert attention was required, eyes converge in a plane further away than the physical depth (screen) plane. During the period a saccade was planned (overt attention) eyes converged back to the depth plane of the screen. From our observation we conclude that eye vergence may serve not only for depth perception but also have a role in covert and overt attention. The findings are interpreted in terms of relaxation during covert attention, perceived depth, and that during covert attention the visual system benefits from a wider view of field.

23.322 **Biasing attentional priority by microstimulation of LIP**

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Saturday AM

People can find objects hidden in a cluttered scene quickly and efficiently. This cannot be done unless there is a prioritizing algorithm, which optimizes the choice of the goal of the next eye movement. It has been suggested that the lateral intraparietal area (LIP) acts as a priority map, which incorporates both bottom-up sensory and top-down cognitive inputs in order to find stimuli similar to the target of the visual search. An eye movement is then made toward the most behaviorally important location in the scene, represented by the highest activity in LIP. In this study, we investigated whether increasing the activity of the LIP priority map can bias saccade goal selection during a visual foraging task.

Two animals were trained to perform a free-viewing visual foraging task in which they searched through 5 potential targets (T) and 5 distractors (+) to find the target that was loaded with reward. To get the reward they had to fixate the target for 500 ms within 8 s. After training, both animals performed the task with a high degree of efficiency by avoiding Ts that had been previously fixated and distractors. On microstimulation trials, a 350 ms burst of 20 µA peak-to-peak biphasic pulses at 200 Hz was injected into LIP 150 ms after the third saccade. We found that on stimulation trials, the animals were more likely to make their next saccade to stimuli that were in the stimulated receptive field than on non-stimulation trials. The strength of this bias was consistent for all visual stimuli, regardless of behavioral relevance. These results demonstrate that the activity of LIP neurons is causally related to a strategy that guides efficient visual search.

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23.323 Attention is predominantly guided by the eye during concurrent eye-hand movements

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Attention is directed to the upcoming goal location of both saccades and reaches . It remains unknown however, how attention is allocated during simultaneous eye and hand movements. We investigated attentional allocation through a 4-alternative forced-choice shape discrimination task (Deubel & Schneider, 1996) while subjects made either a saccade or a reach (or both) when cued by an arrow to one of five peripheral locations. The discrimination shape appeared during the latency period either at the goal (50% of the time) or at one of the other 4 locations. We found that target discrimination was better when the discrimination stimulus appeared at the movement goal than when it appeared elsewhere. Discrimination performance at the movement goal was not better in the combined condition compared to either effector alone, suggesting limited shared attentional resources rather than separate attentional resources specific to each effector. To test which effector dominated in guiding attentional resources, we then separated the goals for the hand and the eye. This was done using two paradigms, 1) cued reach/constant saccade - subjects made a saccade to the same peripheral location throughout the block, while the reach goal was cued by the arrow and 2) cued saccade/constant reach - subjects made a reach to the same location, while the saccade goal was cued. During both eye-hand goal dissociation paradigms, discrimination performance was consistently better at the eye goal than the hand goal. This indicates that limited attentional resources are guided predominantly by the eye during eye and hand movements.

23.324 Sudden hand movements enhance gaze cueing

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Ample evidence supports the idea that social signals, such as eye gaze, influence our voluntary eye movements. However, people move their eyes constantly and most of these eye movements are irrelevant in a social context. It is thus to expect that even stronger shifts in overt attention should be induced by eye movements conveying a potentially relevant action.

We tested this hypothesis with a variation of the gaze cueing paradigm. Participants were required to perform a saccadic eye movement toward a target either to the left or to the right. A colored instruction cue signaled the direction of the saccade. Cueing with varying SOAs was induced either by an averted eye gaze and/or by a small hand gesture corresponding to the initial phase of a pointing movement towards one of the targets. These stimuli were provided either in isolation or in combination with each other. In the latter case, the cued direction could be either matched or unmatched. Participants were informed that the stimuli were spatially uninformative cues. As previously reported, gaze and hand cueing were effective at triggering the saccades in the opposite to the intended direction. A stronger gaze cueing effect was, however, observed when the gaze and hand cue were presented simultaneously. Interestingly, the proportion of saccades following the gaze cue increased irrespective of the hand cue direction.

Relevant actions are usually the product of combined eye and hand movements where the eyes select the target of interest. The mere presence of a sudden hand movement might have been interpreted as a sufficient indication of a forthcoming relevant action that consequently enhanced the saliency of the directional cue provided by the gaze. These findings thus suggest a process that prioritizes potentially relevant actions to which the visual system automatically responds.

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23.325 Attentional bias to brief threat-related stimuli revealed by saccadic eye movements

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According to theories of emotion and attention we are predisposed to orient rapidly towards threat. However, previous examination of attentional cueing by threat signals showed no enhanced capture at brief durations. We propose that the manual response measure employed in previous examinations is not sensitive enough to reveal threat biases at brief stimulus durations. Here, we investigated the time course of orienting attention towards threat-related stimuli in the exogenous cueing task. The type of threat-related stimulus (fearful face or body posture), cue duration (20ms or 100ms) and response mode (saccadic or manual) were systematically varied. In the saccade mode, both enhanced attentional capture and difficulty in disengaging attention from fearful faces and body postures were evident and limited to 20ms cue duration, suggesting that saccadic cueing effects emerge rapidly and appear to be a short lived phenomenon. Conversely, in the manual response mode, fearful faces and bodies impacted only upon the disengagement component of attention at 100ms cue duration, suggesting that manual responses reveal cueing effects which emerge over more extended periods of time. Taken together, the results show that saccades are able to reveal threat biases at brief cue durations consistent with current theories of emotion and attention.

23.326 Evolving illusory motion using eye-movements

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Op artists, such as Bridget Riley, frequently use monochromatic abstract compositions to create works which produce a strong percept of illusory motion in the observer. Previous work has looked at the effects of eye-movements (Zanker, Hermens & Walker, 2008, Perception, 37, ECVP Abstract Supplement: 150) and the image statistics (Zanker, Hermens & Walker, 2008, Perception, 37, ECVP Abstract Supplement: 70) in an attempt to explain and optimise such illusory motion. Preferential looking literature suggests that the eye-movements needed to see this percept are also subject to top-down influences which result in increased fixation time on preferred images. Here, we use a combination of cumulative fixation time and fixation sequence which has been shown to correlate with aesthetic preference (Holmes & Zanker, 2009, Journal of Vision [abstract], 9(8): 26.) to provide the selection pressure for an evolutionary algorithm operating on a chromosome encoding the parameters of stimuli known to produce this percept. By varying the presentation time of the stimuli and tracking the eye-movements of 20 participants in a free-looking paradigm, we show that with increased time to view, participants attention is attracted to those stimuli with a stronger motion percept and that these stimuli are robustly preferred by the participants when retested using a 2AFC experiment 1 week later. The results demonstrate that general aesthetic preferences can be detected using evolutionary algorithms that use oculomotor statistics as fitness information, thus providing a reliable and robust paradigm for use in future studies of subjective decision making and experimental aesthetics.

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See page 3 for Abstract Numbering System

23.327 **Gender Differences in Visual Attention During Listening as Measured By Neuromorphic Saliency: What Women (and Men) Watch**

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Predictive models of eye movements often do not address population differences. Different tasks may play an important role in differentiating eye movements among discrete groups. For example, eye movement behavior is known to vary by gender for an emotion-perception task (Vassallo, 2009). We explore observed differences in eye movements between genders by eye-tracking subjects during a audio-visual listening task, as compared to a free-viewing task.

Thirty-four subjects, balanced by gender, are eye-tracked while watching eighty-five videos of different people who give answers to conversational questions. Videos are filmed outdoors with a natural background of distractors, such as pedestrians and vehicles. After viewing each clip, subjects answer questions about the video to measure any attentional differences. To control for task effects, a separate group of ten control subjects are asked to free view the clips. Interestingly, the main sequence of collected saccades significantly differs across gender (n=33806, peak velocity: $p<1e-15$, amplitude: $p=0.0076$). Saccade sequences are scored by examining the values of the saliency model output of the corresponding video (Itti, 2004) at saccade endpoints. Correlation to saliency is measured by comparing saccade scores to randomly sampled saliency scores with an AUC (area under the curve) metric. Saccades are also scored for their correlation to the component features of saliency (color, orientation, intensity, flicker, and motion) in a similar manner. We also find that correlations to saliency are significantly greater for male viewers over female ($p<1e-143$) and are also significantly greater for female speakers ($p<1e-143$). Furthermore, there is a two-way interaction on saliency correlations between the gender of the viewer and speaker. (2-way ANOVA, df=1,F=15123.48). Gender differences persist across all features, suggesting a broad gender difference in attentional allocation during listening. We also investigate the interplay of gender and saliency with fixations to the viewer's eyes, face, and background objects.

Acknowledgement: NSF

Neural mechanisms: Cortical organization

Orchid Ballroom, Boards 401–409

Saturday, May 8, 8:30 - 12:30 pm

23.401 **High-resolution retinotopic mapping at 7 Tesla with multi-shot 3D sequences**

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High-field (>4T) MRI offers great promise for high-resolution functional imaging of human visual cortex, but a number of technical issues have slowed the pace of its adoption. In particular, susceptibility-induced geometric distortions become more severe at high resolution and high field strength. Such effects are especially worrisome in topographic mapping studies, which typically rely on accurate coregistration between functional and anatomic images in order to render activity patterns on inflated or flattened representations of the cortical surface. We used polar angle retinotopic mapping of the early visual areas at 7T as a test case to compare the single-shot, 2D EPI sequences commonly used for functional MRI with alternative, multi-shot 3D sequences (3D-FFE and 3D-PRESTO) that achieve similar spatial and temporal resolutions, but are less prone to susceptibility effects. Images were acquired at 4 isotropic spatial resolutions (1.12mm, 1.67mm, 2mm, and 3mm) using both 2D-EPI and 3D-FFE/3D-PRESTO sequences. We found marginally higher functional SNR (median $\sqrt{F}$ statistic of activation in the grey matter of V1) for the EPI sequences across all resolutions. However, the lower distortion of the multi-shot 3D sequences lead to noticeable improvements in the smoothness and regularity of the surface-based retinotopic maps, particularly at the highest spatial resolutions. Such sequences may therefore provide a useful alternative to standard EPI imaging at high field strength and high resolution, especially in applications where geometric distortion is of concern, such as surface-based mapping of visual cortex.

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23.402 **Non-linear BOLD response to low-contrast Gabor elements**

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Many studies have demonstrated that the magnitude of the blood oxygenation level-dependent (BOLD) fMRI response in primary visual cortex increases with increasing stimulus contrast, and that the relationship between the magnitude of the BOLD response and the average firing rate in the V1 neural population is linear across a wide dynamic range. These results, however, are for BOLD responses to stimuli with a large angular subtent. We therefore tested the linearity of the relationship between the V1 BOLD response and the inferred V1 neural population response to isolated Gabor patches. Four Gabor patches (3 cycles/deg, 1 octave bandwidth), one in each visual quarterfield, were presented at 3 degrees eccentricity. One trial consisted of all four elements presented simultaneously at the same pedestal contrast in a two-interval forced choice paradigm (150 ms duration with 100 ms inter-stimulus interval); the subject's task was to detect an increment in contrast for one of the four Gabors on one of the two intervals. The Gabors were presented at 4 different contrasts (5%, 10%, 30% and 90%), randomly interleaved in an event-related design with an average (jittered) inter-trial interval of 4.5 s. Separate adaptive staircases adjusted the contrast increment to maintain performance for each pedestal contrast close 79% correct, thereby equating task difficulty across contrast. BOLD data were acquired for 5 subjects using both gradient echo (GE) and spin echo (SE) pulse sequences in the same scanning session at 7 Tesla with 2 mm (isotropic) spatial and 1.5 s temporal resolutions. The SE BOLD data showed the expected monotonic increase in amplitude with increasing contrast, but the GE BOLD response to 5% contrast Gabors was stronger than the GE BOLD response to 10% contrast elements. Because the SE BOLD technique minimizes contributions from large veins, this pattern of results suggests a vascular origin for the observed low-contrast non-linearity.

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23.403 **Orientation-selective fMRI adaptation in primary visual cortex revisited**

Sarah Weigelt[1,2](weigelt@mit.edu), Katharina Pohl[1,2], Wolf Singer[1,2], Axel Kohler[1,2]; [1]Department of Neurophysiology, Max Planck Institute for Brain Research, Frankfurt, Germany, [2]Brain Imaging Center, Frankfurt, Germany

The ability to discriminate orientations is at the core of our visual experience. Orientation selectivity in human visual cortex has been inferred from psychophysical experiments and more recently demonstrated with functional magnetic resonance imaging (fMRI). One method to identify orientation-selective responses is fMRI adaptation, in which two stimuli – either with the same or with different orientations – are presented successively. A region processing orientation should demonstrate an adapted response to the 'same orientation' condition in contrast to the 'different orientation' condition. So far human primary visual cortex (V1) showed orientation-selective fMRI adaptation only in experimental designs employing long adaptation periods (~ 40 s) and so-called top-up stimuli that are thought to keep up the adapted level. This finding has led to the notion that short-term adaptation in V1 (but not V2 or V3) cannot be detected using fMRI. The present study aimed at re-evaluating this question by testing three differently timed adaptation designs. With the use of a more sensitive analysis technique, we show for the first time orientation-selective fMRI adaptation in V1 evoked by a short-term adaptation design.

23.404 **Effect of fMRI study design on the classification accuracy of orientation discrimination**

Tim J Preston[1](preston@psych.ucsb.edu), Miguel P Eckstein[1]; [1]Department of Psychology, University of California, Santa Barbara

Block designs are often used with multivariate pattern analyses (MVPA) of fMRI studies to achieve high classification accuracy rather than fast event-related designs which suffer from low accuracy. This lower accuracy is typically attributed to the interaction between the rapid succession of stimulus events and the temporally sluggish BOLD response. We show that much of the higher classification accuracy derived from the use of block designs is a result of the averaging of fMRI data points during analysis rather than the different temporal characteristics of the two designs. Observers judged the orientation of centrally presented Gabor patches (10° diameter, 1.2 cpd) oriented at +/-45° relative to the vertical. Trial durations were 2 seconds with an initial 200 ms presentation of the Gabor stimulus. Experimental runs consisted of 25 presentations of each condition including 25 fixation trials of equal duration. Observers participated in three scanning sessions which differed only in the ordering of experimental trials: either blocked or fast event-related (m-sequence or genetic algorithm optimized designs). Each observer completed 10 runs per session. We used a linear SVM to assess the orientation discrimination accuracy of retinotopically defined visual cortex in two ways: training and predicting on single trials (fMRI data points shifted by 4 seconds) or trials averaged across blocks. Trials from event-related designs were grouped into three blocks matching the block design. Averaging trials produced a significantly higher classification accuracy than single trial analysis for all experimental designs. Further, the single trial analysis accuracy of the block design was close to chance across visual areas with no significant accuracy difference between designs. Our results suggest that much of the benefit that block designs provide in MVPA fMRI studies is due to the averaging of fMRI data during analysis and this technique can equally well be applied to fast event-related designs.

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23.405 **How much tuning information is lost when we average across subjects in fMRI experiments?**

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Most fMRI studies average results across subjects, but there is substantial individual variability in anatomical structure and BOLD responses. Therefore, averaging is usually performed by transforming each subject's anatomical volume to a standard template, and then averaging functional data from all subjects within this common anatomical space. However, anatomical normalization is under-determined, so this process is likely to introduce some error into the averaged data set. How much tuning information is lost when we average across subjects in fMRI experiments? To investigate this issue we compared averaged and individual results, using a computational modeling approach used previously in our laboratory (Kay et al., Nature 2008, v.452, 352-355). The data consisted of fMRI BOLD activity recorded from the visual cortex of three subjects who viewed a large set of monochromatic natural images. We first estimated voxel-based receptive fields for each subject and calculated the correlation between observed and predicted BOLD responses. We then averaged the fMRI data across subjects (using a leave-one-out procedure to avoid over-fitting), estimated voxel-based receptive field models on the averaged data, and calculated the correlation between observed and predicted BOLD responses. We found that the predictions of models based on individual data were more highly correlated with the observed data than were the predictions of models based on averaged data. In summary, our data suggest that averaging across subjects reduces the information that can be recovered from fMRI data.

Acknowledgement: NEI

23.406 **No Grey Matter Reduction following Macular Degeneration**

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A recent study reported that individuals with central retinal lesions due to macular degeneration (MD) showed grey matter reduction in "foveal" cortex, apparently due to the loss of bottom-up input. Here we ask whether similar structural changes are found in individuals with loss of bottom-up input due to MD, but who show functional reorganization, in which foveal cortex responds to peripherally presented stimuli. We predicted that if grey matter reduction is driven by cortical deprivation, then such structural changes should not be found in MD individuals who show functional reorganization. As predicted, we found no evidence for grey matter reduction in foveal cortex in these individuals. These findings suggest that reorganization of visual processing (i.e., the activation of foveal cortex by peripheral stimuli) may be sufficient to maintain "normal" cortical structure.

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23.407 **The human MT/V5 cluster**

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Introduction. Recent observations of retinotopically organized areas within the human MT/V5 complex suggest two conflicting models for the relationship of these areas to neighboring areas LO1/2: a discontinuous model (Georgieva et al., 2009), with separated central representations and distinct eccentricity distributions in hMT/V5+ and lateral occipital complex (LOC), and a continuous model (Amano et al., 2009), in which LO1/2, MT/V5, and MST share a common eccentricity distribution. Methods. We used functional magnetic resonance imaging (fMRI) at 3T to identify areas within hMT/V5+ and the LOC and recorded responses to motion and shape localizers and to hand action for their characterization. We correlated the functional responses across subjects through the retinotopic data in each subject instead of using an anatomical registration, which resulted in a specificity of the group analysis near the resolution of the functional volumes of (2mm)3. Results. We consistently located areas LO1 and LO2 within the LOC and four retinotopic areas, the likely homologues V4t, MT/V5, MSTv, and FST, within hMT/V5+. Responses in the hand action vs. static hand condition were strong in all areas of the hMT/V5 complex but weak and not significant in the LOC. We found significant shape sensitivity in all areas of both complexes. MT/V5 and MSTv, however, showed half the sensitivity compared to all other areas. Conclusion. The four areas of the hMT/V5 complex share a common central representation distinct from the LOC and their topological organization closely resembles the organization recently observed in the MT/V5 field map cluster of the macaque monkey (Kolster et al., 2009). Areas V4t and FST, located between MT/V5 and LO1/2, show equally strong shape sensitivity as the areas within the LOC. They are, in terms of functional properties as well as topological location, consistent with the previously reported LO-ML overlap (Kourtzi, et al. 2002).

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23.408 **Representations of physical and perceived colour-motion conjunction in early visual cortex**

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In order to reveal how combinations of visual features are represented in early visual areas (V1, V2, V3, V3A and V4), we examined whether they show adaptation to colour-motion conjunctions using functional MRI. Further, we investigated which visual areas show adaptation to perceived conjunctions rather than physical conjunctions using the steady-state misbinding (Wu, Kanai & Shimojo, 2004), which allows separation of perceived conjunction from physical conjunction. Adaptation to physical and perceived conjunctions was evaluated within regions of interest (ROIs) corresponding to the patches of the visual field where misbinding was induced. In one condition, peripheral conjunctions alternated physically every 2 seconds, but the central part remained constant, resulting in a constant percept (physical alternation condition). In a second condition, the central part alternated physically every 2 seconds, but the peripheral target patches remained physically constant (perceptual alternation condition). Two additional conditions were included as the baseline conditions in which both the central and peripheral patches stayed constant or both alternated. We found that most of the early visual areas adapted to physical stimulus combinations, suggesting that these areas encode physical colour-motion combinations even when the percept alternated. The only exception was V3A, which showed stronger adaptation to perceived combinations rather than physical combinations. These results indicate that colour and motion may not be segregated as previously believed. Furthermore, the adaptation to perceived combination in V3A suggests that conscious perception of colour-motion conjunction may be directly represented at an intermediate stage of visual processing.

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23.409 Multiple areas in human cerebral cortex contain visual representations of head rotation

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Our brain uses visual flow patterns to derive important information about the rotation of the eye and head through space and the direction of self-motion. This information is processed in various regions along the visual hierarchy, some of which also receive non-visual signals. Several regions along the dorsal stream are selective for elementary motion, like area V3A, V6 and the middle temporal area (MT). Other areas in this path, like the medial superior temporal area (MST) and the ventral intra-parietal area (VIP), are particularly modulated by optic-flow patterns. They are closely involved in heading perception and are both modulated by vestibular and eye movement signals. Although most of these higher visual areas have been retinotopically mapped, their functional role is still poorly understood. Previously, we have identified a sub-region of pMST, to be modulated by visual flow signals corresponding to a rotation of the head. For this, we used stimuli that allowed dissociation between simulated head- and gaze rotation (see abstract: van den Berg et al.). Here, we show -using psychophysical techniques, high-resolution functional resonance imaging and wide-field visual stimuli- that: (1) perceived ego-rotation corresponds to the simulated head rotation rather than the gaze rotation. (2) like in pMST, regions within area V3A, V6 and pVIP show a specific modulation of the BOLD response to simulated head rotation. (3) these areas have a retinotopic organization. Our observations do not permit us to conclude in which reference frame the receptive fields collect the visual flow: retino-centric or head-centric? Possibly the multiple visual representations of head-rotation differ in this respect.

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Color and light: Mechanisms

Orchid Ballroom, Boards 410–424

Saturday, May 8, 8:30 - 12:30 pm

23.410 Changes in the space-average S-cone stimulation of inducing patterns suggest an interaction among the different cone-types

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BACKGROUND: Induction with S-cone stimulating patterns can cause striking color shifts (e.g., Monnier & Shevell, 2003). In the present study, we explored whether changing the space-average S-cone stimulation of the inducing pattern, holding the differences in S-cone stimulation between inducing and test chromaticities constant, affected the color shifts. METHODS: Chromatic induction was measured with patterns composed of circles that varied in S-cone stimulation using asymmetric matching. The color appearance of a test ring presented with high and low S-cone stimulating circles was matched by adjusting the hue, saturation, and brightness of a comparison ring presented within a uniform gray (EEW) field. The space-average S-cone stimulation of the test pattern was varied, holding the differences in S-cone stimulation between the inducing and test chromaticities constant. For each inducing pattern, measurements for three test-chromaticities that varied in L/(L+M) were obtained. RESULTS: As previously reported, S-cone inducing patterns can cause relatively large shifts in color appearance. The arrangement of the inducing circles (high-S-cone-adjacent/low-S-cone non-adjacent or vice versa) determined the direction of the color shifts toward higher or lower S-cone stimulation, respectively, independent of the space-average S-cone stimulation of the inducing pattern. The space-average manipulation did affect the three test L/(L+M) chromaticities differently, with a general shift toward lower S-cone matches for the high L/(L+M) test. CONCLUSION: Variations in the space-average S-cone stimulation of the inducing patterns did not alter the overall direction of the color shifts but did affect the magnitude of the shifts for the three test-ring chromaticities that varied in L/(L+M) chromaticities. These measurements suggest an interaction among the different cone-types.

Acknowledgement: NA

23.411 Testing models of color deficiencies using normal observers with Ishihara plates simulated for color deficient observers

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The chromatic diversity of complex scenes can be simulated for normal and color deficient observers. Current models of color vision deficiencies allow to simulate for a normal observer the chromatic sensations experienced by a color deficient observers. How real such simulations are is an open question. The goal of this work was to assess the effectiveness of the simulations with normal observers viewing Ishihara plates simulated for color deficient observers. The plates were digitized with a hyperspectral imaging system and the spectral reflectance of each pixel of the plates was estimated from a gray reference surface present near the plate at the time of digitizing. Data was acquired from 400 to 720 nm in 10 nm steps. Images were assumed rendered under the D65. Simulations for normal observers of the perception of dichromatic and of anomalous color vision were done using deMarco's anomalous color matching functions (JOSA-A, 9(9): p.1465-1476, 1992) and Brettel's simulation of color appearance for dichromats (JOSA-A, 14(10): p.2647-2655, 1997). The resulting images were displayed on a calibrated 17-inch, RGB color monitor with flat screen controlled by a computer raster-graphics card providing 24 bits per pixel in true-color mode (VSG 2/5; Cambridge Research Systems, Rochester, UK). Normal observers were asked to read the numbers on the plates displayed on the screen, simulated for normal, protanomalous, deuteranomalous, protanope and deuteranope observers. Ishihara plates were displayed randomly in the same observer category to avoid plate memorization. Comparing the expected results as described in the Ishihara's test instructions with those obtained here values of about 70% to 90% were found to all observers. These results suggest that the models used describe vision of color deficient observers well enough to reproduce answers of Ishihara plates.

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23.412 Equiluminance Settings Interact Strongly With Spatial Frequency

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The minimum motion method is a standard tool used by psychophysicists obtaining perceptually equiluminant display settings for a light of hue A to another fixed light F. This method uses a 4 frame periodic stimulus, whose 1st and 3rd frames comprise counterphase, achromatic gratings and whose 2nd and 4th frames comprise counterphase square wave gratings alternating between lights A and F in quadrature with the square wave of frames 1 and 3. When the luminance of hue A is adjusted to make the motion of this stimulus ambiguous, the resulting light is taken as equiluminant to F. We document dramatic effects of the spatial frequency (SF) of the square wave used in the motion stimulus on the equiluminance settings obtained using this method. Some observers show the following pattern: when the square wave is low SF (3 cycles/deg), in order to be made equiluminant to a fixed gray, a saturated green needs to be made much lower in luminance than it does when the square wave is high SF (6 cycles/deg). For other observers, the reverse pattern holds: their equiluminant green settings are higher for the low than for the high SF square wave. Moreover, whichever pattern an observer shows in her equiluminant settings for green, she is likely to show the reverse pattern in her settings for red lights: i.e., if an observer produces higher equiluminance settings for green with the high than with the low SF square wave, then she tends to produce lower equiluminance settings for red with the high than with the low SF square wave. These findings underscore the importance of matching the SF of the minimum motion stimulus to the SF of context in which the equiluminant lights are to be used experimentally.

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23.413 The role of color in the early stages of visual analysis

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Saturday AM

The visual system is capable of quickly extracting relevant information from a large amount of visual data. In order to do so, the early stages of analysis must provide a compact image representation that extracts meaningful features (Barlow, 1959; Marr 1976). Color in natural scenes is a rich source of information, but a worthwhile question is whether color is sufficiently important to justify its implicit computational load during the early stages of visual processing, when strong compression is needed. A pattern-filtering approach (Punzi & Del Viva, VSS-2006), based on the principle of most efficient information coding under real-world physical limitations, was applied to color images of natural scenes in order to investigate the possible role of color in the initial stages of image representation and edge detection. That study, performed on photographic RGB images, confirmed the effectiveness of the pattern-filtering approach in predicting from first principles the structure of visual representations, and additionally suggested that color information is used in a very different way than luminance information (Del Viva, Punzi & Shevell, VSS-2009). The present study is significantly more detailed and uses the photoreceptor color space of MacLeod and Boynton, where luminance and chromatic information can be expressed separately. The results show that, when strict computational limitations are imposed, the use of color information does not provide a significant improvement in either the perceived quality of the compressed image or its information content, over the use of luminance alone. These results suggest that the early visual representations may not use color. Instead, color may be more suitable for a separate level of processing, following a rapid, initial luminance-based analysis.

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23.414 Filling-in of color spreads to well-localized illusory contours

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PURPOSE: Observers report that a filled-in color from a chromatic light into an equiluminant achromatic surround is bounded by illusory contours (Feitosa-Santana et al, VSS 2009), but a possible explanation is that observers report filling-in because they cannot accurately localize illusory contours. This was tested by measuring (1) observers' ability to localize illusory contours and (2) the frequency of perceived filling-in when the chromatic light that normally fills-in had a higher luminance than the surround. If contour lozalization is poor, then frequency of filling-in should not vary with luminance because the added luminance-contrast edge still reaches a poorly localized illusory contour. METHODS: Three kinds of illusory contours were tested: Kanizsa square from solid "pacmen", Kanizsa square from "bull's eye" pacmen, and horizontally phase-shifted vertical lines. In experiment (1), two thin dark horizontal lines on an achromatic background were presented on either side of a horizontal illusory contour. In different trials, the lines were positioned at various positions above or below the illusory contour; observers indicated whether the lines appeared above or below the contour. In experiment (2), a yellow square with a luminance higher than its achromatic surround was presented some distance from the illusory contour. Without luminance contrast, the yellow square fills-in up to the contour, which was either 4 or 6 min away. Three levels of luminance contrast were tested (5%, 7%, 11%). Observers indicated whether the yellow square appeared to be touching the illusory contour (thus a filled-in color). RESULTS & CONCLUSION: (1) Observers perceived the illusory contour's position with accuracy ±1min. (2) The frequency of filling-in was attenuated with 5% or 7% luminance contrast, and abolished at 11%. Both results are inconsistent with poorly localized illusory contours, and thus confirm that the spread of filled-in color is bounded by illusory contours.

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23.415 Why do coloured filters improve vision?

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Coloured filter media are said to improve colour contrast especially for sport related activities. The improvement is not well defined and apparently includes contrast vision (discrimination based on luminance differences), colour discrimination (the ability to distinguish colours in direct comparison depending on their colour distance) and some other effects like simultaneous contrast and adaptation. We developed an objective measurement method for detecting the effects of coloured filter media on colour perception while excluding the effects of luminance differences.

The apparatus employed in this investigation fulfils the requirements of "colorimetry by visual matching" and does not have the limitations of CRT or TFT displays. It is based on additive mixing of the emission spectra of seven different light emitting diode types (LEDs). Based on this, a freely adjustable spectrum is generated. The selected LEDs covered a continuous spectra in the range of 420 nm to 750 nm. In our initial measurements, the overall luminance level was fixed at 377 cd/m2. We evaluated just distinguishable colour difference on a vertically divided, two degree, test field around a yellow-green reference colour (CIEx=0,466, CIEy=0,453) along five colour directions. Measurements with volume filters (laser goggles (12 participants, 3 repeats), contact lenses (n=12, 3 repeats) and sport filters (n=3, 3 repeats)) were done in a similar fashion; the filters absorbed parts of the reference spectra and induced color shifts in different parts of the tri-stimulus space. Any induced luminance difference where eliminated by adjusting the LEDs' intensity.

For all filters and participants, the smallest colour discrimination ellipses (thresholds) were found in the yellow region, while size and geometry varied widely for each subject. We believe that this major improvement was based on increased colour discrimination in the yellow region and can not be accounted by variation in luminance or the use of a non-uniform colour space.

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23.416 Filling-in with afterimages: Modeling and predictions

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Van Lier, Vergeer, and Anstis (2009) reported that color information in a visual afterimage could spread across regions that were not colored in the inducing stimulus. The perceived color and shape of the afterimage could be manipulated by drawn contours that apparently trapped the spread of afterimage color signals. New simulations of the BCS/FCS model of visual perception (Grossberg & Mingolla, 1985a,b) demonstrates that the model easily accounts for many of the properties of these afterimages. A core idea of the model is that representations of colors spread in all directions at a filling-in stage until blocked by boundary signals. Boundary signals that form closed connected contours can trap the spreading colors to create a surface of relatively uniform color. A side effect of this process is that color contrasts that are too weak to form boundaries may spread beyond their physical location. The weak color contrasts that are often present with an afterimage are one example of this phenomenon. The model simulations further predict that a small closed contour should block the spread of afterimage color into the interior of the contour. Empirical data demonstrate the validity of this prediction.

23.417 The role of color in perceptual organization

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Color is a visual attribute that appears to belong to an object and to its shape. Phenomenally, the perception of an object is often considered identical to the perception of its shape but not to its color, which appears as a secondary attribute. As such it is believed color has relatively little influence in the perception of shape even if it enhances the capacity of an organism to distinguish objects. If color can scarcely influence shape perception, it can be more effective with grouping that is a more simple kind of perceptual organization. Grouping defines what belongs with what and color is one among many possible attributes defining the similarity principle studied by Wertheimer. In other words, color can determine in terms of similarity how elements in the visual field 'go together' to form an integrated, holistic percept. Among the many possible kinds of similarities, grouping by color is believed to be less effective compared with other attributes like shape and luminance. The main purposes of this work are to study the role played by color in determining visual grouping, not only in relation to other similarity attributes but also in relation to other principles such as proximity, good continuation and past experience, and the perceptual shape of objects. Psychophysical experiments revealed several new effects and demonstrated that in spite of previous results color can strongly influence both the form of grouping and the form of shape. These results were extended and strengthened by using a reading task that implies a process of segmentation of words and then phenomenal grouping and shape formation.

Acknowledgement: Fondo d'Ateneo ex 60% (to BP)

23.418 **Illusory backward motion occurs only with a luminance component**

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For stimulus durations shorter that 35 msec, the perceived direction of motion of a stimulus composed of a moving 3-c/deg grating and a static 1-c/deg grating can appear reversed (Derrington and Henning, 1987), even though the direction of motion of the high frequency grating when presented alone is perceived correctly. We tested whether this illusory motion occurs also for stimuli composed of coloured gratings with and without a luminance component. Stimuli consisted of a moving 3-c/deg and a static 1-c/deg horizontal sinewave gratings. The high frequency grating moved at 6-c/deg or 12-c/deg. The gratings were seen through a circular aperture of 5 deg diameter surrounded by a uniform grey background. Stimulus duration was controlled by varying the standard deviation of a temporal Gaussian envelope. A 2-AFC paradigm was used to determine the perceived motion direction of the stimulus. When both gratings contained a luminance component, we found that for stimulus durations between 35 and 125 msec, the gratings appeared to slide on top of each other. The apparent motion of the steady low-frequency grating was in the opposite direction to the high-frequency grating. At durations shorter than 35 msec, the two gratings appeared as a single pattern moving in the opposite direction of the high frequency grating (illusory motion). Interestingly, when either or both gratings were isoluminant, only the high frequency grating was seen moving. Its perceived direction of motion was correct only for durations above 35 msec, but below 35 msec performance was change. In summary, illusory backward motion is only found with stimuli with a luminance component. We suggest that illusory backward motion is due to a higher-order feature tracking system that requires two luminance inputs.

Acknowledgement: Fight for Sight

23.419 **The Role of S-Cone Signals in the Color-Motion Asynchrony**

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Background. In order to perceive simultaneous changes in color (e.g., from red to green) and motion direction (e.g., from upward to downward), the change in the motion direction needs to precede the color change by approximately 80 ms. This indicates color-motion asynchrony. This phenomenon has been investigated only with red and green stimuli that represent the L- and M-cone activity. The purpose of this study was to examine the asynchrony with stimuli that vary along the S/(L+M) axis as well as those that vary along the L/(L+M) axis. Because S-cone signals are processed more slowly than L- and M- cone signals, decreased asynchrony was expected with stimuli that vary along the S/(L+M) axis. Methods. Stimulus was 200 random equiluminant dots in a circular field of 8° in diameter. The direction of the motion of the dots was initially upward (or downward) and changed to downward (or upward) after 300 ms of the stimulus onset. The color of the dots changed once, either along the L/(L+M) or the S/(L+M) axis and the second color lasted for 300 ms. The relative timing of motion direction change and color change was varied from -100 to 250 ms in increments of 50 ms. The observer's task was to judge the predominant direction of motion of the second-color dots. The magnitude of color-motion asynchrony was assessed by the method of constant stimuli from four observers. Results. Surprisingly, the results showed that both stimuli that varied along the L/(L+M) axis and those that varied along the S/(L+M) axis produced perceptual asynchrony of about 90 ms. Conclusion. The equal magnitude of the color-motion asynchrony along the L/(L+M) and the S/(L+M) axes indicates that the color-motion asynchrony takes place in higher cortical areas beyond the integration of cone signals. This further supports the differential processing time model.

23.421 **The effect of luminance intrusion on the chromatic VEP response**

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The use of large-field stimuli to elicit chromatic visual evoked potentials from the S-(L+M) pathway is useful for evaluation of compromised retinas. However the use of large fields has been criticized as containing luminance intrusion due in part to the distribution of macular pigment across the retina. We tested the effects of luminance intrusion on the chromatic component (CII) of the onset VEP waveforms. Over a range of luminance mismatches, the latencies of the chromatic waveform components were unaffected by luminance intrusion. Responses to low spatial frequency luminance onsets are known to be highly variable. Consequently, the affects of luminance mismatches were also highly variable. The degree to which intentional luminance mismatches affected the component latencies depended on the shape of individual achromatic components in the waveforms. However, over a range of luminance mismatches that should encompass that encountered by normal variations in macular pigment, the latencies were unaffected. These results suggest that luminance mismatches due to macular pigment differences across the retina have little effect on the latencies of the chromatic components of the VEP response to large field S cone stimuli.

23.422 **Quantifying the perception of colour in visual saltation**

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In the visual saltation illusion, stimuli are presented first to one location then another in rapid succession which produces the illusion of the intermediate stimuli as jumping in equidistant steps between the two locations (Geldard, 1975). Geldard also noted that if stimuli at the two sites of stimulation were of different colours, the apparent colour of the mislocalised stimuli appeared to be a mixture of the two colours. For example, if stimuli at one site was red and the other site was green then the mislocalised stimuli would appear yellow. In the present study, we systematically quantified this illusory colour change with different colour combinations. In Experiment 1, observers were presented with 3 coloured bars (0.5x2deg, interstimulus-interval of 0.25 seconds); two bars of the same colour were flashed at one location (10 degrees to the right of fixation), and one bar of a different colour was flashed at another location (15 degrees). Saltation was noted with the second bar appearing mislocalised between the first and third bars, and six observers were required to adjust the colour and position of a probe to match the perceived colour and position of the mislocalised bar. We observed that the perceived colour of the mislocalised element does not correspond to its physical colour for a range of colour combinations, but appears to be of an equal mixture of the two physical colours. Additionally, in Experiment 2 we showed that the perceived colour of the mislocalised element can be altered by briefly changing the colour of the background coinciding with its perceived position, and the resultant colour is equal to a mixture of the perceived colour of the bar and the background colour. This finding indicates that phemeonological colour perception in visual saltation relies on the perceived colour and not the physical colour of stimuli.

23.423 **Experimental study of the pre-nonlinearity, nonlinearity and post-nonlinearity stages at medium wavelengths**

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A 560 nm amplitude-modulated flickering stimulus undergoes a brightness change at low to medium intensities and desaturates at high intensities. This change in appearance is consistent with a distortion product produced by a nonlinear stage, which can be used to dissect the visual system into pre-nonlinearity and post-nonlinearity stages whose frequency responses can be measured separately. Despite previous investigations in distortion of temporally varying visual stimuli, the location of the nonlinearity and the frequency and intensity responses of the individual pre- and post-nonlinearity stages are still not understood for a 560 nm stimulus, which is the subject of this study. A Maxwellian-view system was used to generate the visual stimulus. The input-output function of the nonlinearity was measured at different frequencies by matching the distortion product with the change in appearance of a sinusoidal stimulus of equal wavelength and intensity. Changes in the frequency responses were measured at four intensities between 8.56 and 10.41 log10 quanta s-1 deg-2. The results of the experiments show that the peak frequency response for the pre-nonlinearity stage is at 7.5-25 Hz and the upper frequency limit is at 35-45 Hz, depending on intensity. At large amplitude-modulations, there is greater inter-subjective variability and a plateau is reached in the matching data. The post-nonlinearity stage is low-pass and most sensitive at medium intensity levels. The study provides new data for the early and late frequency responses of the visual system including how they differ with systematic variation in intensity and frequency of amplitude-modulated stimuli. The results are consistent with retinal cell physiology data, which indicates an early nonlinearity. Different models are considered as possible explanations to the underlying nonlinearity including an expansive nonlinearity and asymmetric slew rate. The findings of this study are consistent with the Bezold-Brucke, Brucke-Bartley and Broca-Sulzer effects, and have wide possible applications.

Acknowledgement: BBSRC

23.424 **Measuring perceived flicker in field-sequential displays**

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Purpose: To reduce the color breakup phenomenon in field-sequential displays, different color sequences have been proposed in the literature such as WRGB, RGBKKK, RGBCMY, etc. Although some of them alleviate the perceived chromatic artifacts, most of them however introduce flicker in the luminance domain. The goal of this study is to measure and quantify the perceived flicker by using electroencephalography.

Method: A conventional blocked ERP experiment was conducted. The subjects were stimulated by a custom-made field sequential liquid crystal display, in which the RGB LED backlight can generate arbitrary color sequences between 90 and 180 Hz. The on-set was 4 seconds of flickering RGB image followed by the off-set, which was 4 seconds of dark image. A trial consists of 10 consecutive cycles of on-sets and off-sets. A 64-channel EEG recorder (EGI 250) and its software were used to analyze the waveform difference between on-set and off-set as an index of perceived flicker.

Results: Altering the color sequence mutually affects chromatic artifacts and luminous flicker. The best solution to color breakup has the worse perceivable flicker. The outcomes also show higher consistency compared with psychophysical methods. This method can be used to determine the critical flicker fusion frequency for judging the image quality of field-sequential displays.

Perception and action: Reaching and grasping

Orchid Ballroom, Boards 425–439

Saturday, May 8, 8:30 - 12:30 pm

23.425 **Effects of object shape on the visual guidance of action**

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Many studies suggest that the perception of object shape is encoded holistically rather than analytically. However, little is known about how object shape is processed to control grasping movements. It has been proposed that visual control of action utilizes only the most relevant dimensions of an object (Ganel & Goodale, 2003).We tested whether visual control of action also takes into account information about object shape. 26 participants grasped a disk or a bar of identical lengths (bar: 4.1 cm long, disc: 4.1 cm diameter). In 20 % of the trials, the object changed its shape from bar to disk or from disk to bar during the movement. The change occurred early during the movement (after index-finger or thumb moved 2 cm away from the starting position) or late (after 2/3 of the movement distance was covered). In the remaining 80 % of the trials no object change took place. We found that maximum grip aperture depended on object shape. Participants grasped bars with a significantly larger maximum grip aperture than disks. Furthermore, they adjusted maximum grip aperture when object shape changed from bar to disk. Specifically, these adjustments occurred only in the early phase of the movement. Our results reveal that vision for action is sensitive to object shape information. They also indicate that object information encoded holistically is used for corrective adjustments during the grasping movement. Taken together, these results show that holistic processing might play a notable role in vision for action.

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23.426 **Older adults use a distinctive form of visual control to guide bimanual reaches**

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Background: Previous research has shown that young adults are skilled at coordinating the left and right hands when reaching to grasp two separate objects at the same time, or when carrying two objects to the same location. Less is known about the behaviour of older adults with regard to such tasks. We examined the performance differences between young adults (mean age 20) and older adults (mean age 74) in terms of how they coordinate the two hands during a bimanual movement. Methods: Identical objects were located to the left and right of 3 trays laid out in front of the participants along the fronto-parallel plane. Participants picked up the objects (one in each hand) and placed them in the specified tray simultaneously. Movements of the objects were recorded using a VICON 3D motion capture system. Results: Although no group differences were found in overall movement time, the details of the reach movements were not the same. The older adults moved as quickly as possible to the tray vicinity, producing reaches with greater peak velocities than the young. They then spent longer than the young in the ‘near-zero velocity’ final phase of the reach and made more adjustments during this phase. In contrast, the young spent longer in the preceding low velocity phase than the older adults, and made more adjustments during this phase. Conclusions: We propose that, in contrast to the younger group, older adults have more problems using online sensory feedback to correct trajectory errors during the flight phase. As a result they wait until both hands are together so they can visually monitor both objects before making trajectory corrections.

Acknowledgement: Economic and Social Research Council, UK

23.427 **Time-course of allocentric-to-egocentric conversion in memory-guided reach**

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It has been suggested that both egocentric and allocentric cues can be used for memory-guided movements, and that allocentric memory dominates during longer memory intervals (Obhi&Goodale, 2005; Hay&Redon, 2006). In the present study we examined 1) at what point in the reach plan allocentric representations are converted to egocentric representations and 2) the rates of decay of egocentric and allocentric memory. Nine subjects reached for a remembered target in complete darkness after a variable memory delay (2.5s, 5.5s, or 8.5 seconds in total). In the Ego Task the target was presented alone in the periphery on a CRT screen. In the Allo Task the target was presented along with four nearby blue disks (visual landmarks). After the variable delay, the landmarks reappeared at a shifted location, and subjects were instructed to reach to the target relative to the landmarks. In the Allo-Ego Conversion Task the shifted landmarks re-appeared twice: once before the variable delay and once immediately after (just before the reach cue). We analyzed the variance of reaching errors and reaction time (RT) for each memory delay in the three tasks. In the Ego Task, variance increased significantly in medium and long delays compared to the short delay; RT was longer in the short delay than medium and long delays, and the latter was significant. In the Allo Task there was no significant difference in variance and RT across the delays. In the Allo-Ego Conversion Task, there were significant increase in variance and decrease in RT for the medium and long delays compared to the short delay, which was similar to Ego Task. These results confirm that egocentric memory for reaching degrades more rapidly than allocentric memory, but despite this, in our Allo-Ego Task subjects preferred to convert allocentric into egocentric representations at the first possible opportunity.

Acknowledgement: Canada Research Chairs Program

23.428 **Impact of hand position during reaching on the manual following response induced by visual motion**

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It has been recently found that the manual following response (MFR), which is shortly induced by applying a surrounding visual motion during reaching, is modulated by a spatial relationship between gaze and reaching target locations (Abekawa & Gomi 2006 Society for Neurosci.). On the other hand, change in the spatial relationship between reaching target and visual motion locations appeared not to affect the MFR. However, it has not yet been examined whether or not the hand position relative to the motion

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stimulus affects the MFR. To investigate this aspect, we conducted an experiment in which the location of visual motion stimulus (longitudinal grating-pattern motion in 120 x 13 cm) was changed along the reaching path from proximal to distal positions (proximal, middle, and distal). Each stimulus started to move transversally at different hand positions (proximal, middle, and distal) during arm-extension reaching movements. The distal stimulus with the middle hand position induced the greatest MFR among all nine conditions, and that stimulus with the proximal and distal hand positions also greatly induced the MFR. The middle stimulus with the proximal and middle hand positions also induced the MFR clearly, but that with the distal hand position did not induce the MFR significantly. The proximal stimulus with any hand positions did not induce the MFR while the same stimulus induced the MFR during arm-flexion reaching movements. These MFR variations, therefore, could not be explained only by changes in the stimulus location on the retina and in the relationships between the gaze and reaching target locations. The MFR variations observed in the experiment suggest that the MFR is affected not only by the hand position but also by the hand movement direction relative to the stimulus location.

23.429 **Learning reward functions in grasping objects with position uncertainty via inverse reinforcement learning**

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Many aspects of visuomotor behavior have been explained by optimal sensorimotor control, which models actions as decisions that maximize the desirableness of outcomes, where the desirableness is captured by an expected cost or utility to each action sequence. Because costs and utilities quantify the goals of behavior, they are crucial for understanding action selection. However, for complex natural tasks like grasping that involve the application of forces to change the relative position of objects, modeling the expected cost poses significant challenges. We use inverse optimal control to estimate the natural costs for grasping an object with position uncertainty. In a previous study, we tested the hypothesis that people compensate for object position uncertainty in a grasping task by adopting strategies that produce stable grasp at first contact – in essence using time efficiency as a natural cost function. Subjects reached to an object made uncertain by moving it with a robot arm while out of view. In accord with optimal predictions, subjects compensate by approaching the object along the direction of maximal position uncertainty, thereby maximizing the chance of successful object-finger contact. Although subjects' grasps were near optimal, the exact cost function used is not clear. We estimated the unknown cost functions that subjects used to perform the grasping task based on movement trajectories. Our method involves computing the frequency that trajectories passed through a grid of spatial locations in the 2D space and used the results to estimate the transition probability matrix. Formulating the grasping task as a Markov Decision Process (MDP) and assuming a finite state-space, as well a finite set of actions, we can solve for the cost function that generate the MDP as an optimal solution. The estimated costs are consistent with a trade-off between efficient grasp placement and a low probability of object-finger collision.

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23.430 **View-based neural encoding of goal-directed actions: a physiologically inspired neural theory**

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The visual recognition of goal-directed movements is crucial for action understanding. Neurons with visual selectivity for goal-directed hand actions have been found in multiple cortical regions. Such neurons are characterized by a remarkable combination of selectivity and invariance: Their responses vary with subtle differences between hand shapes (defining different grip types) and the exact spatial relationship between effector and goal object (as required for a successful grip). At the same time, many of these neurons are largely invariant with respect to the spatial position of the stimulus and the visual perspective. This raises the question how this combination of spatial accuracy and invariance is accomplished in visual action recognition. Numerous theories in neuroscience and robotics have postulated that the visual system reconstructs the three-dimensional structure of effector and object and then verifies their correct spatial relationship, potentially by internal simulation of the observed action in a motor frame of reference. However, novel electrophysiological data, showing view-dependent responses of mirror neurons, suggest alternative explanations. METHODS: We propose a novel theory for the recognition of goal-directed hand movements that is based on physiologically plausible mechanisms, and which makes predictions that are compatible with electrophysiological data. It is based on the following key components: (1) A neural shape recognition hierarchy with incomplete position invariance; (2) a dynamic neural mechanism that associates shape information over time; (3) a gain-field-like mechanism that computes affordance- and spatial matching between effector and goal object; (4) pooling of the output signals of a small number of view-specific action-selective modules. RESULTS: We show that this model is computationally powerful enough to accomplish robust position- and view-invariant recognition on real videos. It reproduces and predicts correctly data from single-cell recordings, e.g. on the view- and temporal–order selectivity of mirror neurons in area F5.

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23.431 **No pain no gain: Assessment of the grasp penalty function**

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Purpose: In experiments where the outcome of movements result in explicit monetary rewards and penalties, subjects typically plan movements that come close to maximizing their expected gain. But what if an economically optimal movement proves to be intrinsically stressful to the organism? Would subjects trade gain to avoid pain? And if they did so, how would they price biomechanical discomfort in monetary terms? We tested how degree of discomfort affected movement planning in a simple grasping task.

Methods: Subjects attempted to rapidly grasp circular disks (50 mm diameter, 10 mm high). The edge of each disk was marked with two reward regions symmetrically-placed on the circumference. If the thumb and forefinger contact points both fell within the reward regions the subject received a monetary reward and otherwise a penalty. A grasp aimed at the centers of the reward regions would maximize expected reward but such a grasp varied in comfort with rotation angle. From trial to trial we rotated the reward regions, forcing the subject to trade off comfort and expected gain. In one condition ("narrow") the reward regions spanned 40 degrees, in a second 60 degrees ("wide"). Deviating from the center was potentially more costly to the subject in the narrow than in the wide condition.

Results: Participants systematically traded a portion of their potential gain to achieve a more comfortable grasp position. The relationship can be described by a monotonic function of wrist rotation angle. This interrelation implies that biomechanical constraints may have a direct influence on the estimated usefulness of a movement. Our findings demonstrate that the motor system includes biomechanical comfort as one factor component of planning movements that maximize expected gain.

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23.432 **Visual feedback modulates BOLD activity in the posterior parietal cortex more so for visually-guided grasping than for visually-guided reaching**

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When we reach out to grasp an object, the visuomotor system uses vision to direct our hand to the object's location and scale our grip aperture to the object's size. Several lines of evidence from human and non-human primate studies have implicated a network of structures in the posterior parietal cortex (PPC) in the programming and updating of visually guided grasping. The present study was designed to examine whether the availability of visual feedback during movement execution would modulate patterns of brain activation in the PPC for visually-guided reach-to-grasp movements. Participants were asked to either reach out and touch or reach out and grasp novel 3-D objects with or without visual feedback throughout the movement. A voxel-wise analysis was carried out using a 2 (task) x 2 (feedback) ANOVA. Not surprisingly, the availability of visual feedback was found to increase activation in many visual areas in both the dorsal and ventral streams. In addition, grasping (as compared to reaching) invoked activity in motor areas (premotor and primary motor cortex), early visual areas (striate and extra-striate cortex), and areas in both the dorsal [e.g., anterior intraparietal sulcus (aIPS) and superior parietal lobule (SPL)] and ventral (lateral occipital complex, fusiform gyrus, and inferior temporal cortex) streams of visual processing. Importantly, however, task by feedback interactions were observed in several dorsal stream regions. In the right SPL, the left aIPS, and the precuneus in both hemispheres, visual feedback increased the level of activation associated with reach-to-grasp movements relative to those made without visual feedback, a difference that was not apparent in the levels of activation associated with reach-to-touch movements. Taken together, these results add to a growing body of evidence that implicates the PPC in the programming, online monitoring, and updating of visually guided grasping.

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23.433 **Plans for action in posterior parietal cortex: An rTMS investigation**

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Many theories of visuomotor control distinguish between the planning of a movement (i.e., programming the initial kinematic parameters), and the execution of the movement itself (so-called 'online control'). Evidence from neurological patients and functional brain imaging studies strongly support the notion that the posterior parietal cortex (PPC; especially the left hemisphere) plays a critical role in the planning and execution of goal-directed movements. Importantly, however, there is no clear consensus on how different sub-regions within the PPC contribute to movement planning and execution. Some theories suggest that both planning and execution are carried out primarily within the superior parietal lobe (SPL), whereas others suggest that planning is carried out by inferior parietal lobe (IPL) and execution is carried out by the SPL. In the current study we investigated this question using MRI-image guided repetitive transcranial magnetic stimulation (rTMS; 3 pulses at 10Hz). Specifically, we applied rTMS to different sites within the left IPL (angular and supramarginal gyri) and the left SPL (anterior and posterior SPL) either at target onset (planning), or movement onset (execution), while participants (n=12) made open-loop pointing movements to targets in peripheral vision. Thus, participants had vision of their hand and the target during the planning phase; however, vision of the hand and the target were removed at movement onset. The results revealed a significant interaction between the site of rTMS stimulation and the time of rTMS delivery. This interaction was driven by a significant increase in movement endpoint error when rTMS was applied during movement planning compared to execution in the SPL compared to both the IPL and sham stimulation. In short, these data are consistent with the idea that the SPL plays a crucial role in the planning (i.e., programming) of goal directed movements.

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23.434 **Parietal regions specialized for saccades and reach in the human: a rTMS study**

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Primate neurophysiology and human brain imaging studies have identified effector-related regions in the posterior parietal cortex (PPC). However, this specialization is less clear in human fMRI studies. Here we used fMRI-derived regions of interest to navigate transcranial magnetic stimulation (TMS) and causally determine saccade and reach specificity in three PPC regions. In experiment 1, six subjects performed memory-guided saccades and reaches with their dominant, right-hand to remembered peripheral targets in complete darkness. During the interval between viewing the target and the saccadic eye- or reach-movement, we applied trains of repetitive TMS to anatomically defined regions of interest from individual subjects - 1) superior parieto-occipital cortex (SPOC); 2) the more anterior-lateral medial intraparietal sulcus (mIPS); and 3) a yet more anterior dorsal-lateral PPC region near the angular gyrus (cIPS) - in both hemispheres. Stimulation to left mIPS and cIPS regions increased reach endpoint variability to rightward (contralateral) targets, whereas stimulation of SPOC deviated reach endpoints towards visual fixation. Only rTMS to right mIPS and cIPS disrupted contraversive saccades. We then repeated experiment 1 with the nondominant left-hand to investigate whether rTMS-induced errors remain spatially fixed or reverse (experiment 2). Here we found that stimulation of right mIPS and cIPS caused a significant increase in endpoint variability to leftward (contralateral) targets. In our final third experiment, we investigated reaching with or without visual feedback from the moving hand to determine whether rTMS disrupted the reach goal or the internal estimate of initial hand position needed to calculate the reach vector. In both mIPS and cIPS visual feedback negated rTMS-induced reach errors, whereas rTMS-induced, directional reach biases in SPOC remained. Collectively, these results show that a more medial region centered on parieto-occipital junction is involved only in planning of reach (encodes goal representation), and more lateral regions in human PPC have multiple overlapping maps for saccade and reach planning (encodes reach vector information).

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23.435 **Coding of curved hand paths in the Parietal Reach Region**

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The posterior parietal cortex is an interface between perception and intentional actions (3) demonstrated with the memory-guided reach paradigm. Often the typical PRR neuron responds to visual targets briefly flashed in the dark, sustains the activity during the planning period, and has another firing burst with the initiation of the reach. These responses are gain-modulated by arm position yet the tuning remains throughout the planning period. Such planning-activity patterns suggest a representation of the reach goal indicating the direction of a straight reach from the initial position of the hand to the distal target. It is at present unknown (1) whether this planning code would change when the path to the distal target is not straight, and/or (2) whether this code exclusively represents the goal of the reach. We addressed the first question by interposing physical obstacles on the way to some targets to evoke curved hand paths and necessarily elicit an initial rotation of the hand-target movement vector. To address the second question we placed the obstacle outside of the cells' memory response field and compared its memory activity to the first case, in which the obstacle was placed near the cell's response field. We found systematically in 95 cells from two monkeys a transient remapping and re-scaling of the cells' -response fields during the planning of obstacle-avoidance. Furthermore, these dramatic changes occurred whether or not the obstacle fell near the center of the memory-response field, and despite identical retinal input in the dark (i.e. the fixation light and the target in the periphery). These PRR cells transiently maintained a curved hand path code, and returned back to their original response fields when planning straight reaches again.

23.436 **Posterior Cortical Atrophy: An investigation of grasping**

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At last year's VSS meeting (journalofvision.org/9/8/1095/) we presented a patient with posterior cortical atrophy (PCA) who demonstrated a severe deficit in face recognition, problems interpreting and reproducing line drawings of common objects, simultanagnosia, and colour hallucinations. Despite these perceptual difficulties, she was able to accurately guide her hand to stable grasp sites on irregularly-shaped objects, and she showed appropriate grip scaling during reach-to-grasp movements. It has been suggested that such symptomatology represents a 'ventral' form of PCA, in which damage is predominantly restricted to occipitotemporal areas (Ross et al., 1996). The current study explored the visuomotor abilities of three patients with PCA in relation to their perceptual deficits. In one experiment, subjects were presented with two asymmetrical, irregularly-shaped objects and asked whether they were the same or different. They were then prompted to reach out and pick up one of these objects. We found that PCA patients unanimously performed worse on the object discrimination task than age- and gender-matched controls, yet they executed accurate grasps to these same objects. In another experiment, subjects had to reach out and pick up simple, rectangular blocks under free-viewing (closed-loop), no-vision (immediate open-loop), and delay conditions. Control subjects appropriately scaled their grasps in accordance with block size under all task conditions. In contrast, PCA patients scaled effectively during closed-loop and immediate open-loop conditions, but lost this ability following a three second delay. Previous work has demonstrated that introducing a delay in a grasping task forces visuomotor systems to rely on a stored 'percept' of the target object retrieved from the ventral stream (Goodale et al., 1994), which our patients clearly lack. This study supports the idea that PCA may include two unique variants - 'dorsal' and 'ventral' PCA, and reinforces the findings that there are separate neural pathways that mediate vision-for-perception and vision-for-action.

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23.437 Investigating action understanding: Activation of the middle temporal gyrus by irrational actions

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Performing goal directed actions towards an object according to contextual constraints has been widely used as a paradigm to assess the capacity of infants to evaluate the rationality of others' actions. Here we used fMRI to visualize the cortical regions involved in the assessment of action rationality. To this end, we scanned 15 participants, showing videos of human actors reaching over a barrier to grasp a fruit. The conditions were arranged according to a 2x2 factorial design by either changing the height of the barrier, or the height of the arm trajectory. The conditions were: 1) low barrier with high arm trajectory, 2) high barrier with high arm trajectory, 3) low barrier with low arm trajectory and 4) high barrier with low arm trajectory. Thus, in the first three conditions the arm trajectory was not adapted to the height of the barrier, rendering the action non-rational. Directly after scanning, participants rated the rationality of the videos and the ratings of a given subject were directly used to model the contrasts for that subject. Random effects analysis, combining these contrast images from all subjects, showed bilateral activation of the posterior middle temporal gyrus (pMTG). In contrast to rationality, the height of the barrier was indicated amongst others by the activity of the EBA. An additional control experiment, showing random dot texture patterns, animated with exactly the same local motion present in the original videos, confirmed that pMTG activation was related to rationality and not to low level differences in the videos. Our pMTG activations were imbedded in the STS regions processing the kinematics of observed actions [Jastorff & Orban, 2009]. These results together with those of Saxe et al [2004] suggest that rationality is assessed initially by purely visual computations, combining kinematics of the action with visual elements of the context.

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23.438 Role of visual guidance in reaching after right intraparietal sulcus resection

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We report data from a 50-year-old woman (KH) who exhibited gross visually-guided reaching errors shortly after surgical resection of a benign brain tumor restricted to the right posterior intraparietal sulcus. Testing was performed two to three months post-resection. In Experiment 1, we assessed KH's ability to reach to non-foveated targets presented on a touch screen with either the right or left hand. Trials were randomly presented within two conditions: with vision during the entire reach, or without vision (using PLATO occlusion glasses) after reach initiation. KH was significantly less accurate with both hands when reaching for targets presented left but not right of fixation (non-foveal optic ataxia), and only on trials with vision of the limb. These results suggest that the right posterior intraparietal sulcus is involved in online correction of visually-guided reaching. Second, previous studies reported that optic ataxics became more accurate when reaching to remembered target locations when compared to visible target locations (e.g. Milner, Paulignan, Dijkerman, Michel, & Jeannerod, 1999; Milner et al., 2001; Himmelbach & Karnath, 2005). In Experiment 2, we repeated the same task as in Experiment 1, with a five second delay between stimulus offset and reach initiation. In contrast to this previous report, KH was significantly less accurate when reaching to targets after a five second delay (relative to visible targets). We discuss our findings with respect to the neural representations used to guide reaching to visible and remembered target locations.

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23.439 Visual Field Effects of Bimanual Grasping

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Grasping objects is a fundamental skill, required to successfully interact with the environment. Most research on grasping has focused on grasping with one hand, and it has shown that grasping involves a network of fronto-parietal brain regions that controls grasps in a relatively segregated, contralateral fashion. However, one phylogenetically older form of grasping is grasping with two hands. Mechanisms underlying bimanual grasping (BMG) are not well understood, specifically how the brain's two hemispheres integrate their control processes of grasping for the two hands via the corpus callosum. BMG could either involve both hemispheres equally, requiring callosal connections at the level of motor control, or BMG could be predominately controlled by one hemisphere, only requiring callosal connections at earlier, sensory stages. To test this, we asked participants to grasp objects with both hands while fixating either to the left or right of the objects. The dependent measure was the tilt of the maximum grip aperture (MGA) in space. We predicted tilt to be forward on the side of the dominant hand. However, tilt should not be influenced by visual field if BMG were controlled by the dominant left hemisphere only. In contrast, tilt should vary across visual fields if both hemispheres coordinated their BMG control. We found the latter to be true. MGA was less tilted when participants fixated to the left side of the objects than when fixating to the right side. Our results suggest that BMG is not exclusively controlled by the left hemisphere. Further research is required to confirm whether direct input from the right visual field into the left hemisphere rather than input from the left visual field results in more coordinated bimanual grasps.

Attention: Spatial selection and modulation

Orchid Ballroom, Boards 440–456

Saturday, May 8, 8:30 - 12:30 pm

23.440 Attention does alter apparent contrast: Evaluating comparative and equality judgments

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Introduction: Covert attention not only improves performance in many visual tasks but also modulates the appearance of several low-level visual features (e.g. Carrasco, Ling & Read, 2004). Studies on attention and appearance have assessed subjective appearance using a task contingent upon a comparative judgment between two stimuli. Recently, Schneider and Komlos (2008) questioned the validity of those results because they did not find a significant effect of attention on contrast appearance using a same-different task. They claim that such equality judgments are bias free whereas comparative judgments are bias prone and propose an alternative interpretation of the previous findings based on a decision bias. However, there is no empirical support for the superiority of the equality procedure. Here, we compare the sensitivity of both paradigms to shifts in perceived contrast.

Methods: In four experiments, we measured contrast appearance using either a comparative or an equality judgment. With both paradigms, the same observers judged the contrasts of two simultaneously presented stimuli, while either the contrast of one stimulus was physically incremented (Experiments 1&2) or exogenous attention was drawn to it (Experiments

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3&4). Observers' points of subjective equality (PSEs) were derived from cumulative- or scaled-Gaussian model fits for the comparative and equality judgments, respectively.

Results & Conclusions: We demonstrate several methodological limitations of the equality paradigm. For instance, changes in the frequency of 'same' responses make an additional scaling parameter necessary to explain the data. PSE estimates are less accurate: unlike in the comparative judgment, asymmetric criteria for low and high contrasts lead to a consistent underestimation of the PSE relative to veridical contrast. Furthermore, variability across observers is higher in the equality judgment. Nevertheless, both paradigms capture shifts in PSE due to physical (Experiments 1&2) and perceived changes (Experiments 3&4) in contrast. Regardless of the paradigm used, attention significantly increases apparent contrast.

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23.441 **Covert attention affects second-order contrast sensitivity**

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Covert spatial attention affects contrast sensitivity for first-order, luminance-defined patterns, increasing sensitivity 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 typically 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 to enhance texture modulations. Here, we assessed whether covert attention affects sensitivity to second-order, texture-defined contrast. Methods: Stimuli were orientation-defined, second-order, sine-wave gratings. 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. Orientation-discrimination performance was measured as a function of modulator contrast. Stimuli appeared in four isoeccentric locations (5° eccentricity). Exogenous (involuntary) attention was manipulated with a brief peripheral precue adjacent to one of the stimulus locations. Target location was indicated by a response cue after stimulus presentation, yielding three cue conditions: valid (precue matched response cue), invalid (mismatched) and neutral (all stimulus locations precued). Results: Covert attention increased second-order contrast sensitivity at the attended location, while decreasing it at unattended locations, relative to the neutral condition. These effects were more pronounced at high second-order contrasts. The magnitude of improvement was a function of second-order modulator spatial frequency and independent of first-order carrier spatial frequency, and thus could not be explained by increased sensitivity to the carriers. The results indicate that attention improves second-order contrast sensitivity.

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23.442 **Comparison of effects of the spatial attention on stereo and motion discrimination thresholds**

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In order to examine whether effects of the spatial attention depend on the dimension of visual functions we compared magnitudes of attentional influences on stereo and motion discrimination thresholds by using the center-periphery dual visual task paradigm. The visual threshold was measured in the following four conditions. In the center-only condition (condition 1) a square target of 1° size was presented on a CRT monitor at 2° eccentricity in 8 possible directions (up, down, right, left and four oblique directions) in the visual field. In the periphery-only condition (condition 2) the target of 5° size (for stereo) or 2° size (for motion) was presented at 10° eccentricity. In the center-priority condition (condition 3) the central and peripheral targets were presented simultaneously while the observer paid more attention to the central target. In the periphery-priority condition (condition 4) more attention was paid to the peripheral target. The conditions 1 and 2 provided the baseline performance. In Experiment 1 we measured stereo thresholds with a staircase method. A random dot stereogram subtending 29° by 29° was presented for 0.2 s while the observer fixated at the central fixation point. Crossed or uncrossed disparity was given to the target and the position of the target was indicated by a white-line square. The observer's task was to indicate the polarity of depth. In Experiment 2 motion thresholds were measured. Luminance modulation and rightward or leftward motion was given to the target. The observer's task was to indicate the direction of motion. The results showed that stereo thresholds elevated almost exclusively for the less attended target. The magnitudes of stereo threshold elevation were in up to 0.5 log unit while the effects of spatial attention for motion threshold were less clear. It appears that stereo discrimination processing needs more spatial attention than motion discrimination processing.

23.443 **Attention modulates S-cone and luminance signals differently in human V1**

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INTRODUCTION: Attention modulates the steady-state EEG response to luminance and (L-M)-cone gratings by altering the response amplitude and phase (DiRusso et al, 2001). However, little is known about attention modulation in short-wave (S–cone) pathways. We used a combination of steady stage, source-imaged EEG and fMRI to extract luminance and S-cone contrast response functions (CRFs) in retinotopic human V1. We then evaluated how attention affected these CRFs as well as the temporal phase of each component. METHODS: 12 subjects viewed a series of on/off flickering Gabor patches (2cpd, 6Hz, duration 10s) defined by either luminance or S-cone contrast. The contrast and color of each patch were chosen at random. S-cone stimuli were presented at 10, 20, 40 or 80% contrast and luminance stimuli at 5, 10, 20 or 40%. Subjects performed one of two attentional tasks. 1: Detecting near-threshold contrast decrements. 2: Detecting target letters among distracters. Performance was around 75% correct on both tasks. Each combination of contrast, attentional condition and chromaticity was presented 10 times while we collected high-density EEG data. We computed the steady-state, visual evoked current density timecourses in retinotopically-defined V1 using a minimum norm inverse and boundary element models of individual heads. Finally, we extracted the phase and amplitude of the stimulus-driven responses. RESULTS: Luminance and S-cone stimuli generated qualitatively different responses. The amplitude, but not the phase of luminance responses changed with increasing stimulus contrast while S-cone-driven responses showed systematic phase changes in addition to amplitude changes. Attending to the contrast of the Gabor changed the amplitude but not the phase of the luminance responses, consistent with a contrast gain change. Attention changed the phase, rather than the amplitude of S-cone-driven responses. CONCLUSION: Attention affects S-cone and Luminance pathways differentially. This may reflect their segregation in the early visual system.

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23.444 **Attractiveness is leaky (1): Center and Surround**

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Repeated experience with a stimulus form a memory that affects preference decision in future. We have demonstrated that N(ovelty)/F(amiliarity) of a surrounding natural scene (NS) affects attractiveness of a central face (FC), even when the subjects neglected the surround NS (Shimojo, et al., VSS '09). To examine further how N and F interact between a center (task-relevant) stimulus and surrounding (task-irrelevant) stimuli, we prepared three new stimulus sets in which a central FC(, NS, or GF) is surrounded by four others (always in the same object category), and N/F of the center and the surround were manipulated independently. According to pre-ratings, the baseline attractiveness was matched between the center and the surround. The subjects performed two tasks in separate sessions: (1) to rate attractiveness of the central stimulus only, or (2) to rate attractiveness of the whole image. Eye movements were recorded (by EyeLink 2). The eye tracking results ensured the effectiveness of task instructions. Even when the subject focused on the attractiveness of the center only (in the task (1) above), it was implicitly affected by that of the surround modulated via memory. For example, attractiveness of the central new GF changed more positively across trials when the surround GF is new as opposed to old, which was however not true for the central old GF. More in general, there are signifi-

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cant interactions between the central (new/old) and the peripheral (new/old) conditions. Different factors, including (a) segregation of N/F across object categories (Shimojo, et al., VSS '07), (b) modulation of N/F due to task-dependent attention, and (c) implicit contagion of attractiveness from outside of attention, will be considered.

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23.445 **Enhance or inhibit? Behavioral and ERP effects of distractor memory on attentional competition**

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According to competition models of attention, two items compete for a cell's response when they both fall within the receptive field of that cell. This competition can be measured behaviorally as an increase in the response time to one target as its proximity to a distractor increases. This competition can also be observed in two event-related potentials (ERPs): the canonical parietal N2pc increases as a target's distance increases from a distractor, whereas the more temporal Ptc is largest when targets and distractors are very close. Thus, these components are thought to reflect different processes of resolving competition, with the N2pc involved in target selection, and the Ptc thought to reflect processes of target enhancement. Here, we examine the effect of having prior exposure to distractors on behavioral and ERP measures of attentional competition. Participants had to report the orientation of a target, and the distance between the target and a distractor was manipulated. In addition, on half the trials, participants were first given a 200 ms "preview" of the distractor. Thus, participants could use memory to remember and inhibit the distractor on the subsequent search display. The results indicate that although RTs were faster in the preview condition, they were still modulated by the spatial separation between the target and distractor, such that RTs were slowest when the distractor was next to the target. We also observed a reduction in the amplitude of the Ptc in the preview condition, relative to the "no preview" condition. This suggests that prior information about the distractor makes target processing easier. These findings indicate that the inhibition of the distractor may aid in subsequent target enhancement, although competition between targets and distractors is not entirely resolved.

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23.446 **What's up with What versus Where?**

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Two early theories of preatttentive versus attentive processing—Treisman's feature-integration theory and Julesz's texton theory—are often grouped together but in an important way they're opposites. They differ on the issue of 'What' versus 'Where'. Preattentive vision in feature-integration theory knows the identity of basic features in a scene but not where they are relative to each other; they're 'free-floating'. Preattentive vision in texton theory knows where texton gradients are, but does not know the identity of the textons whose difference creates the gradient. In both theories, attending to location provides the missing information.

Our purpose is to re-examine empirical support for the assumptions of the texton theory. Our reason for doing this comes from data of Farell and Pelli (Vision Research, 1993). They measured performance for identifying and localizing targets (digits, flickering checks) in single-and multi-scale displays. The data imply that target identification does not depend on prior knowledge of target location.

We presented arrays of 36 Gabor patches. Orientation distinguished target (horizontal or vertical) from background (oblique) patches. We measured performance as a function of target number in two tasks: pairwise discrimination of target number, and discrimination of homogeneous and heterogeneous target orientations. Brief presentation of the test array was followed by a variable interval preceding the masking array.

Results did not conform to texton theory expectations. Homogeneous vs. heterogeneous discrimination, which depends on target identity, was independent of target number. Number discrimination, which requires only target locations, fell as target number increased. And of the two, performance was lower for number discrimination, which also improved less as ISI increased. These data are the reverse of the theory's predictions and of prior results. Thus, in tasks directly testing texton theory assumptions, target identification does not depend on prior localization.

23.447 **Change of object structure as a result of shifts of spatial attention**

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The perception of ambiguous figures (e.g. duck-rabbit) can be influenced by cueing spatial attention to a part of the image associated more closely with one interpretation (e.g., the mouth of the duck or the rabbit) (Tsal & Kolbert, 1985). The distribution of spatial attention can also affect the perception of ambiguous figures that change only in structure but not in meaning (Slotnick & Yantis, 2005). We asked participants to report their perception of this type of figure (similar to a Necker-cube) after briefly cueing one side. Participants were more likely to perceive the cued side of the figure as the closer side. In a second study, participants viewed the same ambiguous figure for a series of 8-second trials, and reported each perceptual switch with key-press responses. Using an ERP correlate of the distribution of spatial attention (n2pc), we found that more attention was directed toward the perceived closer side 500 ms before the report of perception, and toward the alternative side 500 ms after the report of perception. The distribution of spatial attention appears to affect the perceived structure of a constant visual stimulus.

23.448 **Do the eyes really have it? Ocular and visuomanual judgments of spatial extent.**

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Models of line bisection implicitly consider distance to be the metric by which spatial extent is processed. For example, if a 20 cm line is presented visually, the brain infers or computes its length from the visual angle subtended. An alternate hypothesis would suggest that length (D) is determined from the product of velocity (V) over time (T). We refer to this as the DVT model, which reflects an 'indirect' computation of spatial extent because it does not rely on a direct measurement of distance (D). To investigate the DVT model in a healthy population, we conducted a series of experiments which measured pointing and ocular judgments of spatial extent using the line bisection task. We manipulated line length, position, and the direction of ocular scanning prior to bisection. Scanning led to different biases in bisection than did free viewing suggesting that the mechanism involved in scanning introduced additional perceptual biases of spatial extent. Pointing behavior showed a robust influence from scan direction (i.e., left-to-right scanning created a bias leftward to that of right-to-left scanning), whereas the speed of scanning was inversely related to ocular fixation biases (i.e., slower speeds induced exaggerated biases). We were unable to show a strong effect of timing on bisection behavior perhaps because of the probe(s) used. Rather, to our surprise, we found that ocular behavior, presumably operating in a gaze-centered reference frame, and pointing behavior, operating in a hand-centered reference frame, produced distinct patterns of bisection. In general, pointing behavior generated systematic errors that were impervious to manipulations such as length, line position, or speed of scanning, whereas ocular behavior was far more variable and more susceptible to these manipulations. This suggests that judgments of spatial extent can be made independently for the hand and eye.

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23.449 **Mind wandering preferentially attenuates sensory processing in the left visual field**

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An emerging theory in visual attention is that it operates in parallel at two distinct timescales – a shorter one associated with moment-to-moment orienting of selective visual spatial attention, and a longer one (>10s) associated with more global aspects of attention-to-task. Our question is whether this slower fluctuation in task-related attention biases the same mechanism of early attentional selection as selective attention. Given that past studies have consistently revealed visual field asymmetries in selective visual attention, the objective of the present study was to determine whether sensory processing in the two visual fields is differentially modulated by whether or not one is paying attention to the current task. Participants performed a simple target detection task at fixation while event-related potentials (ERPs) to task-irrelevant visual probes presented in the left and right visual fields were recorded. At random intervals, participants were asked to report whether they were "on-task" or "mind wandering". Our results

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demonstrated that sensory attenuation during periods of "mind wandering" relative to "on-task", as measured by the visual P1 ERP component, was only observed in the left visual field. Alternatively, the magnitude of sensory responses in the right visual field was insensitive to the two different attentional states. Taken together, our results point to a visual field difference in task-related attention, one that mirrors asymmetry found in selective visual attention.

23.450 On the relationship between spatial and non-spatial attention

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Spatial attention orienting is known to enhance the signal in attended location as well as to exclude flanked noise. Moreover, spatial attention orienting is able to modulate the temporal processing, as suggested by the line motion illusion. Non-spatial attention is defined as the processing resources engagement onto the currently relevant object (measured by attentional masking) and processing resources disengagement from the previously relevant object (measured by attentional blink). In the present study we investigated the modulation of the spatial attention orienting on attentional masking. Spatial attention was manipulated by an exogenous (i.e., peripheral and non-informative) cue, while attentional masking was measured as the impaired identification of the first of two rapidly sequential objects. Results showed that, in the attended location, the non-spatial attention engagement on an object seems to occur faster (i.e., reduced attentional masking) than in the unattended location. We suggest that the spatial attention orienting is able to enhance the ability to rapidly engage non-spatial attention over time.

23.451 Linguistic control of visual attention: Semantics constrain the spatial distribution of attention

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Previous research suggests that spatial reference frames mediate linguistically-driven shifts of visual attention (Gibson & Kingstone, 2006). One consequence of reference frame usage is a selection cost when attention is directed along the left/right axis but not the above/below axis (Gibson, Scheutz, & Davis, 2009). This cost is reflected in an "Opposite Compatibility Effect" (OCE) in which slower RTs are observed when distractors located along the left/right axis opposite the cued target are response-incompatible relative to when they are response-compatible. There are two possible explanations of the OCE. According to the "differential validity hypothesis," the OCE arises because the spatial referents of "left" and "right" are less consistent than the spatial referents of "above" and "below" across discourse contexts. In this view, RTs are slower in the incompatible condition than in the compatible condition because attention is distributed more broadly in response to "left" and "right." In contrast, according to the "differential processing hypothesis," the OCE arises because observers are less likely to differentiate between the left and right locations than the above and below locations. In this view, RTs are slower in the incompatible condition than in the compatible condition because this is the only condition in which it is necessary to differentiate between the left and right locations (which takes additional time). The present experiments tested these two accounts by creating three different context conditions varying the necessity of differentiating between the two endpoints: the high differentiation condition (20% compatible/80% incompatible); the medium differentiation condition (50% compatible/50% incompatible); and the low differentiation condition (80% compatible/20% incompatible). Consistent with the differential validity hypothesis, the results showed that the magnitude of the OCE remained stable regardless of context.

23.452 The effect of attention on the multistable motion perception: Does it involve the perceived depth?

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The diamond stimulus, introduced by Lorenceau and Shiffrar (1992), contains four occluders and four moving lines that can be perceived as coherent or separate motion. Here we used it to investigate whether attention alone (excluding the effect of fixation) can bias multistable perception, and whether this effect of attention is due to that attended areas look nearer. Our previous research has found that coherent motion perception increased when the occluders were in front of the moving lines, and decreased when the occluders were behind. Therefore, we predicted that coherent motion should be perceived more under the condition of attending to the occluders rather than the moving lines if attended areas look nearer. Observers' intention was controlled in this study in order to reveal the effect of attention better. In experiment 1, we manipulated attention (attending to occluders or moving lines) as an independent variable. Results showed that the percentage of time perceiving coherent motion during one minute trials was higher in attending to occluders condition than attending to moving lines condition significantly, consistent with our prediction. In experiment 2, one more variable was added: the binocular disparity of the moving lines. It was manipulated at four different levels behind the occluders. We predicted that the effect of attention should decrease with increasing depth, because the effect of attention that affects depth would be minor under large binocular disparity. The results were consistent with our prediction. In experiment 3, we added cast shadow for the occluders as a monocular depth cue to enhance the perceived depth of occluders in front of moving lines, and the effect of attention was found to be eliminated compared with the normal condition. These results all consisted with that attention alone can bias multistable perception by making attended areas look nearer.

23.453 Distractor filtering in media multitaskers

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Despite the near-ubiquity of visual search, performance can differ wildly from person to person, especially under distracting conditions. Recent research suggests that extensive exposure to certain everyday activities (e.g., playing action video games, speaking a second language, media multitasking) may be able to enhance search performance. Here we explored individual differences in frequency of media multitasking (e.g., watching TV while reading or playing video games while talking on the phone) to investigate whether this common behavior can impact the ability to filter out distractions during visual search. Participants searched simple arrays of objects for a shape singleton (i.e., a circle among squares). Half the arrays also contained a color singleton (i.e., a red shape among green shapes). Each participant completed two conditions; in the 'Never' blocks participants were instructed that the color singleton distractor would never be the target shape singleton, and in the 'Sometimes' blocks they were instructed that it could sometimes be the target. Previous work has shown that participants can successfully use this instructional information to improve performance in Never blocks by exercising top-down control to filter out irrelevant singletons. Here we found that overall (collapsed across blocks), media multitaskers responded more quickly than non-multitaskers. z-Transformed results revealed specific ways participants differed; in the Never blocks multitaskers performed relatively worse than non-multitaskers when distractors were present, but both groups showed comparable distractor-related slowdowns in the Sometimes blocks when top-down distractor filtering was not necessary. These results suggest that media multitaskers did not use the information about the distractor's irrelevance in the Never blocks to filter it out to the same degree as non-multitaskers. This is consistent with the idea that those who routinely consume multiple media in daily life demonstrate poorer filtering of irrelevant information in a laboratory setting.

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23.454 The sensory component of inhibition of return

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Inhibition of return (IOR), the slowing of reaction times to a target presented at a location that was cued more than some 300 ms earlier, is usually attributed to attentional or oculomotor mechanisms. The sensory influence of the cue (i.e. masking) is ignored as such sensory effects are believed to occur within a much shorter time-range. The attentional and oculomotor accounts of IOR would predict independence of IOR from similarity between the cue and the target, as long as the cue is equally effective in drawing attention and the target is equally detectable. We asked whether saccadic reaction times (SRT) to a pre-cued location are sensitive to a difference in orientation between the cue and the saccade target; in particular

for stimulus timings that are common in IOR paradigms. We first tested the influence of the brief bilateral presentation of oriented stimuli (Gaussian windowed sine-wave gratings) on SRT to a unilateral grating presented at a stimulus-onset-asynchrony (SOA) of 100, 250, 450 or 650 ms. The target was similar to the cue(s), but of a lower contrast and rotated by 0°, 45° or 90°. SRT showed a strong dependence on rotation for the shortest SOAs, as can be expected from masking of the target by the cue. More interestingly, some dependence on rotation was still found with the 450 and 650-ms SOA. In a subsequent experiment we tested the effect of rotation on IOR (uncued location – cued location SRT) by presenting a single cue (the proper IOR paradigm), with an SOA of 650 ms. We observed that IOR was larger when the orientation of the cue was the same as the orientation of the target. Our results indicate that inhibited visual processing of a repeated stimulus can contribute to IOR independently of a spatial attention bias.

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23.455 **Spatial properties of the Attentional Repulsion Effect**

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Reliable effects of attention on reaction time and accuracy measures have been well documented, yet little is known about how attention affects one's perception of space. Utilizing the attentional repulsion paradigm developed by Suzuki and Cavanagh (1997), the present study examined the effects of transient involuntary spatial attention on the perception of target position. The attentional repulsion effect (ARE) refers to the illusory displacement of two vernier lines away from the focus of attention. In the first experiment, brief peripheral cues captured observers' attention prior to the presentation of a vernier. Responses indicated perceived vernier offset to be away from the cues, replicating the ARE. Moreover, the magnitude of the ARE depended on cue-target distance, indicating that the effects of attention on perceived target location are not uniform and vary systematically as a function of the proximity of the target to the focus of attention. Experiment 2 was designed to determine whether repulsion occurs away from the cue's center of mass or from the cue contour. Perceived repulsion always occurred away from the cue's center of mass, regardless of the arrangement of the contours relative to the vernier lines. However, presenting the vernier within the contours of the cue reduced the magnitude of the repulsion effect, suggesting that the contextual relationship between the cue and the target plays a role in modulating the effect as well. Finally, Experiment 3 demonstrated that increasing the size of the cue increases the magnitude of the repulsion effect when cue-target distance is held constant. Together, these experiments suggest that the magnitude of the ARE depends jointly on the center of the cue's mass and on whether the target is bounded by the cue contour, though attention to the cue's center of mass is largely responsible for producing the repulsion effect.

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23.456 **Individual differences in attentional orienting predict performance outcomes during learning of a new athletic skill**

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Dynamic performance of many athletic motor skills requires rapid orienting of visual attention. For example, previous studies have shown that young, high skill-level hockey players have smaller response time differences between validly and invalidly cued locations in standard spatial cueing tasks compared to low skill-level hockey players (Enns & Richards, 1997). One interpretation of these results is that high-skill individuals are more efficient in deploying spatial attention over multiple locations. However, it is unclear if this effect was brought about by experience in performing the skill, or if individual differences in attentional orienting facilitated development of the skill itself. Here, we tested whether individual differences in attentional orienting predicted success during learning of a new athletic skill. Eighteen novices with no previous golf experience learned to putt a golf ball to targets placed at variable distances. Individual differences in attentional orienting were measured using a variant of the attention network task (Fan et al, 2002) in which a predictive number cue presented at fixation indicated the likely location of a target. The RT difference between invalid and valid trials was used to index volitional orienting. A median split of the orienting scores divided the group into those with small orienting scores and those with large orienting scores. The results indicated that individuals with lower orienting scores had significantly higher accuracy during the early stages of learning in the putting task ($p<.004$). Additional analyses revealed that the orienting score was predictive of whether the individuals would achieve a pre-determined performance criterion ($r=0.69$, $p<0.03$). These results converge with previous findings indicating that during athletic performance, high-skill individuals are potentially more efficient at orienting attention than low-skill individuals. In addition, our findings demonstrate that individual differences in the orienting of visual attention may be predictive of subsequent performance in a novel athletic skill.

Binocular vision: Rivalry and bistability

Vista Ballroom, Boards 501–521

Saturday, May 8, 8:30 - 12:30 pm

23.501 **Detecting contrast differences in binocular and dichoptic vision: we use monocular or binocular channels, whichever gives the MAX response**

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Two eyes are often better than one. Models based on binocular summation of signals from each eye, with interocular contrast gain control and a single binocular output channel, account well for detection, discrimination and perception of monocular and binocular contrast. We now ask whether monocular signals also remain available to perception. Horizontal 1c/deg sine-wave gratings of contrast C were presented to both eyes for 200ms in 2AFC discrimination tasks, to determine whether contrast increments (C+dC) in one eye were more difficult to detect when accompanied by contrast decrements (C-dC) in the other eye. Summation or averaging over the two eyes should make these opposite changes cancel. Results consistently showed no cancellation. Binocular increments or decrements were more detectable than monocular ones, but thresholds for the hybrid increment/decrement condition were close to those for monocular contrast increment (on the binocular pedestal). Since the binocular channel must suffer cancellation, its absence here implies that monocular signals can remain available to perception and decision, alongside the combined binocular response. Despite this, monocular decrements of contrast on a binocular pedestal were unusually difficult to detect. An extended version of our 2-stage gain-control model (Meese, Georgeson & Baker, Journal of Vision 2006), now incorporating left-eye, right-eye and binocular channels, accurately explained the patterns of threshold variation over at least 7 distinct forms of dipper function. Importantly, the model observer is assumed to pick only the MAX response across the 3 types of channel. This normally arises from the binocular channel, which can thus occlude useful information in the monocular channels. But when the pedestal gratings are out-of-phase in the 2 eyes, interocular suppression wipes out the binocular response, and monocular channels mediate the task. This switch from binocular to monocular responses may be the early, local basis for binocular rivalry.

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23.502 **Effects of the combination of color and orientation on resolution of binocular rivalry**

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This study investigated whether visual processes selective to both color and orientation contribute to resolution of binocular rivalry, by taking advantage of the previous finding that binocular preceding stimuli of long duration phenomenally suppress one of the rivalrous stimuli having the same stimulus attribute. Specifically, this study asked how binocular rivalry between dichoptic chromatic gratings having the same color but different orientations (e.g., green/gray right-tilted vs. green/gray left-tilted gratings) would be affected by a preceding chromatic grating also having the same color (e.g., green/gray right-tilted grating) or by the one having a different color (e.g., red/gray right-tilted grating). If color-orientation selective processes contribute to rivalry resolution, modulative effects of the

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preceding stimulus should be larger when the combination of color and orientation in the preceding stimulus was the same as that in one of the rivalrous stimuli, even when the stimulus color was not relevant to binocular rivalry. In the experiment, 2 c/deg square-wave gratings were used as stimuli whose mean luminance was 4 cd/m2 and Michelson contrast was 0.60. The duration of the preceding stimulus was 1 sec and that of rivalrous stimuli was 200 msec. In addition to the orientation-rivalry condition described above, the color-rivalry condition was also designed using the similar principle. Results under the orientation-rivalry condition showed no effect of the color-orientation combination; a strong modulative effect of the preceding stimulus was found but its magnitude did not change depending upon whether the preceding stimulus had the same color as the rivalrous stimuli. Under the color-rivalry condition, however, a small difference due to the color-orientation combination was found. These results suggest that the dominance/suppression of rivalrous chromatic gratings is mainly determined by visual processes responding separately to color and orientation. A small contribution of color-orientation selective processes could be found only over limited conditions.

Acknowledgement: Supported by JSPS grant

23.503 **Dominance of Sharp over Blurred Image Features in Interocular Grouping during "Patchwork" Binocular Rivalry**

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Purpose. Previous studies have reported the dominance of a sharp image when it competes during binocular rivalry (BR) with a blurred (low-pass filtered) version of itself [e.g., Chai, Papathomas, Zhuang, Alais, VSS 2009]. In the current study we continued our efforts to mimic "monovision" correction (two drastically different focal distances for near and far in the two eyes). We investigated interocular grouping of sharp and blurred components of an image under "patchwork" BR [e.g., Kovacs, Papathomas, Feher, Yang, PNAS 1996] that is expected under monovision correction. Methods. Each eye had a 2x3 checkerboard pattern of alternating sharp and blurred patches with the complementary pattern in the other eye. Four types of conditions were compared. (1) Grayscale images with steady fixation (2) Grayscale images with the fixation mark changing position every 2 s. (3) Color condition: Sharp/blurred patches were red/green or vice versa. (4) Control condition for (3): Color patchworks either all-sharp or all-blurred images. Task was to press different buttons to report dominance of sharp/blurred features in (1) and (2) and of red/green in (3) and (4). Results. Strong interocular grouping was observed in all four conditions: 66%,67%,82%,61% in conditions 1, 2, 3, 4. Predominance of sharp patches was always larger versus blurred patches (45%, 41%, 53% versus 21%, 26%, 30% in conditions 1, 2, 3, respectively). Color enhanced the interocular grouping for both sharp and blurred features, as compared with grayscale conditions. Results were not significantly different between conditions 1 and 2. Conclusions. These results corroborate and extend earlier findings for the dominance of sharp features. They help explain how monovision can function, even when the gaze changes, as indicated by condition 2. The well-documented ability of color for interocular grouping (condition 4) explains the enhanced interocular grouping of condition 3 over 1.

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23.504 **MIB and target saliency: how many salient features are necessary for the target to disappear?**

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Attentional competition between object representations can account for the disappearances of salient targets superimposed upon a moving mask – a phenomenon known as motion-induced blindness (MIB, Bonneh et al., 2001). It has been shown that differences in luminance contrast and in shape between a target and a mask lead to the increase of the disappearances duration in MIB (Bonneh et al., 2001, Hsu et al., 2004). But how many feature differences between the target and the mask components would be sufficient to trigger such competition? We used a target which differed from the mask components either in one or in two features (color and/or motion). Participants reported disappearances in all three experimental conditions, but the amount of disappearances was significantly higher in the condition with two distinguishing features than in the conditions with just one distinguishing feature (either color $t(24)=4{,}282$, $p\leq 0{,}001$, or motion $t(24)=7{,}352$, $p\leq 0{,}001$). The amount of disappearances was also higher in the condition where the moving target and the mask differed in color as compared to the condition with the static blue target and the moving blue mask ($t(24)=4{,}481$, $p\leq 0{,}001$). However, differences in the duration of disappearances reached the level of significance only for the condition with two distinguishing target features and for the "color" condition ($t(24)=4{,}709$, $p\leq 0{,}001$). Thus, just one salient feature is enough to trigger competition between object representations. But the more target and mask representations differ in terms of visual features, the more the target disappears.

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23.505 **Crowding occurs before or at the site of binocular rivalry**

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As the ways of studying the nature of consciousness, both crowding and binocular rivalry are commonly used to render visual stimuli invisible. Crowding is the interference of object identification in peripheral vision when an object is flanked by other objects, and binocular rivalry is alternating perception created by presenting two different objects separately to each eye. We investigated whether these two phenomena interacted with each other in orientation discrimination. The task in our experiments was to discriminate the orientation of the target. In Experiment 1, we measured the thresholds of orientation discrimination when the target underwent both binocular rivalry and crowding. Either flankers (surrounding the target to produce crowding) or a competing grating (presented to the same location of the target in the opposite eye to evoke rivalry) increased the thresholds. When both the flankers and the competing grating were present at the same time, the thresholds increased more than the sum of the two effects alone. In Experiment 2, we used flankers undergoing rivalry to examine the effect of rivalry on crowding. The crowding effect with flankers undergoing rivalry was closer to the effect of collinear flankers than that of orthogonal flankers. These results suggest that rivalry does not influence the effectiveness of flankers in crowding, and crowding may occur before or at the site of rivalry. In Experiment 3, we measured mean phase durations to examine the effect of crowding on binocular rivalry. When a collinear grating to flankers was visible, suppression from flankers changed the current percept. However, when an orthogonal grating to flankers was visible, suppression from flankers helped to maintain the current percept. In conclusion, our results suggest that crowding interacts with binocular rivalry and crowding occurs before or at the site of rivalry.

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23.506 **Perceptual memory increases amplitude of neural response in sensory brain regions**

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The way the brain interprets visual input is strongly dependent on visual experience. This becomes strikingly evident when the same ambiguous visual input is seen repeatedly: Whereas continuous viewing of an ambiguous stimulus leads to ongoing abrupt changes in visual awareness, intermittent viewing results in the same perceptual interpretation over and over again. Memory for a certain perceptual interpretation thus boosts this interpretation during later encounters with the stimulus. This is contrary to the effect of adaptation, which inhibits previously seen percepts. As yet there is very limited evidence regarding the neural mechanisms underlying perceptual memory. To investigate these neural mechanisms we measured fMRI when subjects viewed an ambiguously rotating globe with intervening blank periods. As expected the intermittent presentation paradigm resulted in long sequences of reoccurrence of the same percept (either clockwise or counter-clockwise rotation). The build-up of perceptual memory during a sequence of stabilized perception was accompanied by an increase in the amplitude of the BOLD response in motion sensitive brain regions. This increase in amplitude cannot be explained as adaptation to the stimulus, because it is well established that adaptation results in a

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decreased amplitude of the BOLD response. We thus conclude that perceptual memory is represented by an increase in the amplitude of response in those brain regions that represent the memorized percept.

23.507 Differentiating the contributions of surface feature and boundary contour strengths in binocular rivalry

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Binocular rivalry (BR) is typically stimulated with a pair of grating half-images with orthogonal orientations. These half-images can be characterized by their surface boundary contour (outline) and surface feature (interior texture/grating) properties. We have shown when the interior surface feature (grating contrast) is constant, BR predominance of seeing a grating half-image increases with its boundary contour strength (Ooi & He, Perception 2006; Xu et al, Vision Research 2009). Here, we revealed the sole contribution of surface feature to BR. We used 1-deg grating discs (5 cpd, 35 cd/m2). One disc (e.g., horizontal) was fixed at 30% contrast while the other (vertical) assumed one of three contrast levels (30, 50, 85%). Two conditions were tested. (1) Disc-only condition: The grating discs were displayed against a gray background so changing the grating disc contrast varied both its boundary contour and surface feature strengths. (2) Disc-plus-background condition: The grating discs were displayed against a 135 deg grating background. The grating background contrast in one half-image was the same as the grating disc contrast in the fellow eye. This ensured that changing the contrast of one grating disc varied only the surface feature strength of that grating disc, while equalizing the boundary contour strength of the right and left half-images' grating discs. Observers tracked their BR percepts of the grating discs for 30 sec in each trial. We found increasing the contrast of one grating disc increased its predominance and dominance duration in the disc-plus-background condition, indicating the sole impact of surface feature strength. The increases were, however, smaller than that in the disc-only condition where both boundary contour and surface feature strengths contributed to BR. Thus, the present findings along with our previous results reveal both the surface boundary contour and surface feature strengths are separate factors influencing BR.

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23.508 Bistable percepts in the brain: fMRI contrasts monocular pattern rivalry and binocular rivalry

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INTRODUCTION. In monocular rivalry, the observer experiences alternations between different perceptual representations of the same image, in which different components alternate in visibility, but without complete suppression as in binocular rivalry. Surprisingly, no previous fMRI studies have directly compared binocular and monocular rivalry.

METHODS. Here we used fMRI at 3T to image activity in visual cortex while subjects perceived either monocular or binocular rivalry. The stimulus patterns were colored gratings (left & right oblique orientations) or face/house composites. The stimulus components (red or green) were either presented dichoptically for binocular rivalry or as a (monoptic) composite image with both components shown to each eye. Linear polarizers were used for dichoptic presentation. Six subjects performed either a binocular or monocular rivalry report task with the face/house or grating stimuli by indicating alternating percepts with button presses to measure alternation rates. The luminance contrasts were 9%, 18% or 36%.

RESULTS. The cortical activation for monocular rivalry included occipital pole, ventral temporal, and superior parietal cortex, while the areas for binocular rivalry also prominently included lateral occipital regions including MT+ as well as inferior parietal cortex near the TPJ. Both binocular rivalry and monocular rivalry showed a U-shaped function of activation as a function of contrast, i.e. higher activity for most areas at 9% and 36%. The increase in activation at higher contrast can be explained by an increase in neuronal response gain reflected in faster alternation rates, while that at low contrast can be explained by disinhibition (Wilson, 2007).

CONCLUSIONS. Overall, our results call into question models that distinguish binocular from monocular rivalry solely on the basis of V1 interocular competition. Rather our results indicate that binocular rivalry invokes binocular competition and suppression in higher-tier levels, whereas competition in monocular rivalry is relatively focused in early visual areas, with less inhibition.

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23.509 Zero correlation is not a hallmark of perceptual bistability: Variation in percept duration is driven by noisy neuronal adaptation

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When the sensory system is subjected to ambiguous input perception involuntarily alternates between alternative interpretations in a seemingly random fashion. Although it is clear that neuronal noise (on microsecond time scale) must play a role in the dynamics of perceptual alternations, the neural mechanism for the generation of randomness at the slow time scale of the percept durations (multiple seconds) is unresolved. Here significant non-zero serial correlations are reported in series of visual percept durations (for the first time accounting for duration impurities caused by reaction time, drift, and incomplete percepts). This refutes a general belief that a Poisson process governs perceptual alternations and that zero serial correlation is a hallmark of binocular rivalry. Comparing different stimuli, we found that serial correlations for perceptual rivalry using structure-from-motion ambiguity were smaller than for binocular rivalry using orthogonal gratings. After considering a spectrum of computational models it is concluded that noise in adaptation of percept-related neurons cause the serial correlations. This work bridges, in a physiologically plausible way, widely appreciated deterministic modelling and randomness in experimental observations of visual rivalry.

23.510 The Brain changing its Mind: bistable perception and voluntary control investigated with frontoparietal TMS

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In bistable vision, the brain is unsure which of two percepts accurately represents the outside-world. As a result, the conscious percept switches back-and-forth continuously. Neuroimaging studies have shown that frontoparietal regions are activated during this process. The role of these regions constitutes one of the main outstanding questions in visual awareness research. Some have suggested that frontoparietal regions causally induce the perceptual switches. Alternatively, perceptual switches might induce frontoparietal activations, which would speak against a top-down causal influence from frontoparietal regions. During voluntary control, when people 'will' the percept to switch more often, top-down modulation should in any case occur. Subjects are able to voluntary increase the switch rate when watching, e.g., a bistable sphere-from-motion (SFM) stimulus. Are the same regions and/or mechanisms involved in voluntary control and passive bistable vision? Are frontoparietal regions causally relevant? In the current study we addressed these issues by directly interfering with frontal and parietal cortex activity, during passive bistable vision and during voluntary control, in ten participants. Offline rTMS lasting 5 minutes (1 Hz stimulation at 110% of individual motor threshold) was found to significantly reduce the amount of voluntary control over ambiguous SFM vision for 2 minutes after stimulation, as measured by perceptual switch rate. This was true for both parietal ($p<0.05$) and frontal ($p<0.05$) stimulation. Interestingly, no such TMS effects on switch rate were found when the same frontal and parietal cortices were stimulated in the same subjects as they passively viewed the bistable stimulus. This revealed frontoparietal cortices to be causally involved in top-down modulation exercised during voluntary control. Moreover, the exact same frontoparietal cortices did not seem to play a causal role during passive viewing. This speaks against a causal influence from the frequently reported frontoparietal activations during passive bistable vision.

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23.511 Coherent global percepts increase steady-state visual evoked potential (SSVEP)

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Saturday AM

One way to study the neural basis of perception is to measure the effects of the different perceptual states induced by bi-stable visual stimuli on brain responses. Previously, we reported that the steady-state visual evoked potentials (SSVEP) to a bi-stable counter-phase flickering 8-arm radial pattern was modulated according to perceptual state, yielding higher power during perception of rotational apparent motion than during flicker perception. The current study investigated whether this dependence of SSVEP on the perceptual interpretation of an ambiguous display can be generalized to other bi-stable phenomena. We used a plaid pattern undergoing apparent motion in steps of 1/8 cycle every 50 msec, to generate 20 Hz local flicker. Similarly to continuously moving plaids, the stimulus appeared to either move as a whole in one direction (Coherency) or as two gratings sliding over each other (Transparency). The angle between the superimposed gratings was adjusted for each observer, so that the proportion of coherency percept was approximately 50%. During each 1-minute trial, observers indicated their perception continuously (coherency or transparency) by holding one of two buttons while their EEGs were recorded with 64 scalp electrodes. Coherency percept enhanced the SSVEP response at 20 Hz in the posterior (occipital) scalp region compared to the transparency percept. The results of the current study and our previous findings suggest that perceiving coherent global motion (global plaid motion or global rotation) in a dynamic bi-stable display could cause an increased phase-coherence of stimulus-driven neural activity.

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23.512 **Percept-related changes found in the pupillary constrictions to physically-identical, dichoptic luminance changes**

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[Purpose] By taking advantage of binocular rivalry, different perceptual changes can be produced with a physically identical stimulus sequence. When different brightness changes were produced using this technique, the pupillary response exhibited percept-related changes (Kimura et al., ECVP2009). This study investigated the generality of this finding using various stimulus sequences of white and black disks. [Methods] At the start of each trial, the observer dichoptically viewed white (8 cd/m2) and black (2 cd/m2) disks presented on a gray background (4 cd/m2) and pressed a key when one of the disks became exclusively dominant. The key press initiated a stimulus change to one of the followings after a short break; the same dichoptic white and black disks (WB), binocular white disks (WW), binocular black disks (BB), or dichoptic black and white disks (eye switching, BW). For example, when the initial dominant percept was black, the WW condition produced a black-to-white perceptual change. However, the same WW condition produced a white-to-white change when the initial percept was white. [Results and Discussion] The percept-related change in the pupillary response was consistently found with different stimulus sequences; larger pupillary constrictions were evoked when apparent brightness increased more with a stimulus change. In the BW condition, a large contrast increment produced by the black-to-white stimulus change in one eye seemed to have made the white disk perceptually dominant regardless of the initial dominant percept. In the WB condition, an individual difference in the perceptual change was found when the initial percept was black. However, even with these nonsystematic variations in percept, the pupillary constriction amplitude changed consistently with the perceptual change. These findings suggest that, although the pupillary light reflex is believed to be a primitive reflex and mainly mediated by subcortical pathways, it also reflects neural activities correlated with perceptual changes.

Acknowledgement: Supported by JSPS grant

23.513 **Neural correlates of binocular rivalry in human superior colliculus**

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The functional role of subcortical structures in binocular rivalry remains poorly understood. The superior colliculus (SC) is one of the key structures in subcortical visual pathways. To address the question whether the SC participates in binocular rivalry, we used high-resolution functional magnetic resonance imaging to measure the activity of the SC during binocular rivalry. Two orthogonal gratings with different colors (red/green) and contrasts (100% / 15%) were dichoptically presented. While in the scanner, subjects viewed the stimulus through anaglyphic glasses and tracked the relative dominance of these two gratings by pressing one of two buttons. The BOLD signal level of the SC correlated well with subjects' perception, increasing when the high contrast grating became dominant and decreasing when the low contrast one was perceived. This BOLD signal modulation was similar to that observed in the replay condition, during which the two monocular stimuli were physically alternating between the two eyes. BOLD signals consistent with perceptual rivalry alternations were found in the LGN and V1. The subcortical pathway through the SC is considered an alternative pathway to the geniculate-striate pathway, and is often considered to be a pathway supporting unconscious visual information processing. However, our results suggest that binocular rivalry also occurs in the SC, which has significant implications on our understanding of the neural mechanisms supporting unconscious visual information processing.

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23.514 **Dominance times in binocular rivalry reflect lateralized cortical processing for faces and words**

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During binocular rivalry, the relative dominance time of the two images are strongly influenced by lower level image factors such as image contrast (i.e., the image with a higher contrast has a longer relative dominance time). In the current study, we investigated whether lateralized cortical processing for different categories of objects could also influence rivalry alternation dynamics. Since it is known that face processing is biased towards the right hemisphere (e.g., right fusiform face area stronger than left) and processing of visual word form is biased towards the left hemisphere (e.g., visual word form area is usually localized in the left fusiform cortex), we hypothesized that the dynamics of rivalry between faces and words will show a face advantage for left visual field presentation and a word advantage for right visual field presentation. Specifically, a face and a Chinese character of the same size were dichoptically presented either to the left or right visual field, 2.5 degrees from fixation. Subjects viewed the stimuli and recorded the perceptual alternations with key presses. As predicted, the results show that there was an interaction between the visual field of presentation and the relative dominance of the type of stimuli: the relative dominance time for faces over Chinese characters was longer when they were presented in the left visual field while the relative dominance time for Chinese characters over faces was longer for right visual field presentation. We conclude that object category selective cortical areas participate in binocular rivalry competition processes and are part of the mechanisms that determine the dynamics of rivalry competition.

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23.515 **Expectation from temporal sequences influences binocular rivalry**

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We investigate here the implicit encoding of a temporal sequence of visual events and the expectation to complete the sequence. For this purpose, we tested the extent to which a series of non-rivalrous patterns can influence the dominant perception in binocular rivalry. We rely on and extend the pattern suppression phenomenon: when rivalrous oriented Gabors follow non-rivalrous Gabors, observers usually perceive the repeated orientation less often (Brascamp, Knapen, Kanai, van Ee & van den Berg, 2007). Our observers viewed sequences of non-rivalrous Gabors that could be oriented either to the left (A) or to the right (B). Sequences varied in length up to four items, for instance AABA. A pair of rivalrous Gabors then followed the sequence where A was presented to one eye and B to the other. The spatial frequency of the images during this rivalry presentation was slightly different from that of the images during the sequence and observers reported their dominant percept by referring to its spatial frequency (higher or lower than the sequence). We found that the dominant percept during the rivalrous stage was largely predictable from the previous sequence of non-rivalrous patterns. The primary factor was related to adaptation: the more often A was presented during the sequence, the more likely B would be perceived during rivalry. Another factor was related to alternation: after the sequence

BABA, B was more likely to be perceived than after the sequence AABA. These results are consistent with the phenomenon of pattern completion found with the ambiguous motion quartet (Maloney, Dal Martello, Sahm & Spillmann, 2005). In conclusion, binocular rivalry is not only influenced by adaptation of a pattern seen in the past, but also by more complex temporal structures such as the one found in the alternation of two patterns within a sequence.

23.516 **The effect of stimulus interruptions on "fast switchers" and "slow switchers": a neural model for bistable perception**

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Bistable perception is triggered by a physical stimulation that causes fluctuations between two perceptual interpretations. To date, no physiological mechanism has been causally linked to switching events (Einhauser et al., 2008; Hupé et al., 2008), leaving the neural basis of bistability unclear. External interruptions in the stimulus are known to affect perceptual switching rates: with long offsets, stimulus interruptions stabilize the percept, while short offsets trigger destabilization (Noest et al., 2007). The current study explores the latter phenomenon in a Necker cube presented for 600:1200 ms, 900:900 ms, and 1200:600 ms onset:offset durations. Figure-ground contrast varied between 100%, 50%, 25%, and 12.5%. In the flashing conditions, a 100% contrast cube was presented during the "onset phase", followed by a lower contrast cube during the "offset phase". Overall results indicate that destabilization occurs for flashing conditions, though individual results varied. In addition, subjects were evenly split between fast and slow switchers. Slow switchers showed strong biases for one percept, and sensitivity to contrast manipulations. These results suggest a dichotomy between low-level rivalry, of orthogonal orientations for example (Yu et al., 2002), and whole-form perception. Similar patterns have been described in binocular rivalry (Kovacs et al., 1996; Lee & Blake, 1999). Previous research implicates experience (Sakai et al., 1995) and genetic differences (Shannon et al., 2009) to explain why certain individuals experience fast or slow perceptual switching. We discuss our results in the context of noisy neural competition (Marr, 1982; Moreno-Bote et al., 2007). Our neural model makes use of a dynamical system developed by Wilson and Cohen (Wilson, 1999), in which two mutually inhibitory neurons interact. Manipulation of input signal strengths yields broadly similar results to those observed in this psychophysical study, suggesting that input strengths at different levels of processing may explain the divergence between fast and slow switchers.

23.517 **Visual Working Memory Content Modulates Competition in Binocular Rivalry**

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We explored whether the content of visual working memory (VWM) can modulate competition during binocular rivalry. Two arbitrary shapes, one green and one red, were presented above and below fixation for one second at the beginning of each trial. Immediately following the offset of this display, a post-cue indicated whether the upper or lower shape (a high or low tone, respectively) should be committed to VWM for later recognition. Note that color was irrelevant to the task; only the shape had to be remembered. While observers held the shape in VWM, a horizontal and a vertical grating, randomly assigned opposing colors of green and red, were presented dichoptically for 750 ms. Observers reported the orientation of the perceived grating, which served as our measure of rivalry dominance. Color was also irrelevant to the rivalry task. Approximately 4 seconds following the offset of the original shape display, two white shapes were presented to the left and right of fixation, and observers reported which matched the original to-be-remembered shape. Results showed that rivalry dominance was biased by the color of the shape held in VWM. Specifically, observers reported seeing the grating that was the same color as the to-be-remembered shape more often than the other grating. Because both colors had been viewed immediately before the rivalry task, but dominance reflected the color of the to-be-remembered object, we conclude that binocular rivalry can be resolved by the top-down influence of the properties of the object being maintained in VWM. These data demonstrate a novel interaction between the content of VWM and the content of perceptual experience.

23.518 **Where does the mask matter? Testing a local interaction account of Motion-induced Blindness**

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Introduction: Motion-induced blindness (MIB) is the perceptual phenomenon whereby stationary peripheral targets disappear when presented with a moving mask. It has been proposed that MIB is mediated by competitive local interactions between the target and mask. To evaluate this account, we introduced displays in which motion properties of the mask were systematically altered in spatially confined regions of the display (i.e., surrounding the target location or elsewhere). Specifically, these regions contained incoherent motion while the remainder of the displays contained coherent motion (we recently found that incoherent motion enhances target disappearance, and we thus exploited this finding for present purposes; Wells, Leber, & Sparrow, 2009, OPAM). We predicted that if local target-mask interactions underlie MIB, disappearance should be greatest when the incoherent motion is closest to the target. Method: The mask was composed of three distinct, evenly spaced columns of moving dots, with fixation centered in the middle column. Observers were instructed to report the perceived disappearance of a peripheral target, which was presented in one of the outer columns. On 75% of the trials, local coherence was manipulated such that one of the three columns contained incoherent motion while the other two columns were coherent. For the remaining trials, all columns were coherent. Results/Conclusions: Observers reported greater disappearance on trials containing incoherent motion, replicating our previous results. Interestingly, this enhanced disappearance occurred regardless of which column contained the incoherence. Specifically, incoherence in the center column generated the greatest disappearance, followed by incoherence in the target and opposite columns; these latter two produced similar enhanced rates of disappearance compared to the all-coherent condition. These findings do not support a mechanism in which local target-mask competition mediates MIB. Rather, the properties of the mask responsible for the phenomenon seem insensitive to the target location and also appear to scale with eccentricity.

23.519 **Why is Continuous Flash Suppression So Potent?**

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Continuous flash suppression (CFS), a potent form of binocular rivalry introduced by Tsuchiya and Koch (2005), has become a popular tool for rendering stimuli perceptually invisible. But why is CFS so effective at producing interocular suppression? We sought to identify visual properties that empower CFS and, thereby, to infer something about the neural representation of the stimulus being suppressed. In Experiment 1 we measured contrast thresholds for detecting a gabor patch (embedded in 1D, broadband noise) that was dichoptically paired either with a CFS display (dynamic 10Hz noise patterns) or with a gray screen. Compared to contrast thresholds measured without CFS, thresholds under CFS were strongly elevated when the gabor was low spatial frequency (0.5-4cpd) but less so when it was high spatial frequency (8-16cpd). In Experiment 2, we manipulated spatial frequency content of the CFS and found that a low-pass filtered CFS (0.5-4cpd) produced elevated thresholds similar to those measured when the CFS was unfiltered. High-pass filtered CFS (8-16cpd), however, produced no elevation in thresholds. In Experiment 3 we varied the temporal frequency of unfiltered CFS displays. 5Hz CFS elevated thresholds only for a low spatial frequency gabor (1cpd), whereas 20 Hz CFS produced the same pattern of threshold elevations as did 10 Hz CFS. We conclude that transients produced by rapid, abrupt flicker, together with random changes in pattern shape and contrast over time, create a suppressor that is itself immune to adaptation and that selectively impairs low-spatial frequency components of stimuli presented to the opposing eye. This selectivity of suppression underscores the importance of considering spatial frequency content of stimuli suppressed by CFS. Indeed, the present results may shed new light on the selective effects of CFS on different object categories (e.g. tools vs faces) reported in behavioral and neuroimaging studies. We are currently examining this possibility.

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23.520 **Changes in Bistable Perception Induced by Fear Conditioning**

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Background: When observers view ambiguous figures for prolonged period of time, they experience perceptual alternations between two possible visual interpretations (Leopold & Logothetis, 2003). Dubbed bistable perception, this phenomenon has been considered as a useful means to study visual awareness since it induces spontaneous fluctuation in awareness despite constant physical stimulation (Kim & Blake, 2005). To investigate whether visual awareness during bistable perception is affected by emotional valence associated with one of two interpretations, we exploited Pavlovian fear conditioning (Pavlov, 1927). Methods: Among a variety of ambiguous figures, we selected man-rat and duck-rabbit which induced balanced perceptual alternations in a pilot test. Prior to and following conditioning, observers tracked their perceptual experiences during 12 100-sec trials (6 for each ambiguous figure) by depressing one of two keyboard buttons. During conditioning, a pair of unambiguous variants of the man-rat figure was used as conditioned stimuli (CS). For a half of the observers tested, the man image (CS+) was paired partially with electrical finger shock (US) while the rat image (CS-) was unpaired with the electrical shock. For the other half, the rat image was CS+ while the man image was CS-. Reaction time was measured following observers' 2-AFC discrimination task (man or rat) to assess conditioning effect independently. Anxiety test was also given to all observers. Results: For observers who showed faster response to CS+ paired with the shock than to CS- during conditioning, perceptual awareness of CS+ during bistable perception increased following conditioning. Besides, observers who marked high anxiety scores tend to perceive CS- longer following conditioning. Conclusion: Perceptual awareness during bistable perception is affected by fear conditioning. Individual differences in susceptibility of conditioning and the level of anxiety are influential factors.

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23.521 **Spatial aspects of binocular rivalry in emotional faces**

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Previous research has shown that emotional content can influence dominance duration in binocular rivalry, with the period of dominance for an emotional image (e.g. a fearful face) being significantly longer than a neutral image (e.g. a neutral face or a house). Furthermore, it has been found that the greater the foveal eccentricity of a rival pair of simple images, the slower the rate of rivalry. The current study combined these two findings to investigate the dominance of faces and the rate of rivalry in the periphery. Rival face (fearful or neutral) and house pairs subtending 5.2° x 6.7° were either viewed foveally, or the near edge of the stimuli was at 1° or at 4° eccentricity. While neutral faces dominated over houses in only the foveal condition, fearful faces dominated over houses in all three conditions. There was no effect of eccentricity on the rate of rivalry. These results provide support for the dominance of face stimuli over house stimuli, particularly for faces displaying fearful expressions.

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Face perception: Experience

Vista Ballroom, Boards 522–538

Saturday, May 8, 8:30 - 12:30 pm

23.522 **The speed of familiar face recognition**

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Recognizing a familiar person from his/her face is a fundamental brain function. Surprisingly, to date the actual speed of categorizing a face as familiar remains largely unknown. Here we seek to clarify this question by using a Go/No-go familiarity judgment task with photographs of personally familiar (same classroom as the participant) and well-matched pictures of unfamiliar faces, which required speeded responses to individually presented face stimuli. During the recording of high-density event-related potentials (ERP, 128 channels), two groups of young adult participants were instructed either to respond when a photograph of a personally familiar face was presented (n = 11, 6 females), or when the face was unfamiliar (n = 12, 7 female). Face stimuli contained external features (hair), but external indicators of identity were carefully removed (clothes, ….). Each face stimulus appeared for 100ms, followed by a blank screen (1500-1700ms). Behaviorally, faces could be classified as familiar as early as 310-320ms (average RT, 450 ms), about 80ms faster than when unfamiliar face categorization was required. ERP differential waveforms between Go and No-go responses when detecting familiarity showed the earliest difference at occipito-temporal cortex shortly after 200 ms, starting in the right hemisphere, and 10 ms later in the left hemisphere. Differences appeared about 50 ms later for the Go-unfamiliar decision task, with no differences in lateralization of onset times. There were no clear effects of face familiarity on earlier visual event-related potentials (P1, N170). These earliest effects observed in electrophysiological recordings are compatible with the behavioral output taking place at about 100 ms later. They indicate that the human brain needs no more than 200ms following stimulus onset to recognize a familiar person based on his/her face only, a time frame that puts strong constraints on the time-course of face processing operations in the human brain.

23.523 **Tracking qualitative and quantitative information use during face recognition with a dynamic Spotlight**

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Social experience and cultural factors shape the strategies used to extract information from faces. These external forces however do not modulate information use. Using a gaze-contingent technique that restricts information outside the fovea - the Spotlight - we recently showed that humans rely on identical face information (i.e., the eye and mouth regions) to achieve human face recognition (Caldara, Zhou and Miellet, 2010). Although the Spotlight allows precise identification of the diagnostic information required for face processing (i.e., qualitative information), the amount of information (i.e., quantitative information) necessary to effectively code facial features is still unknown. To address this issue, we monitored the eye movements of observers during a face recognition task with a novel technique that parametrically and dynamically restricts information outside central vision. We used Spotlights with Gaussian apertures centered on the observers' fixations that dynamically and progressively expanded (at a rate of 1° every 25ms) as a function of fixation time, Thus, the longer the fixation duration, the larger the Spotlight aperture size. The Spotlight aperture was contracted to 2° (foveal region) at each new fixation. To facilitate the programming of saccades and natural fixation sequences, we replaced information outside central vision with an average face template. This novel technique allowed us to simultaneously identify the active use of information, and provide an estimate of the quantity of information necessary at each fixation location to achieve this process. The dynamic Spotlight technique revealed modulations in the quantity of information extracted from diagnostic features, even for the same facial features (i.e., the eyes). This sensitivity varied across observers. Our data suggest that the face system is not uniformly tuned for facial features, but rather that the calibration modulating the intake of visual information is observer-specific.

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23.524 **What's behind a face: semantic person identity coding in FFA, as revealed by multi-voxel pattern analysis**

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Identifying a familiar face involves the access to and activation of semantic knowledge about an individual. Several studies have shown that the Fusiform Face Area (FFA) is involved in face detection and identification. Conventional studies targeting face identification processes are generally

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limited to visual features, thereby ignoring semantic knowledge about individuals. To what extent FFA has access to person-specific knowledge remains unknown.

In the present study we addressed this issue by designing an 8 x 8 word matrix, consisting of 8 categories: profession, European capital cities, car brands, music styles, pets, hobbies, sports and housing types. Each column represents a category, whereas each row can be interpreted as information about an individual. In the fMRI-scanner, participants were repeatedly presented with blocks of 8 words: either presented in category-related context (column-wise, category condition), or presented in person-related context (row-wise, person condition). Subjects were instructed to memorize all 8 items belonging to each category (e.g., "sports", category condition) and to each person (e.g. "John", person condition). Using this approach, we were able to control for visual and semantic stimulation across conditions.

Univariate statistical contrasts did not show any significant differences between the two conditions in FFA. However, a multivariate method based on a machine learning classification algorithm was able to successfully classify the functional relationship between the two conditional contexts and their underlying response patterns in FFA. This suggests that activation patterns in FFA can code for different semantic contexts, thus going beyond facial feature processing. These results will encourage the debate about the specific role of FFA in face identification.

23.525 **Can we dissociate face perception and expertise?**

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Some of the brain areas in the ventral temporal lobe, such as the fusiform face area (FFA), are critical for face perception, but what determines this specialization is a matter of debate. The face specificity hypothesis claims that faces are processed domain specifically. However, the alternative expertise hypothesis states that the FFA is specialized in processing objects of expertise. To disentangle these views, some experiments used an artificial class of novel objects called Greebles. These experiments combined a learning and fMRI paradigm. However, there are some problems with these studies: the limited number of brain regions examined (only face-selective regions), the high similarity between faces and Greebles, and other methodological issues. Given the high impact of this paradigm, we investigated these issues further. In our experiment eight participants were trained for ten 1-hour sessions at identifying a set of novel objects, Greebles. We scanned participants before and after training and examined responses in the FFA as well as in the lateral occipital complex (LOC). To isolate expert processing, we compared responses to upright and inverted images for faces and for Greebles. In contrast to previous reports, we found an inversion effect for Greebles before training. This result suggests that people interpret the 'novel' Greebles as faces, even before training. This prediction was confirmed in a post-experimental debriefing. In addition, we did not find an increase of the inversion effect for Greebles in the FFA after training. This indicates that the activity in the FFA does not depend on the degree of expertise acquired with the objects. In the LOC we find some indications for an increase of activation for Greebles after training. These findings are in favor of the face specificity hypothesis, with the understanding that the notion 'face' refers to "every stimulus that is interpreted as containing a face".

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23.526 **Adaptation aftereffects to facial expressions viewed without visual awareness**

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Human faces are compelling visual objects whose salience is further boosted when they portray strong emotional expressions such as anger. Can aftereffects associated with adaptation to facial expressions (FEAs) be induced when observers are unaware of those expressions under continuous flash suppression (CFS)? During repeated 5-second adaptation periods, observers monocularly viewed faces that were either visible continuously or were erased from visual awareness by a CFS stimulus presented to the other eye. During brief test trials interspersed between successive adaptation periods, observers were presented with a "morph" face whose emotional expression was the weighted average between two extremes of expression used to create the morph (e.g., angry vs fearful); following each test presentation, observers selected one of two response categories to indicate perception of the test face's emotional expression. In two experiments we found that robust FEAs were generated when adapting faces were visible but were abolished when those faces were perceptually suppressed by CFS; these findings replicate earlier results measuring face identity and gender aftereffects. A third experiment using the same stimuli and procedures produced significant contrast adaptation aftereffects to suppressed faces, confirming that the adapting stimuli were not rendered completely ineffective by CFS. In a fourth experiment, observers performed a luminance discrimination task that required attending to the spatial location of an adapting face, although the face itself could not be seen. In the presence of endogenous attention, significant FEAs were induced by suppressed adapting faces. These findings, together with other evidence, suggest that attentional resources must be available and further allocated to the location of the face stimulus for adaptation aftereffects to occur, even when the face is outside observers' awareness.

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23.527 **Crossing the "Uncanny Valley": adaptation to cartoon faces can influence perception of human faces**

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Adaptation to distorted faces can shift what individuals identify to be a prototypical or attractive face. This effect occurs both across and within sub-categories of human faces, such as gender and race/ethnicity, suggesting that there is a common coding mechanism for human faces (a single face space) and dissociable coding mechanisms for subgroups of human faces. But does this face space extend to non-human faces? The construct of the "uncanny valley" suggests that as human-like features increase, people respond more positively, but at a distinct point, there is an "uncanny valley," a region where the deviations from humanness are stronger than the reminders of humanness, which creates feelings of uncanniness and repulsion. This points to a significant divide between human faces and other faces such that they may not share a common face space. It is also important to note that low-level shape adaptation can affect high-level face processing but is position dependent and hence not face-specific. Thus, it is unclear whether there is a common coding mechanism for all faces, including non-human faces, that is nevertheless specific to faces. This study assessed whether there is a single face space common to both human and cartoon faces by testing whether adaptation to cartoon faces can affect perception of human faces. Participants were shown Japanese animation cartoon videos containing faces with abnormally large eyes. Using animated videos eliminated the possibility of position dependent adaptation (because the faces appear at many different locations) and more closely simulated naturalistic exposure. Adaptation to cartoon faces with large eyes significantly shifted preferences for human faces toward larger eyes, consistent with a position independent, common representation for both cartoon and human faces. This supports the possibility that there are representations that are specific to faces yet common to all kinds of faces.

23.528 **Adaptation to Up/Down Head Rotation in Face Selective Cortical Areas**

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Although faces are naturally seen in both left/right and up/down rotated views, virtually all fMRI work on the representation of face views has examined only left/right rotation around frontal views. Accordingly, we designed an fMRI adaptation study to test multiple cortical areas for up/down viewpoint selectivity. Face-selective regions of interest were determined in a block-designed scan comparing responses to faces versus houses. This identified five face-selective regions of interest: fusiform face area (FFA), occipital face area (OFA), lateral occipital complex (LOC), superior temporal sulcus (STS), and inferior frontal sulcus (IFS). Event-related scans with a cross-adaptation paradigm were used to examine BOLD signals in each face region. Subjects adapted to frontal, up 20°, or down 20° views followed by one of these as a test view, thus producing nine different adapt/test combinations. Twelve subjects with normal vision were scanned. An initial two way ANOVA examined effects of hemisphere and self-adaptation (i.e. identical test and adapt stimuli). This analysis showed an effect of hemisphere (right magnitudes larger) only in FFA, and significant adaptation effects in FFA ($p < 0.001$), OFA ($p < 0.01$), and IFS ($p < 0.028$). A second ANOVA compared results for all adapt and test view combinations to their no adapt conditions in these three areas. FFA and IFS showed a significant cross-adaptation as well as self-adaptation. In general, upward faces produced greater adaptation than adaptation to frontal or downward faces in these areas, thus indicating view selective tuning in the up/down direction. Results in OFA, however, suggest an invariance to up/down head rotation. Thus, up/down head rotation is encoded in some but not all face selective cortical areas.

23.529 **Do bilinguals have a different hemispheric lateralization in visual processing from monolinguals?**

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Previous studies showed reduced hemispheric asymmetry in non-verbal tasks such as face perception for alphabetic bilinguals compared to alphabetic monolinguals (Hausmann et al., 2004). Nevertheless, it remains unclear whether this effect can also be observed in bilinguals of a logographic language (such as Chinese) and an alphabetic language. Since logographic language and alphabetic languages are dramatically different in their orthography and how orthographic components are mapped to pronunciations and meanings, bilinguals of a logographic and an alphabetic language may have different visual experience than bilinguals and monolinguals of alphabetic languages. In this study, we aimed to examine whether reduced hemispheric asymmetry in non-verbal tasks can also be observed in Chinese-English bilinguals. We compared results of Chinese-English bilinguals and English monolinguals in three tachistoscopic identification tasks: Chinese character sequential matching task, English word sequential matching task, and intact-altered face recognition task. In the reaction time data, we found faster response times for both Chinese character and English word targets presented in the right visual field than in the left visual field (i.e. left hemisphere advantage) in bilingual participants; in contrast, faster response times in the right visual field were only observed for English word targets in monolingual participants. In the discrimination sensitivity measures (D-prime), we found that both monolinguals and bilinguals exhibited a left visual field/right hemisphere advantage for Chinese character matching and a right visual field/left hemisphere advantage for English word matching; in addition, there was more lateralization for bilinguals than monolinguals. In contrast to the results of Hausmann et al. (2004), we failed to observe a difference in lateralization in the intact-altered face recognition task between English monolinguals and Chinese-English bilinguals. Our results suggest that different kinds of language experience may have different influences on hemispheric lateralization in visual processing.

23.530 **Face(book) perception: Is the own-race advantage due to perceptual learning?**

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Many research studies, typically employing old-new recognition tasks, have shown that faces of one's own race are often easier to recognize than faces of other races. Many theorists assume a perceptual-learning basis for this phenomenon; because one normally has more exposure to own-race faces, perceptual processes learn to extract information that optimally discriminates members of that race from each other, but these processes may be sub-optimal at discriminating shape differences among faces of other races. In recent years, however, a number of proposals have emerged that suggest a locus in social categorization for the ORA; specifically, that we normally individuate in-group members (such as own-race individuals) but not out-group (other-race) individuals. This distinction in processing is thought to be strategic, because encouraging people to individuate other-race faces has been found to eliminate the ORA. To differentiate between these theoretical alternatives, we used a new task. Faces of specific individuals (with their permission) were downloaded from Facebook. Rather than perform old-new recognition, participants (Hong Kong Chinese and White Australians) learned to name the person from five different photos of their face. Initially, names were learned for individual faces, and then had to be generalized to new photos of the same individuals. Participants only moved to the next block if they could correctly name all the photos in the set. Participants learned eight individuals in each of four blocks, where individuals in one block were the same sex and race. Crucially, participants were strongly motivated to learn to individuate each face, because the time they spent in each phase increased with each error they made. We found a strong ORA (fewer trials to reach criterion for own-race than other-race faces). These results show that there remains a strong perceptual-learning basis for the ORA.

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23.531 **An Own-Age Bias in Adults' Facial Age Judgments**

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We examined the influence of differential experience with own- and other-age faces on adults' facial age judgment ability. In doing so, we were able to ascertain whether experience with a particular age group during a given period leads to more sophisticated processing of those faces regardless of subsequent experience with that age group, or whether continued experience with a given age group is necessary to preserve that level of sophisticated face processing.

Asian young adult participants were sequentially shown 21 randomly ordered Asian faces (seven faces of children, seven faces of young adults, and seven faces of middle-age adults) on a computer and asked to judge the age of each face in years. To determine whether the influence of differential experience on facial age judgment ability is independent of culture, we recruited Asians in Japan ($n = 32$), China ($n = 39$), and Canada ($n = 33$).

A 3 (participant ethnicity: Japanese, Chinese, Asian-Canadian) x 3 (stimulus age group: child, young adult, middle-age adult) x 7 (stimulus age: 7 different faces per stimulus age group) ANOVA with participants' age estimates as the dependent variable revealed that all participants, regardless of ethnicity, showed an own-age bias in their age judgments. That is, relative to age judgments for children's/middle-age adults' faces, participants' age judgments showed the greatest differentiation between own-age faces from the young adult stimulus facial age group. This own-age bias suggests that our visual perception of facial age is continuously recalibrated as we age and subsequently gain the most experience with a new group of own-age individuals, so that we are always most sensitive to small facial age differences within the age group to which we currently belong. Our results suggest that one's current – rather than past – experience with own-age faces may be most influential in our face processing ability.

23.532 **Photographic Memory of Unfamiliar Faces Under 30 Seconds**

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Humans are experts at remembering and recognizing faces. It is now well established that we have photographic memories of familiar faces such as relatives, and public figures. It is however unclear s to the quality of our memory of unfamiliar faces we are exposed to for a short period of time. In the present study, 34 participants studied a target faces only once for 10, 20, or 30 seconds. Afterwards, they were asked to respond SAME or DIFFERENT when seeing either the same target face or a different foil face. The target face differed from the foil faces on a single dimension of difference: the distance between the eyes, which was changed by varying the distance in pixels between the eyes of the target face. Foil faces changed from a very large 10 pixel distance greater than the target's inter-ocular distance to 10 pixels less than the target's inter-ocular distance. There were 500 target face trials and 500 foil face trials. Participants received no feedback. Response choice and response time were measured. There was no feedback. Results showed that in the 20 and 30 second study conditions the participants performed above chance from the outset (74% and 80% respectively), and though receiving no feedback, still improved their identification of the target faces across trials. Performance seems to stabilize from trials 600 to 1000.

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The 10 second study condition shows a diminution in performance nearly reaching a level of chance performance. The same experiment was run with a new face. These findings were replicated. Based on the SAME response data, we estimated that to obtain a high level memory performance of an unfamiliar face (>.75), the minimal exposure time appears to be between 20 and 30 seconds.

Acknowledgement: NIH

23.533 **Plastic representation of face view in human visual system**

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Previous brain imaging studies have demonstrated that perceptual learning could enhance the representation of visual features in human early visual cortex. In this study, we used functional magnetic resonance imaging (fMRI) to investigate how perceptual learning could change the representation of face view in human visual system. We trained subjects to discriminate face orientations around a face side view (e.g. 30 deg) over eight days, which resulted in a dramatic improvement in sensitivity to face view orientation. This improved sensitivity was highly specific to the trained face side view. Before and after training, subjects were scanned to measure their brain responses (BOLD signal) to both the trained face view and untrained face views. We analyzed BOLD signals from cortical areas throughout the visual hierarchy, including early and middle-level visual areas (V1, V2, V3 and V4), occipital face area (OFA), superior temporal sulcus (STS) and fusiform face area (FFA). We found that, relative to untrained face views, BOLD signals in FFA and STS (but not other areas) to the trained face view significantly increased after the training on face view orientation discrimination, which was parallel to the psychophysical result. Our data suggest that the enhanced representation of a face view in higher visual areas could subserve our perceptual ability to discriminate face orientations around the face view.

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23.534 **The Clark Kent Effect : What is the Role of Familiarity and Eyeglasses in Recognizing Disguised Faces?**

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People have the ability to purposely transform the appearance of the facial region with the application of make-up, the growing or shaving of facial hair, the addition or removal of glasses, or the alteration of a hair style or color. All of these different types of transformations have an impact on the ability to recognize a person, though it's unclear how much of an impact, and the degree to which different transformations disrupt recognition. The purpose of this study was to add to existing knowledge about the ability of human subjects to recognize naturalistic faces in disguise. We investigated the effects of different types of attribute changes that altered the appearance of faces from presentation to test, for example the addition or subtraction of eyeglasses. Additionally, the effect of varying levels of familiarity on recognition was examined. Participants were first familiarized by viewing faces three, six, or nine times while performing judgment tasks (e.g., attractive vs. unattractive) with individuals either in disguise (wig and/or glasses), or shown with no disguise. During the testing phase, participants were shown both previously learned and novel individuals, and the faces were shown with and without disguise. Results indicated that any attribute change made from presentation to test lowered identification accuracy, and as the number of attribute changes increased, performance decreased. Eyeglasses hindered recognition, but results indicated little difference between tinted and clear-lens glasses in their effect on performance. The d' scores for addition vs. subtraction of eyeglasses replicated prior work showing that encoding a face with eyeglasses and removing them before the recognition task (subtraction) was more damaging than an addition. Although no significant main effect was found for familiarity, post hoc tests did indicate a significant difference between familiarizing someone three times versus nine times.

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23.535 **Race-specific perceptual discrimination improvement following short individuation training with faces**

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We explore the effect of individuation training on the acquisition of race-specific expertise with faces. The own-race-advantage ("ORA") – superior performance for own-race faces relative to those of less familiar races – has been explained by the tendency to individuate own-race faces but to categorize faces of other races. Here we ask whether practice individuating other-race faces yields improvement in perceptual discrimination for novel faces of the trained race. We predicted that this improvement would not generalize to novel faces of another race to which participants were equally exposed in an orthogonal task that did not require individuation, yet was at least as difficult. Caucasian participants were trained to individuate faces of one race through subordinate-level naming (African American or Hispanic) and to make difficult eye luminance judgments on faces of the other race. In the latter task, participants judged which eye was of a brighter luminance, while identity and brightest eye were always orthogonal. Given these tasks we are able to rule out differences in exposure, attention and reward in producing race-specific improvements. Our results indicate that the skills acquired during individuation training generalize to novel exemplars of a category but, at least in the case of faces from two different races, they do not generalize to faces of another race experienced with equal frequency in a task that required at least as much attention. Our work demonstrates training effects that generalize to novel stimuli using a much shorter procedure (90 minutes of training, half of which was devoted to individuation) than in prior studies. The results suggest that differential effects in recognition performance could depend on differences in perceptual encoding due to differential practice with individuation. This could magnify any own-race face advantage arising from cognitive, perceptual, or social processes that promote individuation of own-race faces relative to other-race faces.

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23.536 **The Effects of Familiarity on Genuine Emotion Recognition**

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Within the field of emotion recognition there have been numerous studies exploring the role of familiarity in emotion recognition. However, few have looked at the effect of familiarity using multiple genuine expressions of emotion. It seems plausible to propose that the more familiar someone is, for example a friend or family member, the more likely that the person's expression will be identified accurately. By focusing on only genuine expressions of emotion, we remove any additional information that may accompany the use of posed emotions (LaRusso, 1978). Also, it is critical to incorporate multiple expressions, rather than only two expressions as in many studies, to test for any differences between emotions, as well as creating a more realistic task. In our study, we used laboratory familiarity training to compare the recognition of emotion in familiar and unfamiliar faces. Half of the faces were familiarized by having people perform judgment tasks. One group had a single judgment task, a second group had six judgment tasks, and a third group was not familiarized with any of the faces. This training used photos of individuals expressing either a happy expression for half of the familiarized participants or a neutral expression for the other half. For the testing phase, both familiarized and unfamiliarized face stimuli were used, each shown with a variety of different emotions (e.g., happy, fear, disgust, confusion, and neutral). Participants then had to accurately categorize the facial expression. The results indicated that there is an effect of familiarity on the accuracy of emotion recognition. The more familiar one is with a stimulus, in this case a person's face, the more likely one is to identify the emotion accurately. This experiment is important because it contributes to our understanding of the effects of familiarity and its interaction with emotion recognition.

23.537 The role of learning in the perceptual organization of a face

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Tanaka & Farah (1993) have documented a behavioral regularity that has been used to argue for holistic representation of faces. The basic regularity is that identification of an anatomical feature of face (e.g., a nose) is aided when that feature is presented in the context of face, and is best when that feature is presented in the context of the original source face (Tanaka & Sengco, 1997). Given that physical characteristics (e.g., similarity between the facial form and that of the feature) are most likely inadequate for producing both of these regularities, the role of learning must, by hypothesis, be critical for understanding the mechanisms for such regularities. The present effort investigates the potential role of learning using stochastic linear systems models for the processing of multidimensional inputs. The models allow for dynamic representations of the presence or absence of dimensional dependencies between features, in the form of channel interactions. The models are capable of making predictions at the level of behavioral latencies and accuracies for a range of tasks, including those used in the original demonstrations of the face superiority effect. Here we highlight the potential role of learning in producing changes in both perceptual sensitivity and bias, as a function of both experience and stimulus context, and use these as predictions for a set of experiments involving multidimensional judgments, in order to show how learning can lead to behaviors that have been taken as indicators of perceptual holism.

23.538 Visual Short term Memory for One Item

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Visual short term memory (VSTM) is a limited capacity system that abstracts visual information from sensory stimulation. Many studies have investigated the storage capacity of this system expressed in the numbers of objects, features, or complexity. Here we investigate the accuracy of visual short term memory for single items. On half of the trials, memory trials, a single face or spatially filtered noise pattern is initially presented. After a one second memory delay, a two-alternative forced choice (2AFC) is presented. On the other half, perceptual trials, participants are presented with a simultaneous 2AFC match to sample task. Both noise and face stimuli are synthesized to contain equivalent low-level visual structure. They have equal spatial frequency profiles and both stimulus classes are generated from the summation of twenty randomly amplified orthogonal linear templates. Results showed participants were more sensitive to face stimuli. The memory delay caused a significant decrease in performance. Interestingly, a significant interaction between the magnitude of the memory decrement and the stimulus type was observed. Specifically, memory trials for noise stimuli showed a larger performance decrement than that observed for face stimuli. These findings suggest that VSTM does not have the capacity to store even a single complex item at the level of detail that is available when an image is present. Significant degradation occurs within a second. Also, the accuracy of VSTM is stimulus specific. Faces seem to be represented by VSTM more efficiently than filtered noise. Because the noise and face stimuli have computationally similar degrees of variation, the differences in performance must be due to internal representation. This suggests that for complex stimuli VSTM likely utilizes previously learned statistical regularities, and is therefore not a general purpose mechanism. Models of stochastic visual memory decay in low-level image space cannot account for our findings.

Scene perception: Objects and scenes

Vista Ballroom, Boards 539–554

Saturday, May 8, 8:30 - 12:30 pm

23.539 When Do Objects Become Scenes?

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Scene-like interactions of pairs of objects (a bird perched on a birdhouse) elicit greater BOLD activity in LOC than the same objects depicted side-by-side (a bird next to a birdhouse) (Kim & Biederman, 2009). Novelty of the interactions (a bird perched on an ear) magnified this gain, an effect that was absent in the side-by-side depictions. LOC is the first cortical stage where shape is distinguished from texture (Cant & Goodale, 2009). Other cortical areas, such as IPS,DLFPC, and PPA did not consistently reveal the pattern of BOLD effects seen in LOC, although it is possible that the effects witnessed in LOC reflected feedback from these areas. Due to the low temporal resolution of the BOLD signal, the time course of these possible effects could not be assessed with fMRI. We used EEG source estimation to determine if interacting and novel depictions produced effects in parietal and prefrontal areas prior to when these effects occurred in occipito-temporal cortex. (The time course of PPA could not be observed with EEG due to its medial location.) While maintaining fixation, subjects performed a one-back task while they viewed a series of two-object displays, presented either as interacting or side-by-side, and in novel or familiar combinations. Occipito-temporal cortex showed earlier divergence of interacting versus side-by-side conditions than parietal cortex. Although novel interactions did not produce a larger BOLD response in parietal cortex, there was a divergence of novelty and familiarity in the EEG signal at about the same time as in occipito-temporal cortex. No consistent pattern was observed in prefrontal cortex. The picture that emerges is one in which scene-like relations are not inferred at some stage following object identification, but are likely achieved simultaneously with the perception of object shape.

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23.540 The Scene Superiority Effect

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In the word superiority effect, two letters are easier to discriminate when presented in the context of a real word, even when the rest of the word is non-predictive of the target letter. For instance, people can better discriminate “word” from “work” than they can discriminate “d” from “k.” The effect disappears when the letters appearing with the target form a non-word letter string (e.g., “orwk” and “orwd”). We explored whether this context effect for letters and words would generalize to objects in scenes. Subjects identified rapidly presented objects that were drawn from a single semantic category (i.e., “offices”). We used an adaptive staircase algorithm (QUEST) to set object detectability at 40% accuracy when viewed against a phase-scrambled scene background. Subjects then performed the detection task with objects superimposed on scene backgrounds that varied in semantic consistency (offices or beaches) and orientation (upright or inverted). As for the word superiority effect paradigm, the background was irrelevant to the object detection task and was unpredictive of which object appeared on any given trial. Consistent with the word superiority effect, subjects were better able to identify target objects when they were displayed on semantically consistent backgrounds. Consistent with subject reports that they were able to ignore the scene entirely as the experiment progressed, the effect disappeared after approximately 100 trials. Together, these results suggest that the scene context can facilitate object identification, but only when the scene semantics are processed.

23.541 What’s behind the box? Measuring scene context effects with Shannon’s guessing game on indoor scenes

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Natural scenes are lawful, predictable entities: objects do not float unsupported, spoons are more often found with forks than printers, and it makes little sense to search for toilets in dining rooms. Although visual context has often been manipulated in object and scene recognition studies, it has not yet been formally measured. Information theory specifies how much information is required to encode objects in a scene, assuming no contextual knowledge. We can then measure, in bits per object, the information benefit provided by human observers’ contextual knowledge. We used a database of 100 indoor scenes, containing 352 unique objects labeled using the LabelMe tool. If all objects were equally probable in a scene, 8.46 bits per object would be required (log2(352)). Taking object frequency into account (i.e., chairs are more common than basketballs), would only reduce this number to 7.22 bits per object. To measure the information required by humans to represent objects in scenes, we adapted the guessing game proposed by Shannon (1951). Between 5-80% of the objects in each scene were occluded by opaque bounding boxes. Observers guessed the identity of each occluded object until the object was correctly named. More than 60% of objects were correctly guessed on the first try, because context massively constrains the identity of a hidden object (What might you guess

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was hidden next to a plate on a dinner table?). Fully 93% of objects were correctly guessed within 10 tries. Overall, we found that observers could represent the database with just 1.86 bits per object when 5-10% of objects were masked. Just 2.00 bits per object were needed even when the majority of objects were masked. This technique can be used to measure the redundancy provided by aspects of context such as scene category, object density and object consistency.

23.542 **When the animal destroys the beach, the beach destroys the animal. Mutually assured destruction in gist processing**

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Observers can report some semantic content of scenes when those scenes are presented for 20 msec, flanked in time by masks. It is likely that only a single object could be selected for attentional processing in this time so this gist processing would seem to involve non-selective processing of the entire image. Similarly, we find that expert observers (radiologists and cytopathologists) can detect subtle signs of cancer at above chance levels in 250 msec exposures of mammograms and Pap-smears. These exposures are unmasked but still preclude normal extended attentional scrutiny. Can multiple gists be computed concurrently? Last year, we demonstrated limits on this ability. We cued observers with one of nine target categories (e.g. beach, animal, bridge) before presenting a masked scene for 20 msec. Targets were present on 50% of trials. Critically, on half of target present trials, an un-cued target category was also present. That is, "beach" would be cued but the scene might include both beach and animal – a "trial-irrelevant", but "task-relevant" target category. Observers were 76% correct when trials contained only cued targets but only 52% correct when trial-irrelevant targets were also present. Critically, animal would not interfere with beach if it were not a target on other trials in the same block. This year, we show that interference is mutual. On each trial, observers reported on the presence of the target and were also asked if any other categories were present. If observers missed the task-relevant "animal", they were actually LESS likely to be able to report a task-irrelevant beach. Of course, in real life, if you were looking for your fork and now for your glass, you are not blinded by the presence of both items in the visual field. We find that "mutually assured destruction" occurs for exposures shorter than 200 msec.

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23.543 **The objects behind the scenes: TMS to area LO disrupts object but not scene categorization**

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Many influential theories of scene perception are object centered (Biederman, 1981) suggesting that scenes are processed by extension of object processing in a bottom-up fashion. However, an alternative approach to scene processing is that the global gist of a scene can be processed in a top-down manner without the need for first identifying its component objects (Oliva & Torralba, 2001). This suggests that global aspects of a scene may be processed prior to the identification of individual objects. Evidence from a patient with object agnosia and bilateral damage to lateral occipital (LO) cortex, an area associated with object processing (Grill-Spector et al., 2001), also suggests that scene categorization can operate independently of object perception (Steeves et al., 2004). We asked whether or not temporary interruption to area LO in neurologically-intact controls with repetitive transcranial magnetic stimulation (rTMS) impairs object and scene processing. Participants categorized greyscale images of objects and scenes as 'natural' or 'man-made'. Subsequently, we targeted area LO, which had been functionally defined with fMRI, and participants underwent five minutes of rTMS. Immediately following, they completed another version of the object and scene categorization task. Preliminary results show that rTMS to area LO impairs categorization of objects but not scenes. This suggests that the global gist used to rapidly categorize scenes remains intact despite an interruption to object processing brain regions.

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23.544 **Visual cortex represents the statistical distributions of objects in natural scenes**

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Natural scenes are comprised of collections of objects with specific types of objects tending to occur in certain classes of scenes. We hypothesize that the visual system might exploit these co-occurrence statistics in order to classify scenes more efficiently. If this is true, then a model that captures the distribution of objects in natural scenes should provide good predictions of visual cortical activity during natural vision. To construct such a model we adapted a recent probabilistic algorithm known as Latent Dirichlet Allocation (LDA). Given thousands of object-labeled natural images, LDA analyzes the label co-occurrences and 'learns' the distribution of objects in various scene classes. (The number of scene classes is a free parameter determined by the modeler; the specific scene classes are latent states learned by LDA). We then presented thousands of natural scenes to subjects while recording fMRI-BOLD activity in retinotopic and object-selective visual cortex. Afterwards, we estimated the scene-specific selectivity of all recorded voxels by regressing the BOLD responses evoked by each image onto the scene classes provided by LDA. We find that specific regions within lateral and ventral occipital-temporal areas are selective for various specific classes of natural scenes. (This is consistent with previous results; Naselaris et al. 2009). Selectivities, as determined by our method, are generally consistent with selectivities defined by standard functional localizers. However, we also find scene selectivity in many areas that are not identified by standard functional localizers. Finally, in order to determine how many distinct scene classes might be represented in anterior visual cortex, we varied the number of scene classes learned by LDA. The best model descriptions were obtained when the model learned 8-18 scene classes. In summary, our results suggest that regions within occipital-temporal visual cortex represent the distribution of objects in certain specific categories of natural scenes.

Acknowledgement: NEI

23.545 **Faces and Places in the Brain: An MEG Investigation**

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Faces and places are ubiquitous in our environment and recognition of both is crucial for everyday life functioning. Magnetoencephalography (MEG) studies have shown that the perception of faces generates specific MEG components including one at 100 ms and 170 ms post stimulus onset, whereas the perception of places generates an MEG component between 200 and 300 ms post stimulus onset. Given that humans grasp the "gist" of a scene within a small fraction of a second, we aimed to investigate the existence of a potential MEG component associated with place perception occurring earlier than that previously described in literature (between 200 and 300 ms post stimulus onset). MEG activity was recorded while 11 participants were presented with pairs of face and place stimuli (S1 followed by S2), that were either the same (repeated condition) or different (unrepeated condition). Fifty percent of the stimuli were famous and fifty percent unfamiliar. MEG activity associated with S1 was used to define regions of interest (ROIs) for faces and places in both hemispheres. Subsequently, the timecourse of MEG activity associated with S2 was examined within the ROIs. Our results showed that the MEG activity associated with face and place perception differed across hemispheres. In right occipito-temporal ROIs we found that the amplitude of MEG activity at 100 ms post stimulus onset was significantly higher for faces compared to places, in line with the previously described M100 for faces. In contrast, in left occipito-temporal ROIs we found the opposite pattern, namely a significantly higher MEG activity at 100 ms post stimulus onset for places compared to faces, a novel component we referred to as M100p. Neither the M100 nor the M100p were affected by familiarity or by repetition, and are therefore likely to be associated with face/place categorization.

23.546 Gamma oscillations decompose the visual scene into object-based perceptual cycles: a computational model

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Several hypotheses exist regarding the functional role of oscillations in the brain. Among these is the well-known binding-by-synchrony hypothesis, suggesting that neurons coding for a specific object or concept tend to fire in synchrony (i.e. within the same cycle), creating a neural code for binding together features of a same object (Gray et al., 1989). Recently gamma oscillations have also been proposed as a competitive "gating" process, implementing a winners-take-all mechanism, allowing only the most excited neurons to fire at each cycle (Almeida, Idiart & Lisman 2009). Here we suggest that both mechanisms can be seen as two aspects of a single process, namely the decomposition of a visual scene into "perceptual cycles", with neurons for each objects firing at successive cycles of the oscillation. We describe a simple model of V1 in which oscillations, binding by synchrony and scene decomposition all emerge automatically and spontaneously from the interactions between three simple, well-known mechanisms, namely feedback inhibition, refractory periods, and lateral (or feedback) connections implementing gestalt principles. Despite its extreme simplicity, the system gives rise to spontaneous decomposition of the scene into perceptual cycles, such that neurons encoding different objects tend to fire on different cycles. The system is applied both to artificial and natural images. We then show that these results persist when oscillations are exogenously imposed from a separate source (as opposed to endogenously generated, "gamma-like" oscillations). This suggests that the basic principle described here may extend to other oscillatory regimes besides gamma.

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23.547 In search of neural signatures of visual binding : a MEG/SSVEF study

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Visual processes are distributed in numerous specialized cortical areas. How neural responses are bound into assemblies to elicit a unified perception remains a central issue in cognitive neurosciences. To address this issue, we conducted an MEG experiment to characterize neural mechanisms of visual coherent motion integration. Stimuli consisting of 2 verticals and 2 horizontals disconnected bars oscillating at 2.3Hz and 3Hz, respectively, were arranged in a "square" like shape. Such periodic stimulations elicit stereotypical oscillatory MEG activities phase-locked to visual stimulation at the first and second harmonics in cortical areas processing the stimulus elements (SSVEP). Subjects' perception, either rigid square or non-rigid square, was modulated by subtle changes in luminance distribution along the bars, resulting in 4 experimental conditions. This design allows separating SSVEP relative to element computation (f, 2f, 4f…etc) and SSVEP linked to motion integration at intermodulation frequencies (nf1 + nf2). The behavioural results confirmed that bars with low-luminance line-ends enhance rigid square perception. MEG analyses reveal focal and percept independent activities at first harmonics on occipital sensors, sources reconstruction showing retinotopic segregation between 2.3Hz and 3Hz activities in V1. We also found more widespread percept independent activities at second harmonics over occipital and parietal sensors. Finally, contrast between rigid and non-rigid percept showed fourth-order intermodulation frequency enhancement localized in the right frontal cortex, likely frontal eye fields (FEF). Overall tagged stimulation and SSVEP analysis provide a precise localisation of cortical activities related to the computation of focal visual elements, consistent with retinotopy. This methodology further highlights an electrophysiological signature of shape processing from ambiguous motion components at fourth-order intermodulation frequency in FEF.

23.548 Incongruent visual scenes : Where are they processed in the brain ?

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Object and context processing interfere in rapid object visual categorization of briefly flashed natural scenes, suggesting that objects and context in a visual scene are processed in parallel with strong early interactions (Joubert et al. 2008). The present fMRI study aimed to investigate cerebral activations elicited by the processing of scenes with either congruent or incongruent object/context relationships. Fifteen subjects were instructed to categorize objects (man-made objects or animals) in briefly presented stimuli (exposure duration = 100 ms), using a forced-choice two-button response. Half the objects were pasted in expected (congruent) contexts, whereas the other half was shown in incongruent contexts. Our behavioural results support previously reported data, showing that object categorization is more accurate (+14%) and faster (-32ms) in congruent vs. incongruent scenes. Moreover, we found that both types of scenes elicited differential neural processing. The processing of non congruent scenes induced increased activations in the right parahippocampal and retrosplenial cortices, as well as in the right middle frontal gyrus ($P < 0.05$ corrected). This higher activity may be due to additional processing of the novel (unfamiliar) relationships between object and context that were inherent to the incongruent scenes. In particular, the increase of activity in the anterior part of the right parahippocampal cortex, previously shown to be involved in object/context binding (Goh et al. 2004), was correlated ($P < 0.05$) with the delay, i.e. increase of reaction time, necessary to process the objects in incongruent contexts. In this region, supplementary neural processing for incongruent scenes could therefore be related to impaired object categorization performance.

Joubert et al. (2008) J Vis 8 (13): 11, 1-18 Goh et al. (2004) J Neurosci 24 : 10223-10228

23.549 Neural coding of scene affordances

Teresa Pegors[1](tpegors@sas.upenn.edu), Russell Epstein[1]; [1]University of Pennsylvania

Previous work has identified cortical regions such as the parahippocampal place area (PPA) that respond more strongly to scenes than to nonscene objects. Little is known, however, about the principles used to encode scenes in this region. One possibility is that scenes are coded based on the actions that they afford. For example, some scenes have highly constrained spatial layouts that afford movement in only one direction (e.g. an alleyway), while other scenes have more open spatial layouts that afford movement in multiple directions (e.g. an open plain). We investigated this issue by scanning subjects with fMRI while they viewed real-world scenes that varied under two dimensions: (1) the extent to which the scene constrained motion (highly constrained vs. unconstrained), (2) whether the direction of afforded motion was leftwards, rightwards, or straight ahead. Constraint and direction of afforded motion values were determined for each image through pre-scan surveys of a separate group of subjects. We examined both main effects and cross-image adaptation for items with similar vs. different affordances. Preliminary results indicate that the PPA responds more strongly to highly constrained than to unconstrained spatial layouts, consistent with a putative role for this region in processing information about the motion affordances within a scene.

23.550 Vision at a glance: the role of attention in the contextual facilitation of visual object recognition.

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Everyday objects are typically embedded within a rich visual setting, surrounded by other contextually related objects. Despite limitations in processing multiple stimuli simultaneously, meaningful associations between objects can enhance visual recognition by activating a familiar contextual schema (e.g., Gronau, Neta, & Bar, 2008). The present study investigated the role of attention in the perception of object-to-object relations, and in the contextual facilitation of visual recognition. Specifically, we asked whether an irrelevant object located outside the focus of attention can facilitate recognition of a contextually associated, task-relevant (attended) target object.

Subjects performed an object classification task for associated object pairs that were presented for a brief duration (59ms, masked). Objects were either positioned in proper relative locations that matched a familiar contextual schema (spatially consistent condition, e.g., a sandwich on a plate) or in improper relative locations that did not match a familiar contextual schema (spatially inconsistent condition, e.g., a sandwich under a plate). When both stimuli were attended and were relevant to task requirements, RTs

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to the spatially consistent object pairs were significantly shorter than to the spatially inconsistent pairs. These contextual effects disappeared, however, when visual attention was drawn to one of the two objects, while its counterpart object was unattended and irrelevant to task requirements. Follow-up experiments further explored the specific attentional conditions under which contextual associations facilitate object recognition. Our results reveal that contextual facilitation is a robust phenomenon that occurs under a variety of visual and attentional conditions, even when objects are merely glanced for a brief duration. Contextual facilitation disappears, however, if the associated information is strictly unattended, despite evidence for the coarse processing of this information. 'Contextual binding' of multiple associated objects, thus, requires attentional resources. Our findings have important implications for the effects of attention on visual object recognition within relative ecological, real-world, environments.

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23.551 **Effects of set size and heterogeneity in set representation by statistical properties**

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Recent evidence suggests that observers show accurate knowledge of the mean size of a group of similar objects, a finding that has been interpreted to suggest that sets of multiple objects are represented in terms of their statistical properties, such as mean size (Ariely, 2001; Chong & Treisman, 2003, Marchant & De Fockert, 2009). A surprising finding is that this effect can be shown across different set sizes (from 4 to 16 members) with little or no detriment to judgements of mean set size (Ariely, 2001; Chong & Treisman, 2005b, exp 1). However, these studies have always held heterogeneity constant whilst manipulating set size. Here, we present data that replicate past findings when heterogeneity is held constant, but show that the accuracy of mean set size estimations decrease when both set size and heterogeneity increase. Our findings suggest that summary representations are not always obtained by averaging together the whole set of items; a feat that often requires a greater capacity than known focused attention processes and therefore has required the proposal of a new perceptual mechanism (Chong & Treisman, 2003, 2005a, 2005b, Treisman, 2006). Instead, summary representations may be based on a sub-sample from the set, within the capacity of focussed attention (Myczek & Simons, 2008). Increased variation in the set leads to more variation in the possible sub-samples and a less accurate approximation of the set summary statistic. These results have implications for current theory and the proposed role this mechanism plays in scene perception (Treisman, 2006; Oliva and Torralba, 2007).

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23.552 **Object identification in spatially filtered scene background**

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We investigated the role of low-passed scene information on object identification in a previous study. We showed that, with short presentation, identification of a low-passed object embedded in a low-passed scene was not better than that of object alone (Chu et al., 2009, VSS). However, this might be due to lateral masking from the scene that has the same spatial frequency spectrum as the object. If so, identification of an object should be improved when the power spectrum of the spatially filtered object is different from that of the spatially filtered scene. In the present experiments, the objects and the scenes were processed by different filters.In Experiment 1, photos of 20 target objects were presented on 20 natural scenes. The objects were either low-passed or high-passed with a 2 cpd cut-off frequency. The scene backgrounds were either low-passed or high-passed with six possible cut-off frequencies (0.4, 0.7, 1.4, 2.8, 4, and 5.6 cpd), resulting into a 2 x 2 design. The viewing duration was 36 ms. The task of the observers was to name the target object. We found that identification of high-passed objects on low-passed scenes was better than the other three target-scene combinations. To investigate the critical role of low-passed scene information, spatial filtering was applied to natural scenes or to phase-scrambled scenes while objects were not filtered. The low-passed scrambled background produced a greater masking effect than the low-passed scene background. Our results suggest that the low spatial frequency information in scene background benefits the processing of high-spatial frequency components of objects through the reduction of lateral masking in the frequency domain.

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23.553 **In search for a magnocellular deficit in Optic Neuritis patients**

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Optic neuritis (ON) is an acute inflammatory disease of the optic nerve. Following visual acuity recovery, several patients report visual discomfort although ophthalmologic assessments show a complete recovery. To evaluate what could induce these complaints, the present study investigates visual processing of healthy individuals and patients with recovered ON. Specifically, magnocellular pathway was assessed. Two types of visual tasks were administered in monocular vision to two different groups of controls and patients. First, 18 controls and 7 patients(4 left ON, 3 right ON) had to detect and categorize low(LSF) or high(HSF) spatial-frequency scenes to assess magno- or parvocellular pathways. Then, performance of 16 controls and 5 patients (4 left ON, 1 right ON) were recorded while performing a denomination task of forms and moving objects (Objects From Motion). These objects could only be perceived by a contradictory movement of black and white dots and mainly require the implication of the magnocellular pathway. Patients showed normal visual analysis in low spatial frequency scenes compared to controls, but had difficulties in naming OFM with their affected eye (AE) ($F(1,19)=17.47; p<.01$). However, in scenes analysis, controls were faster for LSF than HSF ($F(2,34)=6.78; p<.01$), but this "coarse-to-fine" pattern was not found in patients, revealing a slower processing of LSF with their AE. As magnocellular pathways preferentially process LSF and motion stimuli, the current results suggest its impairment following ON, explaining patients' visual discomfort. In addition, given the dissociation between the preserved performance in visual scene detection and categorization and the difficulty in naming OFM, motion processing appears to be a more sensitive measure to evaluate patients' deficits. Given that results cannot be explained by ophthalmologic considerations, they argue in favor of a possible functional reorganization in higher visual areas.

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23.554 **Sustained attention is involved only in dynamic change detection**

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There are two types of change detection, the experience of seeing dynamic change and the detection of completed change. Seeing dynamic change may require sustained attention to a changing area, while the detection of completed change may not (Hollingworth, 2008). This indicates that the former is accomplished by a location-based comparison while the latter involves both location-based and object-based comparisons. The seeing process is dominant when pre- and post-change stimuli are presented with a brief interval, while the detection process is dominant when they are presented with a long interval. This study used the flicker paradigm (each image was presented for 250 ms) in order to focus on the processing of the comparisons involved in seeing change. We used original images in which 8 objects were arranged in a circle and change images in which one of the objects was replaced by another object. We manipulated the interval between two images (200 ms and 1000 ms) and the shift of the image (shift and no-shift). In the shift condition, the objects in the change image were presented in a completely different location from the original image, which disturbs only the location-based comparison. The results showed that in the 200 ms interval condition, where seeing dynamic change is dominant, the number of alternations of the original and change image, which is proportional to the reaction time, before the change detection was larger in the shift condition than in the no-shift condition. In the 1000 ms interval condition, where the detection of completed change is dominant, there was no difference between the shift and no-shift conditions. This result indicates that sustained attention is involved in the experience of seeing dynamic change, but is not involved in the detection of completed change.

Saturday Afternoon Talks

Perceptual organization: Contours and 2D form

Saturday, May 8, 2:45 - 4:15 pm
Talk Session, Royal Ballroom 1-3
Moderator: Elisabeth Hein

24.11, *2:45 pm*

Distortions of illusory shape and motion by unseen motions

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Most models of illusory contours (ICs) have focused on geometric factors as the primary determinant of IC shape. Here, we report a new class of IC displays in which distortions of both perceived shape and motion are induced by unseen, locally ambiguous motion signals that arise from the ambiguity of aperture problem. When an outline diamond is translated behind a counter-translating camouflaged triangular occluder, the perceived motion and shape of the triangular occluder are distorted: the translating occluder appears to contain a strong illusory rotational component of motion, and the angular subtense of the triangle is substantially reduced. We performed a series of experiments that parametrically varied the velocity of the occluding and occluded figures and the aspect ratio of the occluded diamond and (illusory) occluding triangle. Observers adjusted a triangular figure in which the angles of the triangle, as well as the translational and rotational components of motion of the triangle matched the perceived motion and shape of the IC. Our results show that the distortions in perceived shape and rotational motion was primarily a function of angular subtense of both the occluded and occluding figures; other factors, such as the translational velocity, or the velocity of contour terminators, played a negligible role in these distortions. Our results are consistent with a model in which the motions and shapes of the ICs are distorted by an induced motion imparted by the unseen orthogonal component of motion of the occluded diamond. If correct, these data suggest that the observed distortions in shape and perceived motion arise at a very early stage of cortical motion processing, prior to the resolution of the aperture problem.

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24.12, *3:00 pm*

The role of mid-level representations in resolving object correspondence

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To maintain stable object representations over time despite discontinuities in the visual input, the visual system must determine how newly sampled information relates to existing object representations. Despite the long tradition of research investigating this "correspondence problem" it is still unclear what factors influence its resolution. We examined the relative role of spatio-temporal and feature information (e.g., color, size, orientation and contrast polarity) in resolving object correspondence in ambiguous apparent motion displays (Ternus displays). We found that feature information plays an important role in resolving object correspondence and can even overwhelm spatio-temporal information under some conditions. Moreover, it is not just featural identity that can determine object correspondence, but featural similarity can as well. Finally, we found that correspondence was determined by the perceived values (i.e., perceived size and lightness) of stimuli rather than by the physical values (i.e., size and luminance). This suggests that object correspondence is established at higher levels of visual processing than has been previously thought. In summary, we argue that the visual system is remarkably flexible with regard to what information it uses to organize retinal information into functionally meaningful units and to update these representations over time.

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24.13, *3:15 pm*

The role of symmetry and volume in figure-ground organization

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Many objects in our environment are symmetrical and volumetric. These two constraints are extremely effective in 3D shape recovery (Sawada, 2009). In contrast, the spaces between objects, representing the background, are almost never symmetrical and volumetric. Prior studies of figure-ground organization showed that symmetrical regions are perceived to be figures only slightly (albeit significantly) more often than expected by chance Salvagio, Mojica & Peterson, 2008). In this study we examine the hypothesis that the addition of volume enhances the likelihood of seeing symmetrical regions as figures. Experiment. If the observer perceives a given region in a stimulus as a figure (object), then she should be able to recognize the shape of the region; at the same time, we don't expect the observer to be able to recognize the shape of the background (Rubin, 1915). We tested human performance on a shape-matching task using signal detection analysis methods. On each trial, the observer was shown two stimuli one after the other. Each stimulus was composed of several regions horizontally aligned. The viewing duration was 500 ms for each stimulus. A mask was shown for 500 ms between the stimuli. The observer's task was to memorize the shapes of the specified regions in the first stimulus and to judge whether or not the shapes of the regions in the second stimulus were identical to the memorized shapes. The shapes of the regions were controlled to be either symmetrical or asymmetrical. The volumes of the regions were controlled by using the depth cue of surface-contour. The results suggest that it is easier to recognize the shape of regions that are both symmetrical and volumetric. We conclude that perceptual assignment of which regions are figures depends on the presence of 3D symmetry.

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24.14, *3:30 pm*

CSI Berkeley Episode II: Perceptual organization and selective attention

Karen B. Schloss[1](kschloss@berkeley.edu), Francesca C. Fortenbaugh[1], Eli D. Strauss[2], Stephen E. Palmer[1,2]; [1]Department of Psychology, University of California, Berkeley, [2]Program in Cognitive Science, University of California, Berkeley

Last year we described the Configural Shape Illusion (CSI), in which the shape of a rectangular target is distorted by an attached region, or "inducer" (Palmer, Schloss, & Fortenbaugh, VSS-2009): the target's perceived aspect ratio changes toward the aspect ratio of the whole configuration. We also showed that the illusion increases as grouping increases, due to connectedness, proximity, lightness similarity, hue similarity, and shape similarity. We now show that CSI magnitude is an inverted U-shaped function of inducer height that scales with overall target size, increasing rapidly as the height of the inducer increases from zero and then diminishing slowly, but never reversing in sign, as its height increases further. Because grouping strength was previously shown to affect CSI magnitude, we also measured perceived grouping between target and inducers of different sizes. The grouping function was qualitatively similar to the CSI function, and when it was scaled by target size, the correlation between grouping strength and CSI magnitude was 0.91. We suggest that the CSI is caused by the inability to selectively attend to the target to the extent that it is grouped with the inducer, such that the size and shape of the global configuration influence the perceived size and shape of the target. We tested this hypothesis using a Stroop-like interference task in which participants were asked to categorize the target as taller-than-wide or wider-than-tall, when the aspect ratio of the whole configuration (target plus inducer) was either consistent or inconsistent with the target's aspect ratio. The pattern of reaction times was consistent with Stroop interference: response times slowed when the global and target aspect ratios were inconsistent (taller/wider or wider/taller), but no facilitation when they were consistent (taller/taller or wider/wider). The results support a role for selective attention in causing the CSI.

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24.15, *3:45 pm*

Contour Grouping and Natural Shapes: Beyond Local Cues

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The perception of boundary shape depends upon the organization of local orientation signals into global contours. Models generally assume that grouping is based upon local Gestalt relationships such as proximity and good continuation. While there have been reports that the global property of contour closure is involved in this process (e.g., Kovacs & Julesz 1993), a more recent study suggests otherwise (Tversky, Geisler & Perry 2004). This raises the question: is contour grouping completely insensitive to global properties of the stimulus, depending only upon local Gestalt cues?

To address this question, we conducted a psychophysical experiment in which observers were asked to detect briefly-presented target contours in noise. Contours were represented as sequences of short line segments, and the noise was composed of randomly positioned and oriented segments of the same length. We used QUEST to estimate the threshold number of noise elements at 75% correct performance in a present/absent task.

Three conditions were tested. In Condition 1, targets were the closed bounding contours of 391 animal shapes derived from the Hemera object database. These contours afford local Gestalt properties but also a host of global properties, including closure. In Condition 2, we created first-order metamers of these contours by randomly shuffling the order of the angles between neighbouring segments. This preserves all local Gestalt properties exactly, but destroys all higher-order properties. In Condition 3, we also randomized the signs of the angles, thus removing a convexity bias.

While noise thresholds were similar for Conditions 2 and 3, they were significantly higher for Condition 1, suggesting a global influence on grouping. Further analysis suggests that this difference cannot be explained by differences in stimulus eccentricity, element density, or contour intersections produced in shuffled stimuli. Instead the results point to a process of perceptual organization that goes beyond local, first-order cues.

Acknowledgement: This work was supporte by grants from NSERC and GEOIDE

Face perception: Brain mechanisms

Saturday, May 8, 2:45 - 4:15 pm
Talk Session, Royal Ballroom 4-5
Moderator: Bradley Duchaine

24.21, *2:45 pm*

Functional lateralization of face processing

Ming Meng[1](ming.meng@dartmouth.edu), Tharian Cherian[2], Gaurav Singal[3], Pawan Sinha[4]; [1]Dartmouth College, [2]Duke University, [3]Harvard Medical School, [4]MIT

Several fMRI researchers have noted that face induced brain activity is more reliably localized in the right fusiform gyrus than in the left. However, we lack a precise characterization of the hemispheric differences in facial selectivity. Identifying the nature of these functional asymmetries is crucial for understanding the organization of face processing in the human brain. To address this need, we undertook a three pronged approach: 1. We compared brain activation in the left and right fusiform gyri induced by a set of natural images that span a range of facial similarity from random non-faces to genuine faces. 2. We measured the modulatory influence of contextual information on brain activation patterns. 3. We evaluated the temporal dynamics of face processing in the left and right fusiform gyri using a rapid event-related design. Results on all three fronts have revealed interesting hemispheric differences. Specifically, we found that: 1. Activation patterns in the left fusiform gyrus correlate with image level face-semblance, while those in the right correlate with categorical face/non-face judgments. 2. Contextual information transforms graded responses in the left fusiform to categorical ones, but does not qualitatively change the responses in the right. 3. Graded pattern analyses in the left occur earlier than categorical analyses in the right fusiform. Contextual modulation too is evident earlier in the left than in the right. Furthermore, face-selectivity persists in the right even after activity in the left has returned to baseline. These results provide important clues regarding the functional architecture of face processing. They are consistent with the notion that the left hemisphere is involved in rapid processing of 'low-level' face semblance, and perhaps a precursor to categorical analyses in the right (cf. Rossion, et al., 2000; de Gelder & Rouw, 2001; Miller, Kingstone, & Gazzaniga, 2002).

24.22, *3:00 pm*

Robust visual adaptation to face identity over the right occipito-temporal cortex: a steady-state visual potential approach

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Over recent years, visual adaptation has been used as a tool to probe the response properties of face-sensitive areas of the visual cortex in neuroimaging studies (e.g., Grill-Spector et al., 2006), as well as in scalp event-related potentials studies which aim to clarify the time-course of sensitivity to facial features and their integration in the human brain (e.g., Jacques et al., 2007). However, this approach is often limited by low signal-to-noise ratio (SNR), as well as the ambiguity of measurement and quantification of adaptation effects. Here we tested the sensitivity of the visual system to face identity adaptation using steady-state visual evoked potentials (SSVEP, Regan, 1966). Twelve subjects were submitted to a 90s sequence of faces presented at a constant rate (3.5Hz or faces/second) while high-density electroencephalogram (EEG) was recorded (128 channels). Fast-Fourier Transform (FFT) of EEG data showed a clear and specific response at the fundamental frequency (3.5Hz) and its harmonics (7Hz, 10.5…) over posterior electrode sites. EEG power at 3.5Hz over a few contiguous occipito-temporal channels of the right hemisphere was much larger when face identity changed at that rate than when the same face was repeated throughout the sequence. Significant effects of face identity adaptation were found in every single participant following a few minutes of EEG recording only. This effect was not due to low-level feature adaptation, since it was observed despite large changes of face size, but disappeared for faces presented upside-down. This first demonstration of SSVEP adaptation to face identity in the human brain confirms previous observations using a much simpler, faster and higher SNR approach. It offers a promising tool to study unambiguously and more comfortably the sensitivity to processing of visual features in individual faces in various populations presenting a much lower SNR of their electrical brain responses (e.g., infants, brain-damaged patients).

24.23, *3:15 pm*

Early visually evoked electrophysiological responses over the human brain (P1, N170) show stable patterns of face-sensitivity from 4 years to adulthood

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Whether the development of face recognition abilities truly reflects changes in how faces, specifically, are perceived, or rather can be attributed to more general perceptual or cognitive development is debated. Event-related potential (ERP) recordings on the scalp offer promise for this issue because they allow brain responses to complex visual stimuli to be relatively well isolated from other sensory, cognitive and motor processes. ERP recordings in response to faces from 5-16-year-old children report large age-related changes in amplitude, latency (decreases) and topographical distribution of the early visual component P1 and the occipito-temporal N170 (Taylor, Batty & Itier, 2004). To test the face specificity of these effects, we recorded high-density ERPs to pictures of faces, cars, and their phase-scrambled versions from 72 children between 4 and 17 years, and adults. We found that none of the age-related changes in amplitude, latency or topography of the P1 or N170 were specific to faces. Most importantly, when we controlled for age-related variations of the P1, the N170 appeared remarkably similar in amplitude and topography across development, with much smaller age-related decreases in latencies than previously reported. At all ages the N170 showed equivalent face-sensitivity; it was absent for scrambled stimuli, larger and earlier for faces than cars, and had the same scalp topography across ages. These data also illustrate the large amount of inter-individual and inter-trial variance in young children's data. This variability appears to cause the N170 to merge with a later component, the N250 in grand-averaged data, explaining the previously reported "bi-fid" N170 of young children. Overall, we conclude that the classic electrophysiological markers of

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face-sensitive perceptual processes are present as early as 4 years, an observation which does not support the view that face-specific perceptual processes undergo a long developmental course from infancy to adulthood.

24.24, *3:30 pm*

A genetic basis for face memory: evidence from twins

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Compared to notable successes in the genetics of basic sensory transduction, progress on the genetics of higher level perception and cognition has been limited. We propose that investigating specific cognitive abilities with well-defined neural substrates, such as face recognition, may yield additional insights. We used a classic twin design to determine the relative contributions of genes and environment to face recognition ability. Our measure of face recognition ability was the widely used Cambridge Face Memory Test (CFMT), a reliable, normed, well-validated test requiring study and then recognition of faces in novel views and novel lighting. We found that the correlation of scores between monozygotic twins (0.70) was both statistically indistinguishable from our measure's test-retest reliability (0.70) and more than double the dizygotic twin correlation (0.30), evidence that genetic influence accounts for all of CFMT's familial resemblance and for a very large proportion of its total stable variation. We also used an individual differences based study to dissociate face recognition ability from other abilities. A low correlation between CFMT and verbal recognition (0.17) demonstrated that the heritability we observed for CFMT was not the result of motivation, attention, computer-literacy, or general memory. A modest correlation between CFMT and abstract art recognition (0.26) indicated that general visual processes make only limited contributions to CFMT performance. Our results therefore identify a rare phenomenon in behavioral genetics: a highly specific cognitive ability that is highly heritable. These results establish a clear genetic basis for one of the most intensively studied and socially advantageous of cognitive traits, opening a new domain to genetic investigation.

Acknowledgement: Funding for this project was provided by the Economic and Social Research Council to BD, an NIH fellowship to JW, an NSF grant to J. Richard Hackman and Stephen M. Kosslyn, and a DCI Postdoctoral Fellowship to CFC. This research was facilitated through the Australian Twin Registry which is supported by an Enabling Grant from the National Health & Medical Research Council administered by The University of Melbourne.

24.25, *3:45 pm*

Resting-state functional connectivity within the face processing network of normal and congenitally prosopagnosic individuals

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A recent development in human neuroscience is the discovery of resting state networks (RSN) whose coordinated activity can be uncovered using the spontaneous, relatively slow fluctuations (<0.1 Hz) of brain activity during rest, i.e, while participants are not engaged in a predefined cognitive task and when no stimulation is present. Here, using fMRI, we explore whether the well-documented distributed face processing network can be documented under these resting state conditions. Specifically, we characterize the synchronization pattern between key regions, which are part of the core and extended nodes of the face network, as evident by measures of functional connectivity. These regions, including the fusiform face area (FFA), occipital face area (OFA), superior temporal sulcus (STS), amygdala, anterior temporal lobe and other anterior regions, were first localized using a face localizer paradigm and were subsequently used as seed region/s for connectivity analyses of the resting state data. We conducted a whole brain analysis in order to identify any region whose time course correlated with those of the pre-selected seed/s. Using this approach, we have uncovered a set of cortical areas whose activity is significantly correlated during rest, reflecting the presence of a face-selective RSN. Importantly, we also compare and contrast this RSN with that obtained from individuals with congenital prosopagnosia, a deficit in face recognition that is apparently lifelong and occurs despite normal intelligence, sensory abilities and adequate opportunity to acquire normal face recognition. Together, these findings illustrate the inherent synchronization of a normal, distributed face network that involves regions of ventral cortex as well as more anterior regions, and they provide further support for the notion that this system is compromised in individuals with disordered face recognition.

24.26, *4:00 pm*

The body inversion effect is mediated by face-selective not body-selective brain areas

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Similar to faces, discrimination of human bodies is much worse for inverted than upright bodies. Interestingly, this body inversion effect disappears for headless bodies, which implies a critical role for the head in the generation of this effect. Previous studies have shown that the face inversion effect is mediated by the fusiform face-selective area. Given the central role the head plays in the behavioral body inversion effect, here we asked whether the body inversion effect is mediated by face-selective or body-selective brain areas. In two event-related fMR-adaptation experiments, we measured the response of category-selective occipito-temporal areas to pairs of upright or inverted bodies that were either same or different in posture. The first experiment presented whole bodies, while the second used headless bodies. For all body stimuli internal facial features were covered with a gray ellipsoid. Body-selective areas showed a higher response to inverted than upright bodies, but a similar adaptation effect (higher response to different than same pairs) for the two orientations, suggesting similar discrimination for upright and inverted bodies. This pattern was found for both whole bodies and headless bodies. In contrast, face-selective areas showed adaptation effect to upright but not inverted bodies. This pattern was found for whole bodies but not for headless bodies, where there was no adaptation for both orientations. Response of object-general areas (LOC) was higher for inverted than upright bodies and showed no adaptation effect for both orientations. Thus, only the response of the face-selective regions was consistent with the behavioral body inversion effect in that it shows discrimination for upright but not inverted bodies, for whole but not for headless bodies. We conclude that the body inversion effect is not mediated by body processing mechanisms but by face or head processing mechanisms.

Acknowledgement: Israeli Science Foundation Grant to GY 65/08

Binocular vision: Rivalry and mechanisms

Saturday, May 8, 5:15 - 6:45 pm
Talk Session, Royal Ballroom 1-3
Moderator: George Sperling

25.11, *5:15 pm*

Ocular and Image Components in Binocular Rivalry: Measuring their strengths and decay rates

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In binocular rivalry, when different, incompatible images are presented to the two eyes and only one is perceived, there are at least two factors that determine which image will dominate in perception: (1) a competition between the two eyes, with a dominant eye tending to determine perception independent of what image it is receiving, and (2) an image competition in which an image that is currently perceived tends to continue being perceived independent of which eye is receiving it. Here we demonstrate a paradigm for measuring the instantaneous "strength" of each of these components (ocular and image) and how these strengths decay over time. The experiments were carried out by Bartels and Logothetis (unpublished) who presented different, incompatible flower images to the left and right eyes. Usually, only one of the two images was perceived (binocular rivalry). After either 0.3 or 3.0 sec, there was a brief interruption stimuus, subsequently either the same stimuli were presented again or the stimuli were exchanged between eyes. The probability of perceiving a particular image after the interruption is represented in a model that assumes (1) the instantaneous ocular strength of the eye that is receiving the dominant image is represented by a positive number, and the suppressed eye by its negative;

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a second number represents the strength of the dominant image, its negative represents the suppressed image; (2) ocular- and image-component strengths add linearly, (3) the summed strengths are perturbed by additive, Gaussian internal noise; (4) the highest-strength eye+image combination is perceived after the interruption. The transformation of the raw probability-of-perception data into strengths removes all interactions. For these images, ocular strength was greater than image strength. For all subjects individually for all conditions investigated, the strengths of ocular and image components decline over time at same rate, completely in parallel.

Acknowledgement: Supported in part by NIH Award R01-MH068004-02 and NSF grant BCS-08434897

25.12, *5:30 pm*

Separate contributions of magno- and parvocellular streams to perceptual selection during binocular rivalry

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In binocular rivalry, conflicting images presented to the two eyes result in a visual percept that alternates between the two images, even though the visual stimuli remain constant. By dissociating visual stimulus from conscious percept, the study of binocular rivalry can shed light on the neural selection processes that lead to awareness. These selection processes have been shown to occur at multiple levels in the visual processing hierarchy, but the factors that determine the level at which perceptual selection is resolved are not well understood. Interocular switch (IOS) rivalry is a special form of binocular rivalry in which two conflicting images are swapped between the two eyes about three times per second. IOS rivalry elicits two types of percepts: eye rivalry, in which perceptual selection operates on monocular representations, and stimulus rivalry, which requires integration of information from both eyes over time and is thought to occur at a higher level in the visual processing hierarchy. We varied the spatial and temporal frequency of orthogonal gratings in IOS rivalry and measured the proportions of eye and stimulus rivalry. High spatial frequencies were preferentially associated with stimulus rivalry, and for low spatial frequency gratings, higher temporal frequencies promoted eye rivalry. This pattern correlates with the temporal and spatial frequency selectivities of the magno- and parvocellular visual streams. Specifically, it suggests that the magno stream is important for eye rivalry, while the parvo stream is associated with stimulus rivalry. We tested this hypothesis directly by using red/green isoluminant stimuli to reduce the activity of the magno stream and found that isoluminance increased the amount of stimulus rivalry, as predicted by the magno/parvo framework. This framework accounts for a number of stimulus dependencies reported in the IOS rivalry literature and suggests that the magno- and parvocellular pathways have distinct roles in perceptual selection.

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25.13, *5:45 pm*

Plasticity of interocular inhibition with prolonged binocular rivalry

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Anti-Hebbian learning rules have been suggested as a mechanism of synaptic plasticity in inhibitory synapses (Barlow & Foldiak, 1989). The basic idea is that the presence of coincidental pre- and postsynaptic activity increases the efficacy of the inhibitory synapse, while its absence decreases inhibitory strength. We investigated the role of anti-Hebbian learning mechanisms for interocular inhibition during binocular rivalry. In binocular rivalry, different images are presented to the two individual eyes. Rather than perceiving a mixed or averaged version of these images, observers typically perceive fluctuations between the two monocularly defined percepts. Computational models aiming to explain these perceptual fluctuations usually implement a form of mutual inhibition between percept-coding neuronal populations. Here we demonstrate that binocular rivalry is at least partially based on low-level cross-inhibition between monocular neurons with a different eye-of-origin, and that there is plasticity in the strength of these interocular inhibitions that is consistent with anti-Hebbian learning principles. We presented observers with prolonged binocular rivalry stimuli and found that the strength of interocular inhibition decreased over time, resulting in a higher incidence of mixed or superimposed percepts. With various stimuli and interleaved changes in eye-stimulus configuration, we demonstrate that this plasticity of inhibitory strength is stimulus- and eye-specific and exist for both simple gratings and more complex house/face stimuli. Further experiments revealed that recovery from ‘lowered inhibition’ only occurs if both eyes receive consistent visual information with similar features as the preceding rivalry stimuli. Neither monocular stimulation nor binocular stimuli with a different orientation and spatial frequency changed the strength of interocular inhibition back to baseline values. We conclude that, consistent with previously proposed anti-Hebbian learning rules, plasticity in interocular inhibition during prolonged binocular rivalry depends on simultaneity of activity in pre- and postsynaptic monocular neurons.

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25.14, *6:00 pm*

Attentional facilitation of perceptual learning without awareness

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Background: Perceptual learning (PL) – practice-induced improvement in perceptual task performance – is a manifestation of adult neural plasticity. Endogenous (voluntary) attention facilitates PL, but some have argued that attention plays no essential role in PL because PL can occur even when observers are unaware of the “trained” stimulus. We therefore asked whether manipulating attention to stimuli observers remain unaware of would affect PL of those stimuli.

Method: We manipulated endogenous (voluntary) spatial attention to assess whether PL would occur at attended and unattended locations, suppressing trained stimuli from awareness using continuous flash suppression (CFS), a strong form of binocular rivalry where monocular stimuli are rendered invisible by dynamic displays presented to the other eye. During 10 training sessions, observers viewed a CFS display and performed an attentional task on stimuli presented to the dominant eye. This task required attention to stimuli presented in two diagonally-located corners of the display, while ignoring stimuli in the other two corners. Concurrently, the suppressed eye was shown Gabors (the trained stimuli) at retinal locations corresponding to both attended and unattended locations. To equate the amount of practice in directing attention to all locations, on half of each session’s blocks the dominant eye’s attended and unattended locations were switched and no Gabors were presented to the suppressed eye. Before and after the training sessions, we measured contrast thresholds (without CFS) for trained stimuli at attended and unattended locations. To assess learning specificity, we also measured thresholds to “untrained” Gabors with orthogonal orientations.

Results and conclusion: Performance for trained stimuli at attended locations improved dramatically. As these stimuli were suppressed by CFS during training, this finding indicates that attention can facilitate PL without awareness. Smaller improvements were found for the other stimulus/location combinations, indicating that practice in directing spatial attention can also improve performance.

Acknowledgement: This research was supported by an International Brain Research Foundation Postdoctoral Fellowship to DC and NIH Research Grant RO1 EY016200 to MC.

25.15, *6:15 pm*

Baseline fMRI pattern activity in early visual cortex predicts the initial dominant percept in subsequent binocular rivalry

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Binocular rivalry occurs when the two eyes receive conflicting images and rival for perceptual dominance such that only one monocular image may be consciously perceived at a time. There is still no consensus regarding the potential neural sites of these competitive interactions. Here we test whether neural activity occurring before the stimulus can predict the initial percept in binocular rivalry, and if so whether it is activity in early retinotopic areas, or higher extrastraite areas, that is predictive of the initial percept. Subjects were scanned while viewing an image of a face in one eye and an image of a house in the other eye with anaglyph glasses. The rivalrous stimulus was presented briefly for each trial, and subjects indicated which image he or

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she preferentially perceived. Our results show that pre-trial fMRI pattern activity in the foveal confluence is correlated with the subsequent percept, whereas pre-trail activity in the FFA and PPA were not predictive of the initial percept, suggesting a greater causal role for the foveal confluence than higher extrastriate areas in determining the initial percept.

25.16, *6:30 pm*

Left global visual hemineglect in high Autism-spectrum Quotient (AQ) individuals

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This study explores the visual perceptual differences between individuals from a normal population (mean age 25 yr) showing high versus low Autism-spectrum Quotient (AQ). A perceptual rivalry stimulus – the diamond illusion, containing both global and local percepts was used to explore the effects of occluder contrast (that hide the vertices of the diamond) and peripheral viewing, in populations of high (n=23) and low (n=15) AQ. Additionally, multifocal nonlinear visual evoked potentials (VEP), achromatic (24% and 96% contrast) were used to test for the presence of underlying physiological differences in magno- and parvocellular function. Both groups showed an increase in the percentage of global perception with increasing contrast of the occluding stripes, however, no difference was found between AQ groups. A relative increase in global perception with increasing eccentricity of the stimulus from fixation was also seen in both groups. Remarkably, the high AQ group showed a significant reduction in global perception when the stimulus was presented in left hemifield, but not for presentation in right hemifield. This global perceptual hemineglect suggests the possibility of abnormal parietal function in individuals with high AQ. While VEPs were similar at low contrast between hiAQ and loAQ groups, at high contrast there appeared to be interference with normal processing particularly of the magnocellular second order kernel slice. Seven VEP parameters used in a discriminant analysis correctly classified high or low group membership in 95% of the participants.

Scene perception

Saturday, May 8, 5:15 - 6:45 pm
Talk Session, Royal Ballroom 4-5
Moderator: Frans Cornelissen

25.21, *5:15 pm*

Scene categorization and detection: the power of global features

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Scene recognition involves a different set of challenges from those posed by object recognition. Like objects, scenes are composed of parts, but whereas objects have strong constraints on the distribution of their parts, scene elements are governed by much weaker spatial constraints. Recently, a number of approaches have focused on the problem of scene classification using global features instead of encoding the objects within the scene. An important question is "what performance can be achieved using global image features?" In this work we select and design several state-of-art algorithms in computer vision and evaluate them using two datasets. First, we use the 15 scene categories dataset, a standard benchmark in computer vision for scene recognition tasks. Using a mixture of features and 100 training examples per category, we achieve 88.1% classification accuracy (human performance is 95%; the best prior computational performance is 81.2%). For a more challenging and informative test we use a new dataset containing 398 scene categories. This dataset is dramatically larger and more diverse than previous datasets and allows us to establish a new performance benchmark. Using a variety of global image features and 50 training examples per category, we achieve 34.4% classification accuracy (chance is only 0.2%). With such a large number of classes, we can examine the common confusions between scene categories and evaluate how similar they are to the target scenes and reveal which classes are most indistinguishable using global features. In addition, we introduce the concept of scene detection — detecting scenes embedded within larger scenes — in order to evaluate computational performance under a finer-grained local scene representation. Finding new global scene representations that significantly improve performance is important as it validates the usefulness of a parallel and complementary path for scene understanding that can be used to provide context for object recognition.

Acknowledgement: Funded by NSF CAREER award 0546262 to A.O. and NSF CAREER Award 0747120 to A.T

25.22, *5:30 pm*

The Good, the Bad, and the Scrambled: A Perceptual Advantage for Good Examples of Natural Scene Categories

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Recent research has shown that participants are better able to categorize briefly presented natural scene images that have been rated as "good" exemplars of their category, and that this is reflected in the distributed patterns of neural activation obtained through fMRI (Torralbo, et al., 2009). The effect of typicality on categorization/decision processes is well documented (see Rosch, 1978), but it is possible that such effects may also reflect differences in perception. Here we asked whether subjects might actually 'see' good exemplars of a category better than bad exemplars. We asked subjects to simply report whether a very briefly presented (19 ms – 60 ms) image was intact or scrambled. Images drawn from six natural scene categories (beaches, city streets, forests, highways, mountains and offices) were rated as either "good" or "bad" exemplars of their categories. These images were presented in either their original intact state, or 100% phase scrambled (Sadr & Sinha, 2004), and then followed by a perceptual mask. Note that the subjects were never instructed to categorize the scenes nor were they explicitly notified that the image set contained good and bad category exemplars. We measured participants' d' separately for good and bad images, and found that participants were better able to discriminate intact from scrambled images when the images were good category exemplars than bad category exemplars. These results suggest that knowledge about scene category actually allows observers to 'see' natural scene images better, regardless of whether scene category is relevant to task.

Acknowledgement: This work is funded by the NIH (LFF, DB, DW)

25.23, *5:45 pm*

fMRI Decoding of Natural Scene Categories from Line Drawings

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Using full color photographs of natural scenes, we have previously shown that information about scene category is contained in patterns of fMRI activity in the parahippocampal place area (PPA), the retrosplenial cortex (RSC), the lateral occipital complex (LOC), and primary visual cortex (V1) (Walther et al. J. Neurosc. 2009). If these regions are involved in representing category, then it should be the case that we could decode scene category for any natural scene image that participants can categorize, including simple line drawings. In keeping with this prediction, we found that we can decode scene category from fMRI activity patterns for novel line drawing pictures just as well as from activity for color photographs, in V1 through PPA. Even more remarkably, a decoder trained on fMRI activity elicited by color photographs was able to predict the correct scene categories when tested on activity patterns for line drawings just as often as for color photographs, indicating that the activation pattern elicited by color photographs generalized well to line drawings. Conversely, a decoder trained on activity for line drawings was able to decode activity patterns for photographs just as well as for line drawings, but only in the PPA and V2/VP, suggesting that, in these regions, category information is strongly determined by the edge and line information in a photograph. We conclude that line drawings contain sufficient information about natural scene categories to produce scene-specific fMRI activity patterns all along the visual processing hierarchy. Moreover, the specific encoding of this information appears to be similar to that elicited by photographs as shown by successful decoding of scene categories across the two image types. Our findings suggest that scene structure, which is preserved in line drawings, plays an integral part in representing scene categories.

Acknowledgement: NIH 1 R01 EY019429

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25.24, *6:00 pm*

fMRI evidence for two distinct ventral cortical vision systems

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The repertoire of human visual recognition skills is amazingly broad and ranges from rapid "gist"-based scene categorization to the fine scrutiny of minute object details. While ventral occipital cortex is implied in all these abilities, the computational organisation that enables this is still poorly understood. Recent eye-tracking studies have shown that eye-movement characteristics can be used to distinguish between two different modes of perception, one associated more with global processing, and the other with more detailed visual analysis. We reasoned that if these perceptual modes reflect genuinely different cortical processing, we should be able to use eye-movements to tease apart the underlying neural correlate. In our functional MRI experiment, participants freely viewed images of visual indoor scenes while their brains were scanned and their eye-movements tracked. We define two classes of eye-movement events to approximate the different viewing modes. Brief fixations followed by large saccades were defined as "scanning" events, whereas long fixations followed by short saccades represent "inspection" events. These events were subsequently used in the analysis of the fMRI data. Independent component analysis indicated the existence of two clusters in ventral occipital cortex. The cluster of activity in ventro-medial occipital cortex was preferentially associated with scanning events while inspection events were preferentially associated with activity in the ventrolateral cluster. Hence, this shows that fMRI signals recorded from ventral cortex can be segregated based on eye-movements. Information processing during scanning events is suggested to be of statistical nature, given their brevity and the peripheral location of the saccade target. The longer inspection events presumably enabled additional scrutiny of features as well as computation of spatial relationships. Hence, our work suggests that the human ventral stream subdivides into two vision systems that enable perception based on distinct visual information and neural computations.

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25.25, *6:15 pm*

One cortical network for the visual perception of scenes and textures

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Visual scene perception is a core cognitive ability that allows us to recognize where we are and how to act upon our environment. Visual scene perception is therefore crucial to our functioning. Despite this, the neural implementation of visual scene perception remains largely unexplored. Although previous neuroimaging studies have identified several scene-selective brain regions – most notably the parahippocampal place area (PPA), retrosplenial cortex (RSC), and a region along the transverse occipital sulcus (TOS) – data thus far do not indicate the type of neural computations underlying visual scene perception. When a visual system computes a statistic based upon multiple visual features, it is said to perform textural analysis. Clearly, texture analysis is useful to characterize the texture of surface materials. But from a computational perspective, it can also be used to characterize visual scenes. We reasoned that if the brain applies textural analysis to scenes, one would expect it to encode textures and scenes in the same cortical regions. To test this hypothesis, we used long-interval fMRI repetition priming to identify regions in which neuronal activity attenuates on repetition of visually presented textures. This approach allowed us to probe regions that encode visual texture independent of spatial image transformations. Such independence is important because the result of textural analysis (i.e., extracted statistical image information) should be stable across varying retinal projections. This was verified by the observation that rotated and scaled repetitions of the stimuli did not cancel the priming-induced reduction of activity. In addition, we used a classic fMRI 'localizer' sequence in order to independently identify the PPA, RSC, and TOS. Our results reveal that the human brain encodes texture in regions that are also scene-selective. This, we argue, indicates that there is one cortical network for visual scene and texture perception that uses statistical image information in its computations.

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25.26, *6:30 pm*

The structure of scene representations across the ventral visual pathway

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As we navigate the world we encounter complex visual scenes that we can both categorize and discriminate. Prior studies have reported scene category information in both early visual cortex (EVC) and the scene-selective parahippocampal place area (PPA). However, these studies used only a small number of preselected categories, providing little insight into the discrimination of individual scenes or unbiased test of the categorical structure of the representations. Here we use a multivariate ungrouped approach to establish the differential discrimination and categorical structure of scene representations in EVC and PPA. We presented 96 unique, diverse, and highly detailed scenes in an event-related fMRI paradigm with each scene being a unique condition. The scenes were chosen to equally sample from all the combinations of three broad classes based on apparent depth (near/far), content (manmade/natural), and the gross geometry of the scene (open/closed). We then used multi-voxel pattern analysis to establish how the responses of PPA and EVC. Importantly, neither our stimuli nor analyses had any bias towards any particular organization or categorization of the scene stimuli. We found that the response of both PPA and EVC could be used to discriminate individual scenes from one another. However, the scene representations in these two regions differed in their categorical structure. The response of PPA grouped scenes by their geometry (open/closed) despite differences in their perceptual content, consistent with a role in navigation. In contrast, early visual cortex grouped scenes based on the distance to the nearest foreground object (near/far). In neither region did we find evidence for strong grouping by the scene categories often assumed in the prior literature (e.g. beaches, cityscapes). These results suggest while both regions can discriminate scenes each encodes different aspects of complex scenes, providing insight into the transformation of visual information along the ventral visual pathway.

Acknowledgement: NIMH Intramural Program

Saturday Afternoon Posters

Attention: Temporal selection and modulation

Royal Ballroom 6-8, Boards 301–309

Saturday, May 8, 2:45 - 6:45 pm

26.301 The Effect of Extensive Repeated Viewing on Visual Recognition

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The US Army RDECOM CERDEC Night Vision & Electronic Sensors Directorate (NVESD) has conducted numerous experiments involving combat recognition and identification in support of sensor model development. Participants sometimes report feeling fatigued after completing experiments, especially those in excess of 400 trials. If such a fatigue were to exist, it would introduce error into and reduce the sensitivity of NVESD perception modeling experiments. The authors conducted an experiment with 25 participants investigating fatigue associated with extensive repetitions (1008 trials) of visual vehicle recognition and identification tasks. Participants were allowed up to 8 seconds to recognize (Tank, APC, SPA) and identify (e.g. T-55 vs. T-72), each of 144 vehicle thermal images (12 tracked vehicles at twelve aspects) presented 7 times. Results indicate no significant reduction in recognition accuracy and no significant effect on response times.

This contrasts with vigilance tasks, in which the goal is to detect the presence of a rare target and performance declines within the first half hour or so (Parasuraman, 1986). Likewise, we did not observe the typical sensitivity decrement (Parasuraman, 1979), which occurs for rapidly presented events (e.g. 30-60 Hz). Sensitivity decrements increase as memory load increases and image quality decreases, yet performance did not decline in our task, which used a large number of possible targets and degraded thermal images. We propose that our training protocol (2 days of combat ID training with a 96% pass criterion) was able to mitigate the effects of fatigue on attention, despite subjects never reaching ceiling-level performance. Alternatively, time-on-task effects might be restricted to detection tasks, as in most vigilance experiments, unlike the tasks used in the present study. Results indicate that fatigue associated with extensive repetitions of recognition or identification tasks will not introduce error into perception experiments such as those used to support NVESD sensor modeling.

26.302 Is it better to burn out or fade away? The effect of sudden offsets on target recovery

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Does the ability to track moving objects through a temporary disappearance depend on how they disappeared? In the target recovery paradigm, participants track multiple targets moving in a display amongst identical distractors and across a momentary blank of the display. Participants must recover the targets after the blank to successfully discriminate them from distractors at the end of a trial. Keane and Pylyshyn (2006) showed superior performance when objects paused during the blank compared to when they continued to move during blank. They suggested this pause-advantage indicated that people do not extrapolate positions of moving objects during tracking. An alternative account of the pause-advantage is that the objects' disappearance causes the positions of the targets to be memorized and then matched to the objects' positions when they reappear. We investigated whether the pause-advantage depended on the strength of the transient produced by the offset of the objects. To increase the strength of the transient, the objects "burned out" by increasing in size just before their offset. To decrease the transient, the objects "faded away" by gradually decreasing in luminance before their offset. The results showed a significant interaction between transient strength (burn out, fade away) and condition (pause, move), $F(1,9) = 58.61$, $p < 0.0001$. Difference scores constructed by subtracting performance in the move condition from that of the pause condition showed a significantly greater pause-advantage when objects burnt out compared to when they faded away, $t(9) = 7.66$, $p < 0.0001$. These results demonstrate that stronger transients improve the ability to recover moving objects after they temporarily disappear - burning out is better. Stronger transients may improve the encoding of pre-blank positions to memory. The pause-advantage may stem from processing that occurs because of the blank and may not reflect processing related to tracking.

26.303 Temporal Feature Binding of Spatially Separated Features is Faster in the Fovea and across Hemifields

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Temporal feature binding is the ability to distinguish a combination of features shown simultaneously from other binding possibilities. Temporal binding is vital because visual scenes are often dynamic and people constantly move their eyes. In the current study, we investigated properties of binding spatially separated features. In the first experiment, we found that binding spatially separated color and orientation is faster in the fovea than in the periphery. The stimulus was a disk. Half of the disk was spatially uniform but alternated in color over time (e.g., red and green) and the other half contained gratings alternating in time between two orientations (e.g., 45° and 135°). The disk was shown either at fixation or 10° below fixation (suitably scaled in size). For a given trial, one color-orientation pair alternated with another color-orientation pair. Noise maskers preceded and followed the stimuli. Subjects responded by indicating the correct pairing of color and orientation. Subjects could better detect the color and orientation combination when the stimulus was presented in central vision than peripheral vision. (About 10% greater accuracy in central vision at all three alternation frequencies.) In the second experiment, two circular disks each containing either color or orientation features were separated by 8 deg. We found that when the two features were placed in the left and right hemifields, subjects were more accurate in detecting the feature pairings compared to when they were placed in the same hemifield (at the same eccentricity and with the same spatial separation). This observation indicates that binding spatially separate features requires central resources (e.g., attention) which are more available across two hemifields than within one hemifield. Together, the foveal advantage and cross hemifield advantage support the idea that binding spatially separate color and orientation features is achieved at a high level in the visual pathway.

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26.304 Correlated effects of attention and awareness on contrast threshold elevation but not on afterimage formation

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In the debate about the relation between attention and awareness a curious observation is that the two phenomena have opposite effects on afterimage formation: unperceived inducing images leave a weaker afterimage whereas unattended inducing images leave a stronger afterimage. This qualitative difference stands out among other findings that generally show attention and awareness to be similar, albeit not identical. Our starting point is the observation that, beside an afterimage, inducing images also cause contrast threshold elevation. Indeed, this threshold elevation impairs visibility of the afterimages themselves. This renders inconclusive existing reports of opposite effects of attention and awareness on subsequent afterimage perception: a fainter afterimage could either indicate lessened afterimage formation or augmented threshold elevation. We present a new psychophysical method to tease apart these two factors and thereby clarify the effects of attention and awareness on afterimage formation. Using this method, which centers on nulling the afterimage using a physical image, we demonstrate that attention and awareness have similar effects on afterimage formation, and also on threshold elevation. Both are augmented when the inducing image is attended, as well as when the inducing image is perceived. The impression of opposite effects of attention and awareness only arises when afterimage strength and threshold elevation are not distinguished, such as in measures of afterimage visibility. In addition, we show that inter-observer differences in the effects of attention and awareness on threshold elevation are correlated. Inter-observer differences in the effects on afterimage formation, however, are not. Our results indicate that attention and awareness are qualitatively similar in their effects on afterimage formation and threshold elevation, and that this similarity is particularly pronounced at the level of threshold elevation.

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26.305 **Temporal extension of figures: Evidence from the attentional blink**

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Recent research on figure-ground organization has focused on the behavioral consequences of figure-ground assignment, including faster responses and higher accuracy for figures; however, other outcomes exist. For instance, figure-ground assignment has consequences for temporal processing: perceptual processing begins earlier for figures than for background regions, demonstrating a 'prior entry' effect (Lester et al., 2009). Additionally, figures are afforded extended processing relative to backgrounds (Hecht & Vecera, in preparation). One implication of this 'temporal extension' effect is that figures have poorer temporal resolution compared to background regions, and detection of a stimulus presented in close temporal proximity to a figure should be impaired relative to detection of a stimulus appearing after a background region. Consequently, performance in tasks requiring rapid temporal processing of items presented in close succession should be impaired for figure regions relative to ground regions. To assess this conjecture, observers monitored an RSVP stream of letters for two targets. The first was a target letter, embossed on the surface of the figure or the background region of a bipartite figure-ground display presented in the RSVP stream. At varying delays in the RSVP sequence, the second target (i.e., a number) appeared in the stream. In accordance with the proposal that figures have degraded temporal resolution relative to background regions, the attentional blink was moderated by figure-ground assignment. Specifically, reports for the second target were less accurate following figure trials. In other words, when the first target appeared on a figure, the attentional blink was larger than when the first target appeared on a background region. These results support the 'temporal extension' effect of figures.

Acknowledgement: Grinnell College CSFS and travel grants awarded to Lauren N. Hecht

26.306 **Temporal resolution of attention in foveal and peripheral vision**

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Purpose: Attentional blink (AB) refers to people's inability to detect and identify the second of two targets presented in close temporal succession, typically in a rapid serial visual presentation (RSVP) stream. Is the attentional mechanism governing the temporal selection of sensory information the same or different between foveal and peripheral vision? Here we assess the temporal dynamics of attention in foveal versus peripheral vision using the AB paradigm. Method: Six normally sighted young adults participated in each of the two experiments (E1 and E2). RSVP streams of 24 distractor letters with two target letters (T1 and T2) of a different color periodically embedded within them were presented at a rate of 9.44 Hz in foveal or in peripheral vision. Eccentricities of stimuli in the peripheral condition were 4.0° (E1) and 8.0° (E2) in lower right visual field. The stimuli subtended visual angle of about 1.3° and 2.6° (E1), and 0.5° and 3.0° (E2) in the foveal and peripheral conditions, respectively. Foveal and peripheral trials were presented in separate blocks (4 blocks per condition) of 80 trials. Results: Analysis of the proportion of correct T2 reports given correct T1 identification, P(T2|T1), showed the typical AB findings in both the foveal and peripheral conditions. Inverted Gaussian functions were fitted to the P(T2|T1) data to estimate the magnitude of the AB effects. Average magnitudes of AB in the foveal and peripheral conditions were 0.73±0.06 and 0.46±0.07 (E1), and 0.57±0.08 and 0.34±0.08 (E2), respectively. Magnitude of AB was significantly smaller in peripheral than in foveal vision in both experiments ($ps<.05$). Conclusion: The results appear to suggest a weaker temporary reduction in attention in peripheral than in foveal vision during AB. The findings taken together may imply systematic temporal variations in selective attentional deployment across the visual field as a function of eccentricity.

26.307 **Two of a kind: temporal order errors in the attentional blink and in temporal order judgments**

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As everyday observers, we usually presume that temporal properties of our perceptions are due to distal objects. Yet, in the laboratory we can show that these properties rather reflect the temporal dynamics of the underlying visual processes: When two target stimuli are presented in close temporal proximity, the perceived order of these targets is often reversed. The resulting temporal order errors can be found in experimental paradigms like a.) the attentional blink, in which observers are asked to report two targets embedded in a series of rapidly changing distractor stimuli all presented at the same location but at different times; or b.) temporal order judgments, in which the task is to report the first of two near-simultaneous stimuli presented at different spatial locations. Although these phenomena appear to be similar, they have received different explanations, depending on the paradigm. For example, attentional blink theories stress episodic integration, whereas temporal order judgment errors have often been explained through prior entry. We present research investigating the hypothesis that these phenomena are very similar, by assessing the effects that particular manipulations have on both tasks. These manipulations included the presence vs. absence of distractors, the effect of cueing, the target set size, and the particular task involved. We show that performance on the one paradigm predicts performance on the other, consistent with the idea of common mechanisms.

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26.308 **How flexible and fast is the focus of attention? Evidence from the Attentional Blink and Lag-1 sparing**

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When two targets (T1, T2) are inserted in a rapid stream of distractors, perception of T2 is impaired at short inter-target lags, a phenomenon known as the Attentional Blink. Identification accuracy for T2 is sometimes spared if T2 is presented directly after T1 (Lag-1 sparing). Research typically shows that Lag-1 sparing occurs only if the two targets appear in the same spatial location. It has recently been suggested, however, that the spatial relationship between the targets is not the determining factor; rather, Lag-1 sparing occurs whenever T2 appears within the focus of attention (Jefferies, Ghorashi, Kawahara, & Di Lollo, 2007; Jefferies & Di Lollo, 2009). According to this hypothesis, if the focus of attention shifts from the location of T1 to a second location, not only should Lag-1 sparing occur to T2 if it appears at the newly-attended location (Jefferies & Di Lollo, 2009), but Lag-1 sparing should comparably not occur to T2 at the now-unattended T1 location. The second half of this hypothesis – as yet unverified – is tested here by combining an attentional blink paradigm with a peripheral contingent capture paradigm. In Experiment 1, we found that when attention is shifted to a peripheral, task-relevant distractor, Lag-1 sparing occurred if T2 appeared at the newly-attended peripheral location, but not if it appeared at the central stream (i.e., the now-unattended location of T1). In Experiment 2, we found that if insufficient time is allowed for an attention shift to be completed, the focus of attention remains at the T1-location, and Lag-1 sparing is again found if T2 appears in the same location as T1. In summary, the current research tests and confirms the hypothesis that the critical determinant of Lag-1 sparing is T2 occurring within the focus of attention, not the targets appearing in the same spatial location.

Acknowledgement: Natural Sciences and Engineering Research Council of Canada

26.309 **Serial chaining of two cognitive operations: An fMRI and MEG study**

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The capacity of visual short-term memory can be increased significantly when the to-be-remembered objects are presented sequentially across two displays, rather than simultaneously in one display (Ihssen, Linden, & Shapiro, VSS, 2009). Interestingly, a similar performance increase is observed when the (simultaneous) display is repeated. The present study sought to elucidate brain mechanisms underlying the sequential and repetition benefit. We used functional magnetic resonance imaging during a change detection task where participants had to maintain 8 different objects (colours and white shapes). Objects were presented either simultaneously (baseline condition), split into two temporally separated 4-object arrays (sequential condition), or presented twice (repetition condition). Importantly, conditions were matched for perceptual load and visual onset by filling the sequential 4-object arrays with placeholders and presenting a second "empty" placeholder array in the baseline condition. Whole-brain BOLD analyses revealed two main results: Relative to the baseline condition, both sequential and repeated conditions evoked stronger brain responses in extrastriate visual areas. Mirroring memory performance, BOLD amplification in these areas may relate to the higher number of object representations that are activated along the ventral pathway. In contrast to the occipital effects, two key regions of the frontoparietal attention/working memory network dissociated the sequential and repetition conditions. In the inferior parietal lobe and the frontal eye fields, sequential displays elicited reduced brain activation, relative to BOLD responses in the repetition and baseline conditions, which showed no difference. Implications of these findings are discussed within the framework of biased competition.

Acknowledgement: Human Frontiers of Science Programme, Wales Institute of Cognitive Neuroscience

Attention: Divided attention

Royal Ballroom 6-8, Boards 310–319

Saturday, May 8, 2:45 - 6:45 pm

26.310 Evidence for Strategic, Fluid Allocation of Visual Attention

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Attention to a visual object sharpens the representation of that object's features, e.g., location, orientation, hue, velocity, etc. These advantages can be spread to multiple objects in the visual field, but there is a trade-off between the number of items attended and the degree of benefit. Here, we show evidence that visual attention can be allocated strategically and fluidly between objects of variable importance. Observers attended to cued arrows among similar distractor arrows. Following a brief blank period, a single target arrow reappeared with a changed direction, and observers indicated whether its displacement was clockwise or counterclockwise. Accuracy was used to assess the precision of representation of direction, which decreases as the number of attended objects increases. Then, the precision of direction representation for equal-valued targets was compared with the precision for targets of variable value. In the variable value condition, subjects were instructed to maximize their scores based on a point scheme where correctly assessing the displacement direction of High-Value targets was worth twice as many points as Low-Value targets. While subjects' performance showed a relatively precise representation of High-Value targets, the representation of Low-Value targets was impaired. The combined accuracy for judging both High-Value and Low-Value targets was comparable to the previously recorded accuracy for the same total number of equal-valued targets. Analysis via a mixture model that distinguishes between the precision of target representation and probability of failure to represent a target at all (Bays & Husain, 2008; Zhang & Luck, 2008), suggests that this differential benefit of attention is due to strategic allocation of attentional resources, rather than simply attending to High-Value targets and ignoring Low-Value targets. The results of these experiments demonstrate that while visual attention is a limited resource, it can be strategically and fluidly allocated to benefit attended items to varying degrees.

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26.311 Reevaluating the sustained division of the attentional spotlight at high temporal resolution

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Recent fMRI and EEG evidence suggests that attention can concurrently select multiple locations. Most studies, however, generally lack a sufficient temporal resolution to rule out a unique, rapidly switching spotlight sequentially sampling the target locations. For example, using a classic "frequency-tagging" technique Müller and colleagues demonstrated a concurrent EEG enhancement at the tagged frequencies of two disjoint target locations (Müller et al, Nature, 2003). The temporal resolution of this technique is, however, limited to a quarter of a second and often more: a few stimulus cycles are necessary to determine EEG amplitude at the tagged frequency, and higher frequencies (being more sensitive to measurement noise) require even longer analysis windows. So, can the spotlight really be divided in a sustained manner? Or does attention switch faster than can be resolved using existing techniques? The novel method we present here ("broadband frequency tagging") aims at resolving this fundamental question. Ten subjects monitored two patches of randomly varying luminance, to the left and right of fixation, for the appearance of a subtle contrast decrement, over a period of 6.25 seconds in each of 480 trials. Both patches contained an equal amount of power in all frequency bands from 0 to 80Hz over the stimulus presentation period. But critically, at any given time the two stimuli had distinct (and independent) frequency signatures. Using time resolved EEG decomposition in the frequency domain, this broadband frequency tagging paradigm allows us to dynamically monitor the allocation of attention to the two targets. As all tagging frequencies (0-80Hz) can contribute to the decomposition and their respective contributions can be adjusted at will, this technique can be said to provide the best possible temporal resolution. Using this new method, we were able to reconsider the previous conclusion that multiple targets are monitored in parallel.

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26.312 Divided Attention and Subjective Visibility

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Viewers generally feel that they have a richly detailed perception of an entire scene, even though experiments have demonstrated that stimulus-processing capacity in unattended locations is relatively poor. Previous preliminary results from our lab suggests that when stimulus-processing capacity (d') was matched, subjects were more liberal when detecting uncued than cued stimuli. They also reported higher levels of subjective visibility for uncued stimuli in a discrimination task when d' was matched. In the current study, we manipulated attention by varying the the number of items presented. Subjects were asked to determine the tilt of a cued target and then rate the visibility of that target as low or high. The number of items on the screen was either two or four, and the subjects were given the cue/probe after the items had disappeared. When attention is divided between more items, performance decreases as expected. However, when we examined the relationship between performance and visibility ratings, we found it differs between the 4-item and 2-item conditions. At low performance levels, subjects rated visibility to be higher in the 4-item than in the 2-item condition, even though subjects were equally good at discriminating the targets. The results suggest that divided attention can lead to inflation of subjective visibility, especially at low contrast/performance levels. Taken together with other empirical results, we argue that perhaps the inflated visibility of weakly attended stimuli contributes to the fact that viewers are overconfident about what they can see in a single glance when looking at a complex scene.

26.313 Does dividing attention help at all? Competition among multiple attended items

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Focusing attention on a single item isolates it from competitive interactions with nearby stimuli (Reynolds et al., 1999; Kastner et al., 1998). Dividing attention among multiple competing items, however, should fail to isolate the contributions of a single stimulus, leaving their competitive interactions unchanged. Our previous work (Scalf & Beck, in press) confirms that directing attention to multiple items produces more competition than does does directing attention to just one of the items. In the current experiment, we investigate whether directing attention to multiple items reduces competition among those items relative to conditions in which they are unattended. We presented participants with arrays of five complex stimuli in the upper right quadrant of the visual field and a stream of digits, letters and symbols at fixation. We manipulated whether attention was directed to the peripheral stimuli by asking participants to monitor either the five peripheral locations for a color/shape/texture conjunction or the fixation stream for an "a". We manipulated the degree of competition among items by employing sequential and simultaneous presentation conditions. Competition could take place only among simultaneously presented stimuli (Kastner et al., 1998). We find robust competition among items (greater activation under sequential presentation than under simultaneous presentation) across attentional conditions. Although directing attention to five items increased the overall activity they evoked in V4, this effect did not interact with presentation condition; that is, there was no evidence that directing attention to five items reduced their competitive interactions relative to when they were unattended. Our data indicate that when simultaneously directed to multiple competing items, attention is an ineffective remedy for competition for representation.

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26.314 **Judging peripheral change: Attentional and stimulus-driven effects**

Jenna Kelly[1](kelly_j@denison.edu), Nestor Matthews[1]; [1]Psychology, Denison University

Introduction: Previous research has revealed performance advantages for stimuli presented across (bilateral) rather than within (unilateral) the left and right hemifields on a variety of spatial attention tasks (e.g., Awh & Pashler, 2000; Chakravarthi & Cavanagh, 2009; Reardon, Kelly, & Matthews, 2009). Here we investigated whether a bilateral advantage would also be observed for tasks limited by the temporal resolution of attention. Method: Twenty-three Denison University undergraduates completed a 3x3 within-subject experiment. The independent variables were attentional condition (bilateral, unilateral, diagonal) and distracter condition (absent, static, dynamic). Stimuli were Gabor patches in the 4 corners of the screen (14.55 deg diagonally from fixation); 2 were pre-cued as targets on each trial. In two-thirds of trials, 2 Gabor distracters were presented between each pair of corner target positions. In half of these trials, the distracters did not change orientation throughout the duration of stimulus presentation. In the remaining distracter trials, distracter orientations changed orthogonally at random time intervals. After correctly identifying a foveally flashed letter, participants judged whether or not the cued targets had changed orientation simultaneously. Results: When distracters were absent, proficiency (d'/RT) was significantly lower in the diagonal condition than in either of the bilateral or unilateral conditions, which were statistically indistinguishable. This diagonal disadvantage was eliminated in the presence of either distracter type. Discussion: The significantly lower proficiency in the diagonal condition—in which targets were in opposite hemifields—argues against an effect of laterality on this task. This lack of laterality effects in the temporal resolution of attention contrasts with the significant laterality effects previously reported on spatial attention tasks (Awh & Pashler; Chakravarthi & Cavanagh; Reardon, Kelly, & Matthews). This suggests different constraints on the spatial versus temporal resolution of attention, which is consistent with the conclusion of Aghdaee and Cavanagh (2007).

26.315 **Concurrent Task Performance and the Role of Attention in Change Detection**

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Detecting a change in a scene is easy when motion cues are available to draw attention to the location of the change. However, when visual contact with the scene is even briefly disrupted, as in the flickering task of Rensink, O'Regan, and Clark (1997), change detection becomes difficult. A brief mask intervening between alternate versions of a photographed scene slowed change detection markedly relative to immediately successive presentations. The difficulty in the flickering task was attributed to the requirement of focused attention to maintain image components in memory for comparison and the need to direct attention serially to different components until the area of change became the focus of attention. However, attention was not manipulated directly.

The present series of experiments tested whether limiting the attentional resources available would disrupt change detection by having participants perform concurrent n-back or number-repetition control tasks. Experiments 1 and 2 examined the effects on change detection when alternate forms of the images switched every 320 ms. Experiment 1 allowed the use of motion cues, in that alternate forms of images were presented in immediate succession. Change-detection performance was equivalent for the two concurrent tasks. Experiment 2 removed motion cues by using the flickering task with a mask between alternate forms. Change detection performance was adversely affected by concurrent performance of the n-back task relative to the control. Experiment 3 replicated two presentation conditions from the Rensink study, using a 640 ms image alternation rate. In addition to the mask between alternate forms, in one condition, the presentation time of each form was divided by a mask. In both versions of the task, concurrent performance of the n-back task slowed change detection. Overall, the results support the conclusion that attention is important for change detection when motion cues are not available.

26.316 **Conspicuity of peripheral visual alerts**

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Measurement of peripheral visibility of a target typically involves a fixating subject intently waiting for the appearance of the stimulus. In real-world environments such as aircraft cockpits and automobiles, however, the operator is usually engaged in a variety of non-monitoring tasks when visual alerting signals appear. We use the term conspicuity to distinguish the attention-getting power of a visual stimulus from simple visibility. We have developed an experimental paradigm to study visual conspicuity: subjects perform a demanding central task, in which they use a computer mouse to keep a wandering target spot in the central portion of the screen, while simultaneously monitoring a set of peripheral numeric displays for color change events. When such an event occurs, the subject must make a judgment concerning the displayed numeric value, indicating the response with a mouse click on one of two buttons located above and below the item. The strengths of the various alerts are varied within a run using a staircase procedure, allowing us to estimate noticeability thresholds. Visibility of the alerting signals is measured separately in a control experiment in which the subject fixates a location within the central task area, while monitoring the peripheral alert locations. Thresholds in the dual-task experiments are lower than would be expected based on the results of the control experiment, due to the fact that the subjects actively sample the alert locations with fixations while performing the central task. Not surprisingly, more sampling fixations are made to high-frequency alert locations. The results are modeled using N-SEEV (Steelman-Allen et al., HFES 2009), a computational model of attention and noticing that predicts visual sampling based on static and dynamic visual sampling, the bandwidth and value of information in each channel, and the subject's attentional set.

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26.317 **An overview of the attentional boost effect**

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We report a series of studies on a new attentional phenomenon: the attentional boost effect, and relate it to perceptual learning, dual-task interference, and event perception. The attentional boost effect is the surprising finding that when two continuous tasks are performed concurrently, a transient increase in attention to one task enhances, rather than impairs, performance in another task. In the standard paradigm our participants encoded a series of scenes presented at 500 ms/item into memory while simultaneously monitoring an unrelated stream of letters (also presented at 500 ms/item) for an occasional target (e.g., a red X among other colored letters). Previous studies have shown that attention to the letter task transiently increases when a target is detected relative to when a distractor is rejected. Instead of producing dual-task interference, however, performance on the scene encoding task was enhanced by target detection: Memory for scenes that were encoded when the target letter appeared was significantly better than memory for scenes presented before or after the target letter. The attentional boost effect contrasts with the majority of the dual-task performance and attention literature, showing that increasing attention to one task can trigger an attentional process that supplements, rather than impairs, performance on a second task. We report experiments that illustrate the generality of the attentional boost effect across different sensory modalities, different primary tasks, and different time scales (e.g., perceptual processing, long-term memory). We also relate and differentiate this effect to other attentional and memory phenomena such as the attentional blink, temporal grouping, memory isolation effects, and perceptual learning.

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26.318 The effect of peripheral task on the training for enlarging useful visual field

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[Purpose] The size of the useful visual field changes dependently on the attentional state. Previous works have shown that training reduces the influence of the central task, suggesting extending the size of the useful visual field. For the training effect performing the dual tasks perhaps play an important role while the presentation of the central and peripheral stimuli may also play a role. In order to examine whether training extend the size of the usual visual field without peripheral task, we conducted psychophysical experiments to investigate the effect of training on the field size without any peripheral task. [Experiment] We used a rapid serial visual presentation (RSVP) task as the central task and detection of a gradual luminance increment with a temporal Gaussian profile as the peripheral task to measure the size of the usual visual field. The peripheral stimulus was presented at locations with different distances from the fixation point. There were two training conditions: dual-task training and single-task training. During the dual-task training, the participants were asked to perform the central RSVP task and the peripheral detection whereas they were asked to do only central task during the single-task training. The peripheral stimulus was supra-threshold stimulus in the single-task training sessions so that the participant can detect easily if asked to do. Based on the detection rate as a function of the eccentricity, we defined the size of the useful visual field within which the detection rate was higher than 62.5% before and after each type of the training sessions. [Results] The performance of the peripheral task improved and the useful visual field size was expanded with a significant amount both after the dual-task and the single-task trainings. These results suggest that the useful visual field size increases by the training even without performing a peripheral task.

26.319 The Effects of Practice in a Useful Field of View task on Driving Performance

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The Useful Field of View (UFOV) measures the extent of the visual field from which information is extracted in a single glance. The UFOV is influenced by dividing attention, especially in older subjects (e.g., Sekuler et al., 2000), and the effects of attention predict performance in complex tasks like driving (e.g., Myers et al., 2000). Practice in a UFOV task reduces the effects of divided attention in younger and older subjects (Richards et al., 2006), and also has been shown to improve driving performance in older adults (e.g., Roenker et al., 2003). To the best of our knowledge though, no one has examined if UFOV training affects driving performance similarly across the life span. Therefore, we tested younger adults on a desktop driving simulator before and after nine UFOV training sessions. The UFOV task comprised a central identification task and a peripheral localization task performed under focused- and divided-attention conditions. The driving simulator task consisted of short routes in which we measured overall performance as well as reaction time to central detection and peripheral localization tasks. Results from five younger subjects show that, in the UFOV task, performance on the peripheral task under divided attention conditions improved linearly until it was statistically similar to peripheral task performance under focused attention conditions. This result is similar to that found in Richards et al. (2006). In the driving simulator task, however, we did not find an effect of UFOV practice on either the central or peripheral task. We are currently testing older adults to see if UFOV training offers differing benefits across the lifespan, and examining the effect of driving task difficulty on transfer of learning.

Acknowledgement: NSERC, CIHR

Attention: Special populations

Royal Ballroom 6-8, Boards 320–327

Saturday, May 8, 2:45 - 6:45 pm

26.320 On the Relationship between Magnocellular Pathway and Automatic Attentional Orienting: Evidences from Developmental Dyslexia

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Although developmental dyslexia (DD) is frequently associate to a linguistic deficit, the underlying neurobiological cause remains unclear. One prominent vision science hypothesis suggests a specific deficit in magnocellular (M) pathway in DD. However, a recent hypothesis proposes that M-deficits contribute to the etiology of phonological decoding ability (i.e., new word and nonword reading), impairing selectively the attentional orienting process onto letter string. Thus, a specific M-pathway impairment in association with an attentional orienting disorder in DD children with phonological decoding deficit was specifically predicted by this neurobiological hypothesis. In the present study we investigated the M-pathway and attentional orienting in 18 dyslexic (10 with phonological decoding deficit) and in 29 chronological age and IQ matched normally reading children by measuring dynamic stimuli sensibility (i.e., spatial frequency doubling illusion) and the time-course of automatic covert attention (i.e., target detection effect at different SOAs of a non-predictive and peripheral spatial cue), respectively. The results showed a specific deficit of the M-pathway task in dyslexic with phonological decoding deficit. More importantly, the same group of dyslexics with M-deficit presented a sluggish attentional orienting: attentional facilitation was present at longer cue-target SOAs compared with normal readers. These results highlight that a M-deficit linked to a parietal-attentional dysfunction might impair the phonological decoding mechanisms that are critical for reading acquisition.

26.321 Why the contralesional hemifield is scanned by patients with hemianopia but not with hemineglect: computational modeling of mechanisms of neural compensation

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Hemianopia patients have a contralesional visual hemifield deficit yet, during visual search, direct eye movements toward and explore their blind side. In fact, during line bisection tasks, eye movements are guided preferentially to the contralesional blind hemifield and there is a line bisection bias toward this hemifield. In contrast, scan paths from hemineglect patients typically ignore the contralesional hemifield during both line bisection and visual search, and these subjects show an ipsilesional bisection bias. What strategies do hemianopia patients have or develop that compensate for the lack of visual information in their blind hemifield and why is such a compensatory process not accessible in visual neglect? We used a neurophysiology-based computational model to examine possible neural compensatory processes implemented in hemianopia and why these are ineffective in hemineglect following parietal lesions. We propose two different compensation mechanisms that could be employed during hemianopic adaptation to facilitate scanning eye movements towards objects they cannot see in their blind fields. First, a spatial compensatory bias can facilitate search scanning in a complex scene and allows locations in the blind field to attract attention and be fixated. Second, a strategy based on Gestalt grouping, which we implement through extrastriate lateral interactions, permits accurate placement of fixations when viewing the portion of a continuous object that falls into the blind field, such as a horizontal line. We show that, while these compensatory mechanisms facilitate attentional scanning in the blind hemifield in hemianopia, these same mechanisms are ineffective in hemineglect following parietal lesion. We conclude that this type of neurobiologically realistic computational modeling can suggest plausible neural mechanisms of compensation in hemianopia, which can be tested empirically, and which may have some use in guiding rehabilitation strategies.

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26.322 **Processing visual scene statistical properties in patients with unilateral spatial neglect**

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Chong and Treisman (2003, 2005, 2008) found that people judge the mean size of a set of circles as quickly and accurately as that of a single item, suggesting that statistical properties may be processed without focused attention. The lack of awareness of left-side input in cases of Unilateral Spatial Neglect (USN) has been attributed to an inability of focusing attention to the left side, suggesting that the processing of statistical properties may be spared. Five USN patients and five controls compared size of a reference circle to a single circle or to the average size of a briefly presented cloud of circles in either the right or left visual fields or spanning both sides. When spanning both sides, their separate averages were either identical or different (difference from reference in ratio 1:4), with the 'different' condition used to assess relative impact of each side in judging the mean. USN patients were able to make comparisons and average size in either hemifield, though their left-side performance was somewhat degraded. In the spanning condition, while the controls indeed averaged across sides, lowering their threshold, patients showed a higher threshold when needing to depend on the left side of the cloud (when the right-side cloud was closer to the reference). However, they did use both sides of the cloud so that their spanning-condition thresholds were intermediate between those of controls and those expected if they attended only to the right side. We conclude that USN patients perform a weighted average across sides, giving double weight to the right side, perhaps due to "extinction". The ability of USN patients to extract the statistical properties of the visual scene on the neglected side points to a relatively spared spread-attention mechanism serving this operation.

26.323 **Non-spatial attention engagement in Neglect patients**

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According to the most recent studies, the non-spatial, temporal attention disengagement -measured by the attentional blink- is impaired in neglect patients. However, it is far to be clear whether the mechanism of temporal attentional engagement is also impaired in neglect patients. In order to investigate the temporal attentional engagement, two experiments were conducted in a sample of 19 patients with right cerebrovascular lesion (9 with Neglect: N+ and 10 without Neglect: N-) and 9 healthy controls (C). We measured the backward masking as well as the para-contrast masking for centrally presented stimuli. The results showed a specific impairment of the non-spatial attentional engagement in N+. Precisely, N+ showed both a deeper backward and paracontrast masking and a sluggish backward and para-contrast masking recovery in comparison with the two control groups (N- and C). These results suggest that the non-spatial disengagement deficits -typically associated with neglect- could be explained by postulating a primary attentional engagement deficit of the "When" system, controlled by the right inferior parietal cortex.

26.324 **Differentiating Patients from Controls by Gazing Patterns**

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Dysfunction in inhibitory control of attention was shown in children with Attention Deficit Hyperactivity Disorder (ADHD), Fetal Alcohol Spectrum Disorder (FASD), and elderly with Parkinson's Disease (PD). Previous studies explored the deficits in top-down (goal oriented) and bottom-up (stimulus driven) attention with a series of visual tasks. This study investigates the difference in attentional selection mechanism while patients freely viewed natural scene videos without performing specific tasks, and the difference is utilized to develop classifiers to differentiate patients from controls. These specially designed videos are composed of short (2-4 seconds), unrelated clips to reduce top-down expectation and emphasize the difference in gaze allocation at every scene change. Gaze of six groups of observers (control children, ADHD children, FASD children, control young adults, control elderly, and PD elderly) were tracked while they watched the videos. A computational saliency model computed bottom-up saliency maps for each video frame. Correlation between salience and gaze of each population was computed and served as features for classifiers. Leave-one-out was used to train and test the classifiers. With eye traces of less than 4 minutes of videos, the classifier differentiates ADHD, FASD, and control children with 84% accuracy; another classifier differentiates PD and control elderly with 97% accuracy. A feature selection method was also used to identify the features that differentiate the populations the most. Moreover, videos with higher inter-observer variability in gaze were more useful in differentiating populations. This study demonstrates attentional selection mechanisms are influenced by PD, ADHD, and FASD, and the behavioral difference is captured by the correlation between salience and gaze. Furthermore, this task-free method shows promise toward future screening tools.

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26.325 **Cross-modal integration in a patient with partial damage to the Inferior and Superior Colliculus**

Martijn van Koningsbruggen[1](m.koningsbruggen@bangor.ac.uk), Robert Rafal[1]; [1]Wolfson Centre for Clinical and Cognitive Neuroscience, Bangor University, Bangor, UK

Simple reaction times for visual targets are reduced for bi-lateral visual stimuli, compared to just one stimulus presented in one hemifield - the redundant target effect. The same reaction time pattern can be obtained for auditory targets: reaction times for targets presented to both ears are faster than for targets presented to only one ear. More interestingly, if two stimuli from different modalities are presented simultaneously, reaction times decrease even further relative to uni-modal bilateral stimuli. This reduction is larger than predicted based on statistical facilitation alone, and has been attributed to sensory cross-modal integration. The Superior Colliculus (SC) is thought to be crucial for integrating auditory and visual information. Here we tested a rare patient who suffered from a traumatic haemorrhagic avulsion of the dorsal midbrain resulting in a near-complete lesion of the left inferior colliclus, and damage to caudal part of the left SC. The patient's reaction times were prolonged for both auditory and visual targets in the contra visual field relative to her ipsilesional visual field. In addition, there was no benefit of RTs of presenting bilateral visual targets. Unlike healthy controls, the patient's reaction times to auditory targets were slower than to visual targets. However, the patient detected bilateral auditory targets faster than unilateral targets, suggesting an intact auditory redundant target effect. More interestingly, similar to healthy controls, the patient demonstrated a benefit in reaction times to cross-modal targets in both visual fields. When a visual stimulus was presented simultaneously with an auditory target, RT were faster than when only a visual, or only an auditory target was presented.

26.326 **Impaired selection- and response-related mechanisms in adult-ADHD**

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A substantial amount of research has been directed at identifying the neurocognitive processes responsible for the inattentive, hyperactive, and impulsive behaviors observed in children and adults with attention deficit/hyperactivity disorder (ADHD). Of the many potential cognitive processes that have been suggested, a large body of evidence points to impairments in executive functions. The present study focuses on response suppression and on executive control in adults with and without ADHD using a global-local task with a manipulation of saliency (Mevorach, Humphreys & Shalev, 2006b). This task enables us to separate out three types of effects: effects reflecting the selection of local and global elements in displays, effects reflecting the ability to attend to the more or less salient aspects of a display

and effects reflecting the ability to filter out irrelevant incongruent information. Participants with ADHD demonstrated an exaggerated effect of relative saliency. Typically, interference from the distractor is greater when the target is low in saliency and the distractor high in saliency, compared with when the target has high saliency and the distractor low. In individuals with ADHD this bias towards high saliency stimuli, and the difficulty in attending to low saliency stimuli, was greater than in the control participants. In addition, the ADHD group yielded an increased congruity effect compared to the control group. That is, participants with ADHD showed more difficulties in filtering out irrelevant incongruent information. The former effect represents a difficulty in selection mechanisms whereas the latter effect represents a difficulty in response related mechanisms in adult-ADHD.

26.327 **Global and local attentional processing following optic neuritis**

Celine Cavezian[1,2,3](ccavezian@fo-rothschild.fr), Celine Perez[1,2,3], Mickael Obadia[3], Olivier Gout[3], Monte Buchsbaum[4], Sylvie Chokron[1,2,3]; [1]Laboratoire de Psychologie et NeuroCognition, CNRS, UMR5105, UPMF, Grenoble, France., [2]ERT TREAT VISION, Fondation Ophtalmologique Rothschild, Paris, France. , [3]Service de Neurologie, Fondation Ophtalmologique Rothschild, Paris, France., [4]Department of Psychiatry, Radiology and Neuroscience, Mount Sinai School of Medicine, Mount Sinai Medical Center, New York, N

After an optic neuritis (i.e., acute inflammation of the optic nerve), several patients report visual discomfort although ophthalmologic assessments show a complete recovery. To evaluate if attentional impairment could contribute to these complaints, the present study investigated global and local processing in healthy individuals and patients with recovered optic neuritis. Ten healthy controls (38.39±6.15 years) and eleven patients (33.81±5.57 years) with recovered right or left optic neuritis episode(s) completed a letter-detection task. The target to-be-detected (the letter "O") was presented either in the right or the left hemifield and either as a small letter surrounded by flankers or as a single large letter. Response time and response accuracy were recorded. Although no significant group effect was observed regarding the number of erroneous responses, a trend toward a significant group x stimulus size x hemifield interaction was observed ($F(1,19)=42.63$; $p=.059$). With large stimuli, participants, either controls or patients, showed a lower number of errors when stimuli were presented in the left than in the right hemifield. When small stimuli were presented, healthy controls showed a similar number of errors in both hemifields whereas optic neuritis patients made a greater number of errors when these stimuli were presented in the right than in the left hemifield. Regarding response time, no significant group main effect or interaction was observed. However, a significant stimulus size x hemifield interaction revealed that small stimuli were processed faster when presented in the right hemifield whereas large stimuli were processed faster when presented in the left hemifield. Altogether, our results did not suggest any global or local attentional anomaly in optic neuritis patients. Both healthy controls and patients showed the classic hemispheric specialization for local and global attention, in that the right hemisphere is dominant for global processing while the left hemisphere is dominant for local processing.

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Neural mechanisms: Adaptation, awareness, action

Orchid Ballroom, Boards 401–411

Saturday, May 8, 2:45 - 6:45 pm

26.401 **BOLD activation in the visual cortex for spontaneous blinks during visual tasks**

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We are usually unaware of the temporary disappearance of the visual scene during blinks, even though blinks cause a large illumination change of the retina, as well as related BOLD responses in the visual cortex (Bristow et al., NeuroImage, 2005). We wondered whether spontaneously occurring blinks (in contrast to blocks of voluntary blinks, op.cit.) triggered significant (possibly contaminating) BOLD responses in standard retinotopic and visual experiments. Methods. We monitored in a 3T scanner the monocular eye signals of 14 subjects who observed 4 different types of visual stimuli, including rotating wedges and contracting/expanding rings, Mondrians and graphemes, while fixating. All stimuli were presented centrally and did not exceed 3 degrees eccentricity. We performed event-related single-subject analyses on blinks. Results. We observed the pattern of activations documented for voluntary blinking, with the strongest activation in the anterior calcarine and PO sulcus. This activation was present for every subject and whatever the visual stimulus. It peaked outside of the regions coding our visual stimuli, but often abutting them. ROI based analysis of the 3-deg central V1 region revealed indeed significant BOLD modulation following blinks. Discussion. We replicated the intriguing finding that blinks activate mostly the periphery of retinotopic areas. Since a blink should trigger both a decrease of BOLD signal (due to luminance decrease) and a BOLD response to the dark transient, the anisotropy of the net BOLD response may be caused by different sensibilities to luminance and transients in the center and the periphery. In that case, we may expect that stimulus response modulations by attention also modulate the net BOLD response to blinks. In any case, our results strongly advocate for systematic monitoring of blinks during fMRI recording, since any correlation, even weak, between the distribution of blinks and a tested protocol could trigger artefactual activities in retinotopic areas.

26.402 **Cortical adaption to reversing prisms in normal adults measured by fMRI**

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A number of studies have investigated visuomotor adaptation to altered visual input by wearing inverting or reversing prism spectacles (e.g., Stratton, 1897, Miyauchi et al., 2004). Behavioral adaptation usually develops within a few days. However, cortical adaptation results in the literature have been controversial. Last year, we have presented part of a study in which we investigated visuomotor adaptation to reversed visual inputs (Lin et al, VSS 2009). In this study, subjects wore left-right reversing prismatic goggles continuously for 14 days. Every few days we measured the BOLD responses to retinotopic stimuli comprised of wedges and rings. For each subject, we defined the baseline organization of the occipital and parietal visual field maps using phase-encoded traveling wave analysis. Then we measured receptive field alterations within these maps across time points, using population receptive field (pRF) analysis (Dumoulin and Wandell, 2008).

We have shown that a systematic shift of visual field coverage in intra-parietal sulcus (IPS) region, from the normal coverage in the contralateral space before prism adaptation, to expanding into the ipsilateral space throughout the adaptation period (Lin et al, VSS 2009). Now we present results to show a systematic shift of visual field coverage back to the baseline status between the day after adaptation period and a two-month later measurement. These results confirm cortical adaptation and differentiate between early stages (early visual field maps) and later stages (IPS) of the dorsal pathways for visual and visuomotor processing. A mechanism of re-weighting the inputs to these neurons is proposed to interpret the neuronal re-tuning results. Furthermore, whether a new ipsilateral receptive field has emerged during prism adaptation besides the original contralateral receptive field for the voxels within IPS maps has been investigated by modeling each pRF with two Gaussians each in one hemifield (Dumoulin et al, SfN 2009).

26.403 **Putting the Prisms Back On: Both Maps of Visual Space Persist, as Revealed by Rapid Cortical Re-adaptation to Left-Right Visual Field Reversal**

Alyssa A. Brewer[1](alyssa.brewer@gmail.com), Brian Barton[1], Ling Lin[1]; [1]University of California, Irvine

Introduction: In this study, we exploit the dynamic nature of posterior parietal cortex to examine cortical functional plasticity induced by a complete reversal of visual input in normal adult humans. Using retinotopic fMRI measurements, we have previously demonstrated changes within the spatial representations of multiple parietal visual field maps following extreme alterations of visual input from left-right reversing prisms (Lin et al, VSS 2009). Data from adult barn owls suggest that after long-term adaptation to a large shift in visual input from prisms the altered representations of visual space persist (Linkenhoker and Knudsen, 2002). Here

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we investigate whether there is a difference in the timing or degree of a second adaptation to the left-right visual field reversal in adult humans after long-term recovery from the initial adaptation period. Methods: Three subjects previously participated in a 14-day continuous adaptation to left-right reversing prisms. These same subjects returned for a 4-day re-adaptation to the reversed visual field 1-9 months later. Subjects again performed a daily battery of visuomotor testing and training. We used traveling wave stimuli to measure the occipital and partietal visual field maps in each subject before, on the 4th day, and one day after the 4-day re-adaptation period. The receptive field alterations within these maps across time points were analyzed using the population receptive field method (Dumoulin and Wandell, 2008). Results/Conclusion: The data demonstrate a faster time course for both behavioral and cortical re-adaptation. By the end of this much shorter re-adaptation period, the measurements again show a shift of visual field representation from contralateral towards ipsilateral visual space in parietal cortex. These measurements of cortical visual field maps in subjects with severely altered visual input demonstrate that the changes in the maps produced by the initial long prism adaptation period persist over an extended time.

26.404 **Novel insular cortex and claustrum activation observed during a visuomotor adaptation task using a viewing window paradigm**

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Previous literature has reported a wide range of anatomical correlates when participants are required to perform a visuomotor adaptation task. However, traditional adaptation tasks suffer a number of inherent limitations that may, in part, give rise to this variability. The overt nature of the required visuomotor transformation and sparse visual environment do not map well onto conditions in which a visuomotor transformation would normally be required in everyday life. For instance, when one must utilize the relationship between a vehicle's steering wheel and the resultant movement to drive down the street, the nature of the required transformation is most likely encompassed in the higher order goal of driving down the road. To further clarify these neural underpinnings, functional magnetic resonance imaging (fMRI) was performed on twelve (5M, age range 20 – 45 years old; mean age = 27) naive participants performing a viewing window task in which a visuomotor transformation was created by varying the relationship between the participant's movement and the resultant movement of the viewing window. The viewing window task removes the focus of the experiment away from the required visuomotor transformation and more naturally replicates scenarios in which haptic and visual information would be combined to achieve a higher-level goal. Activity related to visuomotor adaptation was found within previously reported regions of the parietal lobes, frontal lobes, and occipital lobes. In addition, previously unreported activation was observed within the claustrum and insular cortex, regions well-established as multi-modal convergence zones. These results confirm the diverse nature of the systems recruited to perform a required visuomotor adaptation, and provides the first evidence of participation of the claustrum and insular cortex to overcome a visuomotor transformation.

26.405 **Multiple scales of organization for object selectivity in ventral visual cortex**

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Object knowledge is hierarchical. For example, a Labrador belongs to the category of dogs, all dogs are mammals, and all mammals are animals. Several hypotheses have been proposed about how this hierarchical property of object representations might be reflected in the spatial organization of ventral visual cortex. For example, all exemplars of a basic-level category might activate the same feature columns or cortical patches (e.g., Tanaka, 2003, Cerebral Cortex), so that a differentiation between specific exemplars is only possible by comparing the responses of neurons within these columns or patches. According to this view, category selectivity would be organized at a larger spatial scale compared to exemplar selectivity. Little empirical evidence is available for such proposals from monkey studies, and no direct evidence from experiments with human subjects. Here we describe a new method in which we use fMRI data to infer differences between stimulus properties in the scale at which they are organized. The method is based on the reasoning that spatial smoothing of fMRI data will have a larger beneficial effect for a larger-scale functional organization. We applied this method to several datasets, including an experiment in which basic-level category selectivity (e.g., face versus building) was compared with subordinate-level selectivity (e.g., rural building versus skyscraper). The results reveal a significantly larger beneficial effect of smoothing for basic-level selectivity compared to subordinate-level selectivity. This is in line with the proposal that selectivity for stimulus properties that underlie finer distinctions between objects is organized at a finer scale than selectivity for stimulus properties that differentiate basic-level categories. This finding confirms the existence of multiple scales of organization in ventral visual cortex.

26.406 **Theta-burst transcranial magnetic stimulation to V1 impairs subjective confidence ratings and metacognition**

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Lesions to V1 may lead to blindsight - the ability to perform visual tasks despite the absence of visual awareness. Blindsight is a controversial phenomenon, partly because it is a rare condition and researchers rely on verbal reports. Previous work has shown that brain stimulation applied during visual presentation can induce blindsight-like behavior in normal populations. Here we adopt a different approach, capitalizing on a relatively new protocol of stimulation known as theta burst stimulation (TBS). TBS has been shown to suppress visual activity for up to ~30 minutes. During this period, we can perform intensive psychophysical testings without the tactile and auditory interference caused by brain stimulation. We used post-decisional wagering to objectively assess the effect of TBS on subjective awareness and metacognition. Subjects received TBS to the visual cortex, a control site (Pz), and sham TBS in counter-balanced sessions. Subjects performed a grating orientation task and indicated their confidence. High-confidence responses resulted in higher score when the discrimination was correct but negative score when incorrect. Subjects were told to maximize their overall score. TBS to the visual cortex resulted in a decrease both in performance and confidence. Further, we found that the TBS resulted in a lowered correlation between confidence ratings and accuracy, and this misplacement of confidence ratings led to subjects' failure to maximize their overall score. This impairment of metacognitive ability has previously been shown to be one of the hallmarks of blindsight. The current study shows that TBS to the visual cortex lowers visual performance, subjective confidence ratings, and metacognitive capacity. The fact that TBS is applied before but not during the psychophysical testing means that there is the opportunity to perform brain imaging during the task in order to further characterize the neural mechanisms that underlie these effects.

26.407 **Awareness-related activity in prefrontal and parietal cortices reflects more than superior performance capacity: A blindsight case study**

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Background: Brain imaging studies on visual awareness have often reported activity in prefrontal and parietal cortices. One interpretation could be that such activity reflects the capacity to perform visual tasks, which is usually high when one is aware of the stimulus, and at near-chance-level when one is unaware. The opportunity to study a blindsight patient allowed us to test this interpretation, by creating performance-matched conditions with dramatic differences in subjectively reported levels of awareness. Patient GY has a damaged primary visual cortex in the left hemisphere ("blind"), with the right side being relatively intact ("normal). It is well-documented that he can perform forced-choice tasks better than chance in his "blind" visual field.

Methods: We presented gratings of strong contrast to his "blind" field, and weak contrast to his "normal" field, such that performance in a spatial 2AFC task was matched between the two. We assessed the level of aware-

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ness by standard subjective report ("Seeing" vs "Guessing"), confidence rating, and post-decision wagering. All of these measures supported the conclusion that the level of awareness differed dramatically, even though performance capacity was matched between the "blind" field and "normal" field stimulations.

Results: 1. Comparing "normal" field vs. "blind" field stimulations, we found robust activations in the prefrontal and parietal cortices. 2. Whereas accuracy in the "normal" field (correct vs. incorrect trials) was driven by activity in the occipital and temporal cortices (sometimes bilaterally), accuracy in the "blind" field was driven mainly by subcortical activity, with a clear lack of activation in the occipital cortex.

Conclusions:1. Activity in prefrontal and parietal cortices is likely to reflect the ability to monitor and report perceptual certainty appropriately, rather than just superior visual performance capacity. 2. Blindsight is supported by subcortical mechanisms, as previously suggested.

26.408 **Blindsight and enumeration: A case study**

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"Blindsight" is a term first coined by Weiskrantz et al. in 1974 to describe residual visual performance in the cortically blind. It has been postulated that blindsight could be due to the retinotectal pathway projecting information past V1 to later cortical structures. Our interest was in whether the pathways responsible for blindsight could also support enumeration. We tested a 53-year-old male, C.H., who had suffered a medial right occipital lobe stroke seven months previous. The stroke resulted in an upper left homonymous quadrantanopia. In order to determine whether there were any residual abilities in the blind field, we first tested basic detection and discrimination skills. C.H. was able to determine whether or not a 7° X 7° visual angle object was presented in his blind field with near perfect accuracy though his accuracy was only 90% for smaller (4.6° X 2.2°) figures. C.H. also discriminated between large X's and O's and horizontal and vertical bars with good accuracy when the figures were large (78% for X vs. O and 73% for horizontal vs. vertical bars). Throughout these tests C.H. staunchly maintained that he could not see the stimuli and that he was only guessing. Because it was clear that C.H. had some residual ability in his blind field, we tested his enumeration. The enumeration task involved 1-3 items. These items were 1.5° X 1.5° black diamonds, 0-2 in his blind field and 1-3 in his non-blind field. Across all conditions, C.H. was able to use the information in his blind field and identify the total number of items presented at levels of performance that were well above chance. Because C.H. appears to use blind field information to enumerate, we postulate that enumeration ability may be mediated by the same structures that support blindsight.

26.409 **Unconscious Activation of the Prefrontal No-Go Network**

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How "intelligent" is the unconscious fast feedforward sweep? To test this issue, we used functional magnetic resonance imaging to investigate the potential depth of processing of unconscious information in the human brain. We devised a new version of the Go/No-Go task that included conscious (weakly masked) No-Go trials, unconscious (strongly masked) No-Go trials as well as Go trials. Replicating typical neuroimaging findings, we observed that response inhibition on conscious No-Go trials was associated with a (mostly right-lateralized) "inhibition network", including the pre-supplementary motor area (pre-SMA), the anterior cingulated cortex, middle, superior and inferior frontal cortices as well as parietal cortex. Here we demonstrate, however, that also an unconscious No-Go stimulus can travel all the way up to the prefrontal cortex, most prominently the inferior frontal cortex and the pre-SMA. Interestingly, if it does so, it brings about a substantial slow-down in the speed of responding; as if participants tried to cancel their response but just failed to do so completely. The strength of activation in the "unconscious inhibition network" correlated with the extent of unconsciously triggered RT slowing, which suggests that the observed prefrontal activations are truly "functional". These results expand our understanding of the limits and depths of the unconscious fast feedforward sweep of information processing in the human brain.

26.410 **Functional specialisation in Supplementary Motor Area (SMA): A functional imaging test of the spatial vector transformation hypothesis**

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A recent debate in the literature involves the extent to which supplementary motor area is dedicated to the planning of motor responses. It has been suggested that this region may play a role in a more general manner through the calculation of spatial vector transformations. Evidence for this is provided via a number of non-motor studies, such as mental rotation tasks, where the activation in this region is more closely tied to the calculation of spatial relations than to motor demands (see Leek & Johnston, Nature Reviews Neuroscience, 10, 78, 2009). Here we present a series of functional imaging experiments that attempt to further elucidate the functional properties of supplementary motor area by contrasting the demands placed on this region from a variety of motor and non-motor tasks that make use of spatial vector transformations in a number of ways. The results indicate that the anterior sub-division of SMA, responds more strongly to demands associated with non-motor transformation tasks compared with the more posterior regions of SMA that responds more strongly to motor based tasks. The experiments are discussed in terms of the spatial vector transformation hypothesis.

26.411 **Functional specialization in Supplementary Motor Area (SMA): Evidence from visuo-spatial transformation deficits in Parkinson's disease**

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Leek & Johnston (2009, Nature Reviews Neuroscience, 10, 78-79) have suggested that one function of the anterior (pre-) SMA in humans is the computation of abstract visuo-spatial vector transformations. According to this hypothesis, pre-SMA should be involved in any visual task that requires the transformation or remapping of a spatial location (vector) regardless of whether there is a motor component to the task. We have previously examined this using functional brain imaging of pre-SMA during the performance of visuo spatial transformation (e.g., mental rotation, mental grid navigation) and non-transformational (VSTM for static spatial locations, non-spatial numerical operations) - see Johnston & Leek, 2010 Vision Sciences Society). Here we report evidence from studies that tested this hypothesis using data from Parkinson's disease (PD) patients. One known aspect of the underlying pathology of PD is the consequent effects of dopamine depletion in the basal ganglia upon functioning of medial frontal cortex. Thus, PD provides a good model for studying SMA dysfunction and its effects on visuo-spatial processing. The spatial vector transformation hypothesis predicts that PD patients, with impaired SMA function, are likely to exhibit deficits on tasks that require spatial vector transformation. The results showed that, as predicted, PD leads to impairments on transformational but not on non-transformational tasks. These findings support the vector transformation hypothesis and suggest that regions of the SMA are involved in highly abstract visuo-spatial computations that go beyond the preparation and planning of movement. Indeed, these findings suggest that the SMA supports abstract visuo-spatial processes that are potentially recruited in a wide range of visual and spatial tasks.

Perceptual learning: Specificity and transfer

Orchid Ballroom, Boards 412–426

Saturday, May 8, 2:45 - 6:45 pm

26.412 **Interference and feature specificity in visual perceptual learning**

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Perceptual learning (PL), defined as experience-dependent performance improvement on a visual feature often shows specificity to the trained feature. Recently it was reported that when one type of task is trained, followed by a similar but different type of task, PL on the first task is disrupted with specificity to some trained features. Systematic investigation of the relationship between PL specificity and interference may lead to a better understanding of the PL mechanism. In the present study, we examined whether feature specificity is related to interference in the texture discrimination task (TDT), which shows learning specificity to the orientation of background elements but not to that of target elements. We conducted a series of experiments where the orientation of target elements or background elements was manipulated under two types of training paradigms, blocked or roving, with 36 participants. First, we found that TDT learning was interfered with when orientations of background elements were changed in the blocked paradigm but not in the roving. Second, the changes in orientation of target elements resulted in a reverse effect: TDT learning occurred in the blocked paradigm but not with roving. Given that TDT learning is specific to background element orientation but not to target element orientation, these results indicate that interference in TDT learning (blocked) is feature specific while that is not the case for roving. These results provide important implications regarding the mechanism for TDT learning and interference. First, learning of background element orientation in TDT and disruption may mainly involve a low-level stage of visual processing. Second, it may be either that learning of target element orientation is not requisite for TDT learning or that learning of target element orientation mainly involves a higher stage of visual information processing, given that roving is suggested to impede more central stages.

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26.413 **Task transfer effects of contrast training and perceptual learning**

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Previous research has shown transfer of perceptual learning (PL) training with contrast and orientation across different locations in the visual field (Xiao et. al., 2008). The current study examined the cross-transfer of PL training with orientation and contrast within a specific location in the visual field. Subjects were given 4 days of testing and PL training. A two interval forced choice procedure was used with two sequentially presented displays. On each display subjects were presented with a centrally located letter and a Gabor patch located in one quadrant (both embedded in noise). Subjects were required to indicate a change in the letter to control for eye fixation. The Gabor patch was orientated horizontally or vertically (the standard) or was tilted off horizontal or vertical. Subjects were required to indicate whether the first or second display contained the tilted orientation. All stimuli were presented with 40% of the pixels replaced with 2-dimensional Gaussian noise. During the first day participants' orientation discrimination (0-10 degrees off-axis in 0.25 degree increments) and contrast sensitivity (1-100% contrast) thresholds were determined using two interleaving staircase functions (1 up/4 down and 1 up/2 down) for vertically and horizontally oriented Gabor patches. During days 2 and 3, participants were trained on contrast sensitivity using two interleaving staircases (1 up/4 down and 1 up/2 down); during this training all Gabor patches were either oriented vertically or 10 degrees off axis. Day 4 used the same procedure as day one to assess contrast sensitivity and orientation discrimination thresholds. Results suggest that perceptual learning training resulted in improved performance for contrast for both the trained (vertical) and untrained (horizontal) orientations; the improved performance for contrast training was not found to transfer to orientation discrimination. The importance of these findings to task specificity of perceptual learning training will be discussed.

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26.414 **Task-specific perceptual learning of texture identification**

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Previous studies have shown that practice lowers identification thresholds for textures embedded in noise, and that such perceptual learning is stimulus-specific and long lasting. Here we ask whether better detection of the relevant signal is sufficient to improve identification, or whether experience in distinguishing the textures is necessary. In other words, is perceptual learning of texture identification task specific, or does it simply reflect improved stimulus detectability? Separate groups of subjects practiced texture detection or identification on Day 1; on Day 2 they performed either the same task as on Day 1, or transferred to the untrained task. Stimuli were 10 briefly (200 ms) presented band-limited noise textures embedded in static noise. Detection performance was measured with a Yes/No task, and identification performance was measured with a 10-AFC task. Texture contrast was varied across 7 levels using the method of constant stimuli; feedback was provided on each trial. We calculated d' at each contrast level to compare psychometric functions across tasks and days. On Day 1, psychometric functions spanned the full performance range for both tasks. On Day 2, after practice with the same task, texture identification improved substantially at all contrasts, whereas texture detection improved only slightly. There was no transfer of learning from detection to identification, and some evidence for transfer in the opposite direction. Therefore, better detection of the stimulus is not sufficient to improve identification of noisy patterns. Learning requires telling the patterns apart - perceptual learning of texture identification is task-specific as well as stimulus-specific.

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26.415 **Learning like an expert: a training study on the effects of visual noise in fingerprint identification**

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Studies in visual expertise focus on identifying mechanisms that allow experts to be more efficient and effective at identifying their items of expertise. Many visual expert groups, such as fingerprint examiners, are required to identify and characterize their items of expertise under visually demanding conditions. Therefore, one potential mechanism that develops could be a learned relative immunity to the effects of visual noise. To investigate this the present study uses a combination of EEG and behavioral measures to determine the effects of visual noise across the course of an extensive visual training paradigm. Participants were trained on a fingerprint identification tracing task that simulates the actual real-world training fingerprint examiners undergo. Throughout the course of training, participants performed a separate XAB task in which they were instructed to identify which of two clear print images matched a test image presented in bandpass filtered noise. To distinguish any training effects from those caused by repeated exposure to the XAB task, a separate control group who did not undergo any additional training was also measured. Results show significant overall behavioral improvements across both groups for the low visual demand condition and only improvements in the training group for the high visual demand condition. However, EEG data show a qualitative and quantitative shift in the P250 component in opposite directions between the control and training group across both conditions. This interaction provides evidence that training causes a change in neural processing that is separate from that which results from repeated exposure. These results have potential implications to both the perceptual learning and visual expertise literature and point to the possibility of different types of learning styles that develop for visually complex stimuli in degraded conditions.

26.416 **Transfer of object learning across distinct visual learning paradigms**

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Perception and identification of visual stimuli improve with experience. This applies to both simple stimuli and complex objects, as shown in perceptual learning paradigms in which visual perception is challenged by degrading the stimuli, e.g. by backward masking or adding simultaneous noise. In each of these paradigms, perceptual learning is specific for the stimuli used during training. However, there can also be differences between paradigms, because they challenge the visual processing system in different ways. It is thus possible that paradigm-specific processes are needed to optimize performance. This would result in a failure of perceptual learning effects to generalize across paradigms. Here we present the first study designed to investigate whether visual object learning is specific to the type of stimulus degradation used during training. Sixteen participants were trained to recognize and name pictures of common objects. The stimulus set included 40 object images, but each participant was trained on only half of them. Half of the participants was trained in a backward masking paradigm, and the other half in a simultaneous noise addition paradigm. After five days, performance thresholds were measured in four tests: (1) the trained paradigm with the 20 trained objects, (2) the trained paradigm with the 20 new, untrained objects, (3) the untrained paradigm with the trained objects and (4) the untrained paradigm with new objects. Both groups showed a learning effect that increased gradually across days. These training effects were specific for the trained objects. In addition, an object-specific transfer to the untrained paradigm was found. The group trained in the simultaneous noise addition paradigm showed a complete transfer of performance to the backward masking task. The transfer was only partial when reversed. These findings indicate that both general learning processes and processes specific for the type of stimulus degradation are involved in perceptual learning.

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26.417 Perceptual learning with bisection stimuli can only be disrupted on a short timescale

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We previously showed that perceptual learning was disrupted when bisection stimuli with short outer line distances were presented randomly interleaved trial-by-trial with bisection stimuli with long outer line distances, so called roving. Here, we went to the other extreme and presented short and long bisection stimuli in separate, directly following sessions. It has been previously reported that such a presentation regime disrupts consolidation of perceptual learning. However, we found no disruption of learning, neither with our bisection stimuli nor with the same experimental setup used in a previous study. We propose that consolidation in perceptual learning with simple stimuli is either rapid or cannot be disrupted.

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26.418 Explicit and implicit learning in motion discrimination tasks

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Perceptual learning has been studied as a mechanism by which people automatically and implicitly learn. Alternatively, learning can occur explicitly mediated by conscious feed-back which controls and guides the subjects' performance. The aim of this study was to examine whether the explicit and implicit learning could produce different patterns of results in a visual motion discrimination task.

We exposed 12 participants to four different sessions. A preliminary training session consisted of 120 trials of motion discrimination task repeated three times in different days to measure the explicit learning. The subject had to discriminate among 4 directions in motion test presented at 10% of coherence (considered as parathreshold). A pre-test in which the baseline was evaluated by the correct responses average in the motion discrimination task for each direction. The implicit learning session was tested using the classic paradigm of task-irrelevant perceptual learning (TIPL) (Seitz and Watanabe, 2003) in which learning was mediated by subliminally pairing one selected direction with specific targets of an unrelated training task. This phase consisted of 120 trials repeated 7 times in three days. After that a post-test similar to the pretest indicated the implicit learning effect. In the explicit learning the improvement is relatively poor and not significant . In the implicit learning the effect was clearly significant for the trained direction, while the subjects did not improve their performances in the other directions. These results of the stronger learning effect obtained in TIPL suggest that visual motion learning can benefit more from direct lower level processing then from mediated attention mechanisms related to explicit learning.

26.419 Learning to discriminate face view

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Although perceptual learning of simple visual features has been studied extensively and intensively for many years, we still know little about the mechanisms of perceptual learning of complex object recognition (e.g. face). In a series of seven experiments, human perceptual learning in discrimination of the orientation of face view was studied using psychophysical methods. We trained subjects to discriminate face orientations around a face side view (e.g. 30 deg) over eight days, which resulted in a dramatic improvement in sensitivity to face view orientation. This improved sensitivity was highly specific to the trained face side view and persisted for six months. Different from perceptual learning of simple visual features, this view-specific learning effect could strongly transfer across changes in retinal location, face size and face identity. A strong transfer also occurred between two partial face images that were mutually exclusive but constituted a complete face. However, the transfer of the learning effect between upright and inverted faces and between face and paperclip object was very weak. These results shed light on the mechanisms of perceptual learning of face view discrimination. They suggest a large amount of plastic changes at a level of higher visual processing where size-, location- and identity-invariant face views are represented, but not at a level of early visual processing or cognitive decision.

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26.420 Promoting generalization by hindering policy learning

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A pervasive question in perceptual and motor learning concerns the conditions under which learning transfers. In reinforcement learning, an agent can learn either a policy (i.e., a mapping between states and actions) or a predictive model of future outcomes from which the policy can be computed online. The former is computationally less expensive, but is highly specific to the given task/goal, while the latter is computationally more expensive, but allows the agent to know the proper actions to take even for novel goals. Policy learning is appropriate when forward look ahead is not required and the number of policies to be learned is small, while model learning is appropriate under the opposite conditions. Therefore, by manipulating these factors in a given task, the degree of transfer should be predictably altered as well. The current study tests this hypothesis with a navigation task requiring subjects to steer an object through a novel flow field to reach visible targets as quickly as possible. We vary the predictive component of the task by manipulating the amount of control subjects have over the object. Half steer the object for the entire duration of the experiment, which favors policy learning, while the rest lose control intermittently, which adds a look ahead component to the task and favors model learning. We vary the number of policies to be learned by manipulating the number of target locations the subject reaches where large numbers are expected to favor model learning. Half have only two target locations to reach while the rest have twelve. Performance on transfer tasks where the environment is held constant, but the goal is altered, is better for those subjects trained under conditions that favor model learning. These results suggest that developing training tasks that discourage simple policy learning is critical if generalization is desired.

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26.421 The Role of Sleep in Implicit Statistical and Rule Learning

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Statistical learning is an established method of measuring implicit knowledge gained through observation. Rule learning employs a similar paradigm, but the knowledge gained is assumed to be more abstract and explicit. These two forms of learning have been considered separate mechanisms, and little is known about how their representations are stored in long-term memory or whether sleep provides a benefit for consolidation of such representations, as has been found in many implicit procedural learning tasks. The current study examines whether sleep benefits both statistical and implicit rule learning in a similar manner, and whether a short practice before test offers greater explicit insight into the underlying rules, as had been reported previously for abstract numerical rules. In our experi-

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ments, subjects first observed scenes of arbitrary shapes arranged as triplets repeated in random order for two minutes. The triplets contain a simple statistical structure, as particular triplets of shapes always appear together in fixed order, and two embedded rules: a size rule following an AAB pattern (small-small-large), and a color rule following ABA (dark-light-dark). After a twelve-hour delay, either overnight or over the day, subjects were tested on their knowledge of both the statistical structure and the size rule. A subset of subjects also completed a short "reminder" practice session before test. We found that the simple statistical structure was retained after twelve hours during the day but performance was improved by sleep (Day, M=64.6; Night, M=79.3). Rule knowledge was not retained, but emerged after sleep (Day, M=53.6; Night, M=61.8). However, a short practice session before test did not provide greater access to the implicitly learned rules (Day, M=54.7). These results indicate that sleep benefits the implicit knowledge gained during statistical and rule learning in a similar manner, but does not necessarily lead to improvement in discovery of explicit rules.

26.422 **Laterality-Specific Perceptual Learning on Gabor Detection**

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Introduction: Several studies have demonstrated visual performance advantages for stimuli distributed across the left and right hemi-fields (bilateral stimulation) versus stimuli restricted entirely within one lateral hemi-field (unilateral stimulation) (Awh & Pashler, 2000; Alvarez & Cavanagh, 2005; Chakravarthi & Cavanagh, 2009; Reardon, Kelly, & Matthews, 2009). In the present perceptual learning study, we investigated the extent to which practice-based improvements in peripheral Gabor detection are specific to –versus generalize across- bilateral and unilateral training regimens. Method: Twenty Denison University undergraduates completed the study. The independent variables were training group (bilateral training versus unilateral training), session (pre versus post), Gabor target laterality (bilateral versus unilateral), and Gabor distracter (present versus absent). Each trial began with a pair of bilateral or unilateral cues indicating the peripheral positions (14.55 deg diagonally from fixation) at which a Gabor target would appear, if present. Half the trials contained Gabor distracters positioned between cued target positions. After correctly identifying a foveally flashed letter, participants judged whether a Gabor target had been present or absent at either cued peripheral position. For each participant, bilateral and unilateral performance was measured before and after five laterality-specific (i.e., bilateral only or unilateral only) training sessions. Results: Signal detection analyses revealed laterality-specific improvements in the proportion of hits (i.e., "present" responses on target-present trials) when distractors were present ($F(1,18) = 8.833$, $p = 0.008$, partial eta-squared = 0.329), but not when distracters were absent ($F(1,18) = 0.002$, $p = 0.963$, partial eta-squared <0.001). There was no evidence for laterality-specific improvements in the proportion of false alarms (i.e., "present" responses on target-absent trials) whether distractors were present ($F(1,18) = 0.006$, $p = 0.939$, partial eta-squared <0.001) or absent ($F(1,18) = 0.257$, $p = 0.619$, partial eta-squared =0.004). Conclusion: The findings are consistent with lateral hemi-field constraints on attentional selection.

26.423 **Dissociating between long-term and short-term visual learning**

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Practice can induce considerable improvement in one's ability to perform a visual task. When the improvement is long lasting, it is usually referred to as perceptual learning and considered to reflect plasticity of the brain. A substantial part of this improvement occurs at the beginning of training (Ahissar and Hochstein, 1996). However such short-term improvement can also reflect other processes than brain plasticity such as adaptation and strategic shifts (Goldstone 1998). The objective of the present study was to dissociate the mechanisms that underlie long-term (LT) and short-term (ST) improvement in a pop-out detection task comprising of 8 sessions held 1 to 3 days apart from each other. Observers were required to detect a target defined as a uniquely oriented line among homogeneously oriented lines. Search displays were presented briefly and then masked. Improvement, measured as increased detection accuracy with practice, was observed both within the first session (ST improvement) and between each session and the following one (LT improvement). ST Improvement generalized to displays in which the target and distractors features on the task-relevant dimension (orientation) swapped, but not to displays in which a change occurred on an irrelevant dimension (color). By contrast, LT improvement generalized to displays in which a change occurred on color, but not to displays in which target and distractors orientations swapped. These results suggest that LT perceptual learning modulates early representations that are fine-tuned to specific features, whereas ST improvement modulates later representations in which the different stimulus features are bound.

26.424 **The stimulus specificity of motion perceptual learning does not arise from stimulus-specific improvements in visual memory or changes of decision strategy**

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Perceptual learning is often studied using Same/Different and 2AFC tasks and the stimulus-specific improvement is attributed to perceptual factors. However, two-interval tasks involve visual memory and decision strategies that can change in stimulus-specific ways too. To test whether the improvement is due to perceptual or non-perceptual factors, we compared single-interval (Yes/No) and two-interval (Same/Different) tasks in two within-subject studies of visual motion discrimination.

Method: Stimuli were random-dot cinematograms (RDC, 100% coherence, speed 10 deg/sec, duration 400 msec). Each block involved two motion directions 5° apart (e.g., -52.5° vs -47.5°). The implicit reference direction (e.g., -50°) and the task were fixed in each block. In single-interval trials, observers indicated which direction was presented; In two-interval trials, observers indicated whether two sequentially presented RDCs moved in same or different directions. Each session began with single-interval blocks and switched halfway to Same/Different blocks. Auditory feedback throughout. Experiment 1 pretested one reference direction, trained an orthogonal direction for four days, and post-tested the original direction. 13 naive observers. Experiment 2 was similar, but two reference directions (e.g., -50° and -37.5°) were trained in alternating, homogenous, 60-trial blocks. 15 more observers.

Results: Both tasks improved with practice: d' increased by approximately two thirds along identical learning curves. Small but reliable switch costs between tasks. The stimulus specificity index (SI) varied between 40% and 60% across conditions in the group average, with large individual differences. No evidence of stimulus-specific improvement of visual STM or of changes in Same/Different decision strategy. The bootstrap standard deviation of the SI estimate was two times higher in the two-interval than the single-interval data. No evidence that interleaved training improved transfer.

Conclusion: Learning of motion direction discrimination is driven by perceptual factors. Specificity indices are hard to measure because of individual variability. The Yes/No task affords higher statistical power than Same/Different.

26.425 **Perceptual learning in amblyopic children aged 8-16 with or without previous patching treatment**

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Perceptual learning is known to improve amblyopic vision in older children and adults. The present study investigated the effect of perceptual learning on amblyopic vision in children aged 8-16 and its relationship with previous patching treatment.

Children were divided into two groups. The patching group consisted of 10 children who had previously been treated with the patching method for >18 months. The non-patching group consisted of 14 children who had not been treated with eye-patching. During training the children identified whether a full-contrast square-wave grating was tilted 45o or 135o from vertical in a staircase procedure that estimated the cutoff spatial frequency over 60 one-hour daily sessions (over 14,000 trials). After training the grating acuity improved greatly in all non-patching group children, many having grating acuity improved to near 30 cpd. Grating acuity was not significantly improved in most patching group children who had better grating acuity to start with. Meantime, E-acuity was improved more or less in both groups, with the magnitude varying from child to child. Some children in the patching group had improved E-acuity near 20/20 or better, but none in the non-patching group had improved E-acuity close to normal. Stereo acu-

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ity was also improved in some children in both groups. Currently a number of children from two groups are doing E-acuity training and the results will be reported as part of the abstract.

Our preliminary results indicate that training induced grating acuity improvement is mainly shown in non-patching group, and this improvement is not directly related to letter acuity improvement, probably as a result of different mechanism underlying grating acuity and letter identification, which is inconsistent to previous reports. Moreover, perceptual training alone may not be a sufficient treatment for older amblyopic children. Rather it works best for children with previous patching history.

26.426 **Transfer of perceptual learning to completely untrained locations after double training**

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Visual perceptual learning can transfer completely to a new location if the new location is trained with an irrelevant task (Xiao et al., Current Biology, 2008). This feature-plus-location double training result suggests that perceptual learning may occur in non-retinotopic brain areas, and learning transfers as spatial attention to the new location is improved through location training. What unknown is how double training will affect performance in other completely untrained locations.

We found that (1) Vernier learning was normally location and orientation specific. However, if Vernier was trained at the V and H orientations, one orientation at the upper left visual field (ori1_loc1) and the other at the lower left visual field (ori2_loc2), each serving as location training for the other orientation, learning transferred not only completely to trained locations (ori1_loc2 & ori2_loc1), but also equally to the completely untrained visual quadrants in the right visual field (ori1_loc3/ori2_loc3). (2) Similar results were found when Vernier was trained at one quadrant and motion direction was trained at a diagonal quadrant as location training, in which Vernier learning transferred to the diagonal quadrant, as well as to other completely untrained quadrants at the same (5o) and different (10o) eccentricities. (3) However, in a texture discrimination task (Karni & Sagi, 1991), although the usually location specific learning could transfer to a diagonal quadrant when the transfer location was trained with detecting an array of ovals among circles, learning transferred less significantly to a third completely untrained quadrant.

The first two experiments suggest that the observers may have learned the strategy to attend to a peripheral target in a clear field after double training. However, the third experiment indicates that training for precise spatial attention is still required for learning to transfer to a completely untrained location in a cluttered area.

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Motion: Mechanisms and Illusions

Orchid Ballroom, Boards 427–438

Saturday, May 8, 2:45 - 6:45 pm

26.427 **Detection of radial frequency motion trajectories**

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Humans are extremely sensitive to radial deformations of static circular contours (Wilkinson, Wilson, & Habak, 1998, Vision Research). Here we investigate the detection of motion trajectories defined by these radial frequency (RF) patterns over a range of radial frequencies, using the method of constant stimuli combined with a two-interval forced-choice (2IFC) paradigm. The stimulus was a radially symmetric difference-of-Gaussians blob (peak spatial frequency: 2.74 cpd, bandwidth: 1.79 octaves at half amplitude) moving around the trajectory defined by an invisible RF pattern (motion RF), or by a circle of equivalent mean radius, for one complete revolution. The observer's task was to identify the interval containing the motion RF as a function of deformation amplitude; threshold was defined as 75% correct performance. Radial frequencies of 2 – 5 cycles were tested at a mean radius of 1.0 arc deg and a mean rotation speed of 3.14 arc deg/s (2.0 s for a complete revolution). Detection thresholds ranged from 0.8 – 4.6 arc min and followed a power function with an average exponent of –1.48 as a function of radial frequency. This decreasing trend was consistent with that found in static RFs, although detection thresholds for motion RFs were significantly higher (0.2 – 0.5 arc min for static RFs). Whether the sensitivity to motion RFs is dependent on local cues or global shape is currently under investigation. Importantly, we showed that these novel stimuli should be a useful tool to investigate trajectory learning and discrimination.

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26.428 **No impact of luminance noise on chromatic motion perception**

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The purpose of the present experiments was to investigate the mechanism underlying the perception of chromatic motion. In Experiment 1, we measured contrast thresholds in a direction discrimination task at TFs ranging from 1 to 16 Hz. Results show a bandpass sensitivity function for luminance motion, and lowpass function for chromatic motion, with greater sensitivity for chromatic motion at TFs below 4 Hz, roughly equal sensitivities at 4 Hz, and greater sensitivity to luminance motion at TFs above 4 Hz. In Experiment 2, a direction discrimination task was used to measure contrast thresholds for luminance and chromatic motion as a function of noise contrast in two conditions: an intra-attribute condition (luminance signal and noise, chromatic signal and noise) and an inter-attribute condition (luminance signal with chromatic noise, chromatic signal with luminance noise). Analysis of threshold versus noise contrast curves in the intra-attribute condition shows different calculation efficiencies and levels of internal equivalent noise for luminance and chromatic motion direction discrimination. Inter-attribute noise failed to produce an increase in contrast thresholds at any TF. This shows a double dissociation between colour and luminance motion processing. Taken together, the results of Experiments 1 and 2 indicate that chromatic motion and luminance motion are processed by distinct mechanisms and are consistent with the notion that chromatic motion is processed by a tracking mechanism. Further experiments will investigate the mechanism underlying chromatic motion processing at higher TFs.

Acknowledgement: NSERC Essilor chair

26.429 **Motion adaptation affects perceived shape**

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Adaptation to a moving image causes subsequently presented stationary stimuli to appear to move in the opposite direction. Motion adaptation also affects the perceived location and size of stimuli. After adaptation to motion in one direction, the positions of subsequently presented static stimuli appear shifted in a direction opposite to that of the adapting stimulus (Snowden (1998), Current Biology 8, 1343-1345; Nishida & Johnston, (1999), Nature, 397, 610-612). Similarly, adaptation to expanding and contracting motion has been shown to alter the perceived size of objects consistent with the direction of the motion after-effect (Whitaker, McGraw & Pearson (1999), Vision Research, 39, 2999-3009). Here we demonstrate that adaptation to motion also affects the perceived shape of stimuli. Observers were presented with rectangular stimuli, and asked to determine whether, in comparison with a square, they appeared stretched or squashed in the vertical direction. Judgements were made in three conditions (i) a baseline, with no adaptation (ii) after adaptation to a vertically expanding pattern of motion, during which dots above the horizontal midline moved upwards, and dots below the horizontal midline moved downwards, and (iii) after adaptation to a vertically compressing pattern of motion, during which dots above the horizontal midline moved downwards, and dots below the horizontal midline moved upwards. In each case, the point of subjective equality (the apparently square rectangle) was calculated to determine whether perceived shape was affected by motion adaptation. Adaptation to a vertically compressing motion caused subsequently presented rectangles to appear stretched in the vertical direction; adaptation to expanding motion had no effect on perceived shape. We conclude that, in addition to its effects on apparent motion, position and size, motion adaptation can also affect perceived shape.

26.430 Phantom motion aftereffect using multiple-aperture stimuli: A dynamic Bayesian model

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Using random-dot kinematograms, previous studies found that motion aftereffect (MAE) exists not only in the area of adaptation, but also in non-adapted visual field, a phenomenon termed "phantom MAE". The present study examined whether phantom MAE also exists for a stimulus comprised of multiple drifting gratings, and to what extent MAE can affect local motion processing. In addition, we developed a computational account of phantom MAE within the framework of Bayesian sequential learning. In Experiment 1, an adapting stimulus exhibited global motion via randomly-oriented drifting gratings in two non-adjacent quadrants. In a subsequent testing stimulus, drifting gratings were shown either in the adapted (to measure concrete MAE) or in non-adapted areas (to measure phantom MAE). For translational, circular and radial adapting motion, phantom MAE was found to be significant, although weaker than concrete MAE. The existence of phantom MAE demonstrates that motion aftereffect is processed in a global manner. In Experiment 2, random motion flow was assigned to the testing stimuli. Grating orientations in the testing stimuli were sampled from uniform distributions (range = ±30 degrees), centered at directions either orthogonal or parallel to illusory motion direction. Observers were asked to discriminate motion direction after adapting to coherent or random motion stimuli. Responses to testing stimuli with orthogonal orientations were different from responses to parallel orientations only after adapting to coherent motion, but not after adapting to random motion, indicating a top-down influence of MAE on local motion processing. A dynamic Bayesian model was developed to quantify adaptation-induced changes on multiple motion channels, each selective to a specific velocity. The simulation showed that prolonged exposure to a moving stimulus changed the width of the tuning function differently for different motion channels. The model predicted the existence of phantom MAE, as well as the qualitative difference between phantom and concrete MAEs.

26.431 The Accordion Grating illusion measured by a nulling paradigm

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Dynamical viewing of an elementary square-wave grating by moving toward it creates the Accordion Grating illusion. Observers report a non-rigid perceptual distortion of the grating including two illusory effects: (i) an expansion only perpendicular to the stripes when moving the head towards the pattern and (ii) distortion of the physically straight stripes of the grating. Whilst the illusory expansion perpendicular to the stripes can be explained by the interactions between ambiguous and unambiguous motion signals generated at line interiors and line ends, a differential geometry model with a 3-D representation of the classical aperture problem is here proposed to account for the illusory curvature. Four subjects were tested in a nulling psychophysical experiment. The expected perceptual curvature was balanced by a physical counter-distortion calculated by the model. The amount of physical curvature necessary to nullify the illusion led to a precise quantification of the illusion and verified the proposed model.

26.432 Spatial scaling for the Rotating Snakes illusion.

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In the Rotating Snakes illusion, vigorous motion is perceived in a static figure comprised of repetitive luminance micropatterns: black, dark-gray, white, and light-gray. Our previous study (Hisakata & Murakami, 2008) showed that the illusion strength increased with eccentricity, implying that motion processing units related to this illusion have preferred stimulus sizes that systematically vary with eccentricity. To investigate the quantitative details about the effect of eccentricity on the illusion, we measured the illusion strength while manipulating stimulus size and eccentricity. An array of micropatterns arranged as a ring with the strip width of 2 deg rotated about the fixation point. The background was filled with static random noise. After the stimulus ring was presented for 500 ms, subjects answered whether the ring appeared to rotate clockwise or counter-clockwise. The size of each micropattern was manipulated by changing the number of micropatterns per ring, and the eccentricity was manipulated by changing the radius of the stimulus ring. Results indicated that the illusion strength, i.e., the physical velocity that just nulled the illusory motion, decreased with decreasing size and reached the minimum at a particular size at each eccentricity. We applied the spatial scaling technique to the illusion strength and found that all data converged into a single function when both stimulus size and nulling velocity were scaled according to scaling factors as a linear function of eccentricity. Compared with the scaling factors in previous studies, the estimated scaling factors for the Rotating Snakes illusion were analogous with those estimated for contrast detection thresholds and motion detection thresholds, both believed to reflect cortical architecture at early stages of the visual system. These results suggest that processing units at early stages internally produce motion signals related to illusory motion from the retinal image of the stimulus for the Rotating Snakes illusion.

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26.433 fMRI adaptation to anomalous motion in the "Rotating Snakes" patterns

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Stationary patterns with a specially designed repetitive pattern, such as the "Rotating Snakes" (Kitaoka & Ashida, 2003), can elicit illusory perception of motion. By using a conventional fMRI contrast, we have shown that the "Rotating Snakes" figure activates human MT+ (Kuriki et al, 2008). Activity in V1 was not evident, which can be either because motion signals arise within MT+ (Thiele et al, 2004), or because our motionless control stimulus (for comparison of BOLD signals) that consisted of the same local patterns might have elicited local motion signals (while globally cancelled out). In this study, we used an fMRI adaptation paradigm that does not require an explicit control stimulus, in order to assess direction-selective responses in the visual areas to the "Rotating Snakes" pattern. Four disks that comprised repetitive patterns of white-yellow-black-blue were used. They appeared as rotating in this direction when viewed naturally. After an adapting stimulus (S1) followed by a blank interval, a probe stimulus (S2) of either the same or the reversed color order (hence eliciting illusory motion in the same or the opposite direction) was presented. The spatial phase was altered between S1 and S2 to avoid local coincidence. The fixation mark was blurred to relax fixation to some extent because hard fixation can abolish illusory motion. Attention was controlled by a fixation task. Regions of interest were defined for each participant by separate localizer runs. A 3-T scanner (Siemens Trio Tim) was used. Event-related averages of time-courses revealed larger BOLD responses for reversed S2 than for the same S2 in MT+, indicating direction-specific adaptation. The difference was smaller but evident in V1-V4 and V3A. The overall results suggest that local motion sensors in V1 are indeed activated by the illusion figure, which is in line with most of currently proposed models.

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26.434 Is the Rotating Snakes an Optical Illusion?

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The "rotating snakes" (Kitoaka 2003) is a well-known illusion in which a static image of a repetitive pattern moves as it is examined during free viewing (the apparent movement ceases after several seconds of stable fixation). We have discovered that it is possible to eliminate this illusion by viewing the image through either a pinhole or defocused by a +2D plus lens.

We posit a largely optical, rather than neural, explanation of the effect. The optics of the eye are not uniform over visual space nor stationary over time. Under natural viewing conditions (>3mm pupil) the MTF varies significantly when measured at different visual eccentricities. Fluctuations in accommodation create temporal variations in the magnitude of defocus of the retinal image. Viewing the image through pinholes or a plus lens produces a uniformity in the MTF regardless of eccentricity, and also reduces or eliminates the impact of temporal fluctuation of accommodation on retinal image quality.

The "rotating snakes" illusion can be viewed online at http://www.ritsumei.ac.jp/~akitaoka/rotsnake.gif

26.435 Minimum motion threshold correlates with the fixation instability of the more wobbling eye

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Even if we look at a stationary object with maintained fixation, the eyes are actually making tiny random oscillations. Previously a correlation was found between the minimum detection threshold for unreferenced motion and fixation instability, such that observers with poorer fixation performances had higher thresholds (Murakami, 2004). Therefore fixation instability is a part of internal noise that limits motion perception. Which of the two eyes is more influential? To answer this question, the minimum motion threshold was measured in binocular viewing and was compared with the fixation instabilities of the two eyes. Within a blurred window at 0 and 8.5 deg eccentricities, a random-dot pattern moved in one of eight possible directions differing by 45 deg. The threshold was determined as the speed corresponding to the correct response rate of 53.3% in direction identification. Fixational eye movements of each observer were recorded and the SD of microsaccade-free instantaneous velocities was taken as the index of fixation instability. Inter-observer correlations were based on these data for 56 normal adults. The thresholds at both eccentricities positively correlated with the fixation instability of both eyes, duplicating the previous finding. Interestingly, the positive inter-observer correlation became more evident ($r = 0.5$, $p < .0001$) when the threshold was compared with the fixation instability of the more wobbling one of the two eyes. After partialing out this correlation component, there was no more residual correlation between the threshold and the fixation instability of the less wobbling eye. Even when the motion task was conducted in monocular viewing, the performance still correlated with the more wobbling eye's statistics, no matter which eye was actually open during the task. These results suggest that we are calibrated so as not to see motions slower than the velocity noise originating from the eye making larger fixational eye movements.

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26.436 Directional judgment between leftward and rightward motions modulated by angular deviation from the horizontal axis

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Our performance of distinguishing between leftward and rightward motions is limited by internal noise. This study aimed at clarifying what is the optimal stimulus to counteract this noise and to yield the best performance. First, we found that slightly tilted (e.g., by 22 deg) directions deviating from the horizontal were better discernable than purely leftward and rightward directions. Within a blurred window, a random-dot pattern moved in one of two possible directions that were mirror-symmetric about the vertical, and the correct response rate was measured in the two-alternative forced response paradigm. Compared with purely horizontal directions (0 deg versus 180 deg), the judgment for two oblique directions (e.g. 22 deg versus 158 deg) was slightly better, even when the physical velocity was identical. This advantage became weak as the angular deviation from the horizontal increased, and the performance became worse when the task was to distinguish between 67 and 113 deg. Second, we found a similar advantage of slightly oblique directions when they were not displayed physically but produced internally in the brain as a result of motion integration between horizontal physical motion and vertical illusory motion. A central Gabor patch with a horizontally drifting carrier was surrounded by another grating drifting vertically. Subjects perceived the Gabor patch as moving in an oblique direction due to integration between horizontal carrier motion and vertical induced motion. The detection performance as determined by the correct response rate of leftward/rightward judgment was enhanced at a relatively slow surrounding speed, when the Gabor was perceived as moving obliquely. A similar modulation of detection performance was also observed when we replaced induced motion with motion aftereffect. These results suggest that interactions with the critical internal noise for the present tasks reside in a higher-order motion processing stage, where vectorial integrations and center-surround interactions take place.

Acknowledgement: Nissan Science Foundation

26.437 Time distorts space in both directions during apparent motion

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Just like Heisenberg's uncertainty principle in quantum physics, it is notoriously difficult for our visual systems to accurately determine both the timing and the position of moving objects. Previous literature has consistently shown that the perceived position of objects is influenced by their own motion or the neighboring motion context. Interestingly, all the reported phenomena (e.g., Frölich effect, motion induced position shift, flash-lag effect, etc) correspond to spatial mislocalization along the direction of motion. Here we report that a simple temporal manipulation during an apparent motion sequence can also cause the moving object to be mislocalized in the direction opposite to the motion. A single dot was displaced at a constant speed (apparent motion, 80 ms/step) across 10 locations equally distributed on an imagery circle at 2.5 degrees eccentricity. While the remainder of the sequence was kept constant on each trial, at one "critical" location we modified either the onset latency of the dot (keeping its position constant), its spatial position (keeping its onset latency constant) or both dimensions together (keeping its speed constant); we asked observers (N=8) to report the critical dot's perceived location relative to a static landmark. The most interesting finding was obtained from the onset latency manipulation: when the dot was presented too early in time, participants perceived it as ahead of the critical location; but when the dot was presented too late, participants tended to perceive it as trailing the critical location, i.e., in the direction opposite to the motion sequence. The influence of timing manipulations on perceived space was found to be about 35% of the equivalent spatial manipulations. This time-based illusory distortion of space may be due to a recalibration mechanism, whereby internal representations of the global motion context are regularly compared to external information.

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26.438 Modeling and measurement of the human contrast sensitivity surface

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The Spatiotemporal Contrast Sensitivity Surface (STCSS) is a comprehensive characteristic of visual sensitivity (1/threshold), measured using luminance gratings of variable spatial and temporal frequencies of modulation (Kelly, 1979). Estimating the entire STCSS is important for basic and clinical vision research, but it requires massive data collection. Novel adaptive procedures allow one to rapidly estimate the full STCSS (Lesmes et al., 2009) by making assumptions about the form of the STCSS and its underlying psychometric functions. By doing so, estimation at one stimulus condition informs and improves estimation at other conditions. The precision of estimating the STCSS by the adaptive procedures depends on the validity of these assumptions. We explored how different parametric descriptions affect STCSS estimation in different tasks.

Observers discriminated speed or direction of motion in drifting sinusoidal gratings, while grating contrast was varied according to one of two Bayesian adaptive procedures: Psi (Kontsevich and Tyler, 1999) or qCSF (Lesmes et al., 2008). Both procedures use a strategy that selects stimuli expected to yield the largest information gain about psychometric parameters. Psi procedure estimates thresholds and slopes of psychometric functions separately for each spatiotemporal frequency. In speed discrimination, observers reported which stimulus moved faster in a 2-IFC task. In direction discrimination, observers reported which direction they saw among two opposite directions, in a 2-AFC task.

In both tasks we obtained sensitivity surfaces of similar shapes, which supports the view that the STCSS has a task-independent shape (Nakayama, 1986; Gepshtein et al., 2007). The slopes of psychometric functions covaried with thresholds in speed discrimination, but they did not vary in direction discrimination. These results indicate that a complete characterization of visual sensitivity should include both slopes and thresholds of psychometric functions across spatiotemporal frequencies, rather than only the thresholds used in previous parametrizations.

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Eye movements: Smooth pursuit

Orchid Ballroom, Boards 439–446

Saturday, May 8, 2:45 - 6:45 pm

26.439 Integration of motion information for smooth pursuit during multiple object tracking (MOT)

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Previously, we showed that observers could simultaneously perform multiple object tracking (MOT) and pursue the array of MOT targets without loss of performance on either task (Watamaniuk et al., 2009). We proposed that local motion information is maintained for MOT, while pursuit uses a velocity signal obtained by integrating the local motion of the MOT elements. However, in that work, the MOT array always moved at the same constant velocity, and therefore, a predictive pursuit movement could maintain eye velocity without requiring integration. Here, we test this, by changing the speed of the array at a random time. The MOT stimulus was composed of nine dots (0.2 deg diameter) that moved randomly within a virtual region measuring 8 by 8 deg for 3 sec. Observers were initially cued as to which four of the dots to remember by a brief color change. All dots returned to the same color until the end of the trial, when one dot again changed color and had to be identified as a member of the cued set or not. The array began moving from left to right at 7deg/sec. In 60% of trials, the array speed was randomly increased to 11.5 deg/sec or decreased to 2.3 deg/sec for 500 msec, beginning 700-2000 msec after motion onset. Observers pursued the array either with or without performing the MOT task. We found that eye velocity changed in response to the array speed change after a normal latency (112 msec mean) regardless of whether the MOT task was performed, and MOT performance was unimpaired. The results suggest that local motion information is continuously integrated for pursuit even when individual, non-consistent motion signals are attended, supporting simultaneous access of global and local motion signals for pursuit and MOT tasks.

26.440 Anticipatory smooth pursuit eye movements in response to global motion

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Anticipatory smooth pursuit eye movements in the direction of expected target motion can be elicited by symbolic visual or auditory cues (Kowler, 1989). Stimuli in these studies, small targets moving against dark or structured backgrounds, convey the perceptual impression of an object moving across space. Are such interpretations necessary for anticipatory pursuit? We studied random-dot kinematograms (RDKs), composed of dots with very brief lifetimes. RDK's can be pursued (Schütz et al., VSS 2009), but they generate global motion signals, rather than the percept of discrete moving objects.

RDKs were composed of dots (4') moving coherently (2.5 o/s) either up, down, right or left. Dot lifetimes were 52, 104, or 208 ms. The direction of motion was cued by either: (1) the spatial offset of the initial stationary fixation stimulus away from screen center, opposite to the direction of upcoming target motion; or (2) a tone whose frequency indicated whether dots moving downward would change direction to either down-right or down-left. Uncued motion directions, and unlimited lifetime dots, were also tested.

Anticipatory smooth eye movements (ASEM) were prominent. Neither their onset time nor velocity depended on dot lifetime. By contrast, both peak eye velocity and steady-state pursuit gain varied with lifetime. Steady-state gains with the longest lifetime approached 1. Gains with the shortest lifetime ranged from 0.1 to 0.7, depending on subject and direction of motion.

These results show that anticipatory smooth pursuit eye movements can be elicited with global motion, and do not require representations of an object moving across space. Dot lifetime did not affect anticipatory eye movements, but did affect steady state pursuit. These differential effects of dot lifetime suggest that the study of the pursuit of random-dot kinematograms may be a useful way to dissociate the response to expected and immediate target motion.

Acknowledgement: NSF 0549115

26.441 Compensation for equiluminant chromatic motion during smooth pursuit

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When we move our eyes, the world appears to remain stable. The visual system reconstructs a stable world in spite of the motion of the retinal image resulting from eye movements. During smooth pursuit eye movements, the retinal image moves in the opposite direction. To compensate for such retinal image slip, the visual system is arguably comparing retinal image velocity and estimated eye velocity. Our interest was whether equiluminant motion is compensated in a similar way by velocity comparison. According to the conventional view that color and motion are processed through separate neural pathways, compensation for color motion could have different properties. Alternatively, as we argued previously (VSS, 2007), early processes for luminance and color motions mediated by the magnocellular and parvocellular pathways might feed into a common velocity comparator. It is also unclear whether S-cone chromatic modulation, for which the koniocellular pathway is suggested to be responsible, is also compensated by similar velocity comparison. We measured the retinal image velocity required to reach subjective stationarity for a sinusoidal grating, using chromatic modulations determined in reference to a cone contrast color space in which two axes correspond to the chromatic tunings of the LGN neurons (L-M axis and S axis). The grating was drifting at various velocities. Results indicated that the retinal velocity at the point of subjective stationarity for both L-M-axis and S-axis chromatic modulations were faster than that for luminance modulation. Equiluminant chromatic motion is known to appear to move slower than luminance stimuli (e.g. Cavanagh et al. 1984). Our results suggest that speed reduction at equiluminant motion mediated by both parvocellular and koniocellular pathways takes place at an early processing level with retinocentric coordinates, followed by velocity comparison in which reduced retinal image velocity is compared with estimated eye velocity to compensate equiluminant motion during smooth pursuit.

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26.442 Pursuit eye movements on visual illusions

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The dissociations between visual perception and visual guided action have long been suggested (Goodale & Haffenden, 1998). Studies showed that the saccadic eye movements were guided by real physical stimuli rather than by the perceived visual illusions. In the present research, we explored which guides the pursuit eye movements, physical stimuli or visual illusions. In the case of Hering illusions, where radiant lines induce a perceived curvature for a physically straight line, a ViewPoint PC60 video eye tracker was used to record the eye movements during observers pursuing a red dot target moving along a straight line, a Hering illusory curve (physically a straight line), or a curve with curvature match the Hering illusion. The results showed that the eye scanning paths of pursuing a target moving alone an illusory curve are more similar to those of viewing a real curve than to those of viewing a straight line, what the illusory curve is physically. This suggested that the visual illusion guides the pursuit eye movements in the case. We then applied similar paradigm to test the Wundt, Müller-Lyer, and Ebbinghaus illusory patterns, which exhibited illusory curvatures, line segment lengths, and sizes, respectively. By analyzing the gaze paths of pursuing targets moving along those illusory rails, we found that the scanning paths followed the illusory rather than the real physical patterns. The results suggested that pursuit eye movements may be guided by the what rather than by the how visual information processing streams.

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26.443 Temporal Integration of Focus Position Signal during Compensation for Pursuit in Optic Flow

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Saturday PM

The pattern of motion on the retina, or optic flow, during smooth pursuit eye movements is the difference between the instantaneous motion in the scene, caused for example by self-motion, and that of the eyes. Previous studies have shown that the optic flow component caused by pursuit is partially removed from the percept. In those studies the distorting effect of pursuit on the focus location has been attributed to the vector addition of the instantaneous pursuit velocity. For example, the expanding flow resulting from forward self-motion plus the laminar flow resulting from pursuit leads to a shift of the focus of expansion in the pursuit direction. However, during pursuit the focus also gradually moves over the retina in the direction opposite to the pursuit, and the potential effect of this on the perceived focus location is disregarded in the instantaneous vector sum account. In a different field of study, it has been shown that the momentary position of a moving target is misestimated in the direction opposite to the direction of target motion, probably because observers report the target's average position over a time interval prior to locating the target. Here we present evidence that this temporal integration effect also plays an important role in locating the focus. We presented expanding, contracting and rotating flow fields during pursuit and asked observers to report the position of the focus. We found that the mislocalization pattern bore signatures of both the vector sum account, which predicts shifts in different directions for each flow type, and the temporal integration account, which predicts shifts in the pursuit direction for all flow types. Additional experiments, in which the presentation duration, flow speed, and uncertainty of the focus location were manipulated, consolidated the idea that this novel component of focus shift indeed reflected temporal integration.

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26.444 **Bayesian analysis of perceived motion during smooth pursuit eye movement**

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We've known for over a century that estimates of pursuit speed are typically lower than estimates of retinal speed. The benchmark is the Aubert-Fleischl phenomenon, the name given to the perceived slowing of moving objects when they are pursued. Many other pursuit-related phenomena can be accounted for in a similar way: stationary objects appear to move (the Filehne illusion), motion trajectories are misperceived, perceived heading oscillates (the slalom illusion) and slant increases. When compared quantitatively, the slowing required to explain these phenomena is remarkably consistent. Estimates of pursuit speed are evidently lower than estimates of retinal speed – but why? Recent Bayesian accounts of retinal motion processing may provide an answer. These rely on a zero-motion prior that reduces estimates of speed for less reliable motion signals. This would explain the phenomena above if signals underlying eye-velocity estimates were less precise, a prediction tested by comparing speed discrimination for pursuit (P) and fixation (F). Using a standard 2AFC task, we found trials containing P-P intervals were harder to discriminate than F-F intervals. We also found that speed matches for F-P intervals revealed a strong perceived slowing of pursued stimuli (Aubert-Fleischl phenomenon). A control experiment showed that poorer P-P discrimination was not due to the absence of relative motion. We used a Bayesian observer to fit psychometric functions to the entire data-set. The model consisted of a measurement stage (single non-linear speed transducer + two sources of noise), followed by a Bayes estimator (SD of prior free to vary). The model fit the data well. In order to explain the other phenomena listed above, however, the model demonstrates that estimates of retinal motion and pursuit must be added after the Bayes estimation stage. Adding signals beforehand (at the measurement stage) cannot predict changes in velocity, just speed.

Acknowledgement: The Wellcome Trust

26.445 **A recurrent Bayesian model of dynamic motion integration for smooth pursuit**

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The quality of the estimate of an object's global motion, over time is not only affected by the noise in motion information but also by the spatial limitation of the local motion analyzers (aperture problem). Perceptual and oculomotor data demonstrate that during the initial stages of the motion information processing, 1D motion cues related to the objects edges have a dominating influence over the estimate of the objects global motion. However, during the later stages, 2D motion cues related to terminators (edge-endings) progressively take over leading to a final correct estimate of the objects global motion. Here, we propose a recursive extension to the Bayesian framework to describe the dynamic integration of 1D and 2D motion information. In the recurrent Bayesian framework, the prior defined in the velocity space is combined with the two independent measurement likelihood functions (Likelihood functions representing edge-related and terminator-related information) to obtain the posterior. The prior is updated with the posterior at the end of each iteration step. The recurrent Bayesian network is cascaded with a first order filter to mimic the oculomotor dynamics in the final output of the model. This oculomotor dynamics was tuned with single blobs moving in 8 different directions. The model parameters were fitted to human smooth pursuit recordings for different stimulus parameters (speed, contrast) across three subjects. The model results indicate that for a given velocity with increase in contrast, the latency decreases and for a given contrast with increase in velocity, the acceleration increases similar to what is being observed in smooth pursuit recordings . Also, The latency for a tilted line is shorter compared to the latency for the blob.

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26.446 **Oculoceptive fields for smooth pursuit eye movements**

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When confronted with several moving objects, the smooth pursuit system has to integrate information over a region of the visual field to determine the direction of the eye movements. We spatially mapped the influence of different motion vectors with the ultimate goal of finding an 'oculoceptive field' of the pursuit system. We asked subjects to pursue a random-dot pattern consisting of 20% correlated signal dots moving rightward or leftward at 10°/s. The pattern was presented inside a circular window with a radius of 20 degrees of visual angle. A perturbation was then added to the pattern, consisting of additional correlated dots moving at an angle offset obliquely upwards or downwards from the pattern direction. The perturbation angle was varied between 5° and 90°, and the perturbation was present throughout the duration of the stimulus in one of 5 regions forming a gaze-contingent circular window with a 10° outer radius and a 2° inner radius. The effect of the perturbation was to deflect the pursuit from the horizontal pattern motion direction into the perturbation direction. The perturbation had the largest effect when the angular difference to the pattern motion direction was small (up to 10°), even though the vertical component of the perturbation was much bigger for larger angular differences. Perturbations with an eccentricity angle larger than 10° tended to be discarded, indicating that this integration is not a simple vector summation process. Rather, motion signals close to the pursuit direction seem to be weighted much heavier than others. Perturbations presented behind the pursuit target had similar effects as those that were ahead of the pursuit target. Our results indicate that the analysis of visual motion during smooth pursuit is focused on the direction of ongoing pursuit. The oculoceptive field for pursuit is centered on the pursuit target.

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Memory: Encoding and retrieval

Orchid Ballroom, Boards 447–460

Saturday, May 8, 2:45 - 6:45 pm

26.447 Measuring the accuracy and precision of visual representations in validly and invalidly spatially pre-cued visual working memory

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Valid pre-cuing of spatial attention improves visual identification, especially in the presence of visual noise in the stimulus (Dosher & Lu, 2000). The current study used orientation-report methods to measure the accuracy and precision of stimulus representations in visual working memory (VWM) (Zhang & Luck, 2008) following either a valid or an invalid location pre-cue. Gabor patches of varying contrast appeared at each of four corners at 5 deg eccentricity about fixation. The Gabors were selected from 20 9°-spaced orientations. External noise was added on half the trials, with the contrast of the Gabors adjusted accordingly. One of the four locations was pre-cued 150 ms before the oriented Gabors and then the delayed report-cue appeared 800 ms after the Gabors indicating the to-be-reported location. Observers clicked on a Gabor from a 20-orientation palette to report the orientation. The precision and accuracy of the visual representation was measured through the spread of responses about the orientation of the to-be-reported stimulus. The pre-cue was valid on 5/8 of trials, while another location was cued for report in 3/8 of trials. The reports in validly cued trails, which could have supported encoding earlier in the delay interval, showed higher accuracy and good precision about the correct orientation. Performance in reporting the correct orientation was dramatically reduced in invalidly cued trials, where the report-cued location was unpredictable until 800 ms after the stimulus, and observer's reports were more broadly tuned, incorporating more guessing errors. As in spatially cued attention, invalid cuing was especially damaging in high external noise for a number of observers. Several observers showed very poor performance for invalidly cued trials in high external noise. These data can be considered as a mixture of a good precision encoding and guessing, with the availability of the processes dependent on cuing and on external noise.

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26.448 Figure-ground perception is impaired in medial temporal lobe amnesia

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Amnesia resulting from medial temporal lobe lesions is traditionally considered to be a selective deficit in long-term declarative memory. In contrast to this view, recent studies suggest that high-level perceptual processing may also be compromised in the disorder (e.g., Lee et al., 2005; Barense et al., 2007). Here, we tested figure-ground segmentation in two densely amnesic patients with focal lesions to the medial temporal lobes resulting from herpes viral simplex encephalitis. For each display, two adjacent regions shared a contour and participants reported whether they perceived the left or the right region as the figure (e.g., Peterson et al., 2000). In experimental stimuli, the central contour portrayed a familiar object on one, high-denotative, side. In control stimuli, no known objects were portrayed on either side of the central contour, but one side was a part-scrambled version of one of the high-denotative regions. Relative to age and education matched controls, the patients failed to show effects of familiarity on figure assignment, with neither patient reporting seeing the figure on the high-denotative side of the edge any more often than on the matched scrambled side. The lack of a difference arose because the patients were highly likely to see both the part-scrambled and the high denotative regions as figure. Moreover, both patients identified less than half of the familiar objects they saw as figures. The pattern of performance suggests that the patients may have been responding on the basis of the familiarity of the individual features of the objects, rather than on the basis of the overall familiar configuration of the object as a whole. These results suggest that fast access to familiar configurations and conscious object recognition of portions of figures may be impaired in medial temporal lobe amnesia.

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26.449 Frequency of exposure modulates cortical activity in the contextual associations network

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Objects are typically encountered embedded in a context with other objects, rather than appearing in isolation. The parahippocampal cortex (PHC) and the retrosplenial complex (RSC) are major components in a network that is more active for stimuli with such typical contextual associations compared with stimuli with weak contextual associations. Contextual processing provides a bridge between previous research that ascribed spatial functioning to the PHC and RSC and other research that demonstrated that these areas mediate episodic memory. Here we aimed to enrich this bridge by asking what is the effect of frequency of occurrence on activation in this network. The idea was that highly contextual objects that are encountered more often would elicit more associations than objects with weak contextual associations, and even compared with other highly contextual objects if these are not encountered as frequently. Participants viewed four types of objects in an fMRI scanning session: strongly contextual objects that are encountered frequently, strongly contextual objects that are encountered rarely, weakly contextual objects that are encountered frequently, and weakly contextual objects that are encountered rarely. Both strength of contextual associations and frequency of occurrence were determined using surveys. First, as has been shown before, activation in the context network demonstrated a strong main effect of context, whereby activation increased significantly for strong context compared with weak context. More importantly, both the RSC and the PHC were more active for frequent objects than to rare objects, supporting our context-related hypothesis. We will discuss the difference between the exposure effect on RSC and on PHC, and will also tie exposure to the potential role of the prefrontal cortex in the interaction between context, number of associations and frequency of occurrence.

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26.450 How does occlusion affect search and memory processes for targets and distractors?

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Occlusion of visual details is a ubiquitous problem in real-world visual search. The lack of visual details requires that a searcher either process incomplete objects or amodally complete objects in order to identify the target of the search. The current study had participants search for conjunction targets among pictures of real-world objects that were not occluded or were occluded 25%, 50%, or 75%. In addition to the level of occlusion, the type of occluder was manipulated in that the occluder was either a visible multi-colored mask or matched the background color (invisible occluder). Search was more difficult as the levels of occlusion increased, but the effect was limited to the higher occlusion levels. Participants were also more accurate, but no faster, in searches when there was a visible occluder compared to an invisible occluder, indicating that the ability to attribute the disrupted visual information to a visible occluding element was advantageous. Following the search, participants' memories for the search objects encountered were tested. Interestingly, memory for the target objects were more affected by the increasing levels of occlusion than memory for distractor objects, especially at higher levels of occlusion. However, whether the object had been occluded by a visible occluder or not had no effect on memory. In a separate experiment, the ability of the participant to remember the portion of the object occluded was tested by presenting partially occluded objects and testing the occluder's location. Participants were near, but reliably above, chance performance at remembering the location of the occluder on distractor objects. However, participants were significantly better at locating the occluder on target objects. The memory results may indicate differences in how amodal completion affects target and distractor object visual memory representations in that targets may have more precise representations compared to more abstract representations of distractors.

26.451 **Wait a few seconds: Newly learned spatial statistics enhance visual short-term memory**

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The current experiments investigated how learned spatial statistics affect visual short-term memory (VSTM). In all experiments, a VSTM task was used in which a sample array was presented, followed by a 1000ms delay, followed by a test probe. Participants indicated whether the probe was present in the sample array. Sample arrays consisted of six novel shapes, similar to those used in previous studies of visual statistical learning. Structured arrays consisted of base pairs, i.e. pairs of shapes that always appeared in the same relative spatial positions (e.g. shape-A always appears above shape-B). On unstructured arrays, shapes were presented in random locations, with the restriction that the global configuration was one that could appear in the structured arrays. In experiment 1, sample arrays were presented for 2000ms. Performance was better on structured arrays, suggesting that spatial statistics can be used to enhance VSTM. Participants could also recognize the base pairs at the end of the experiment. In experiment 2, sample array inspection time was reduced to 500ms. All effects of spatial structure were eliminated, consistent with the idea that learning spatial statistics depends on inspection time. In experiment 3, participants passively viewed the structured and unstructured arrays prior to performing the VSTM task (with 500ms inspection time). As in experiment 2, performance on the VSTM task was equivalent for structured and unstructured arrays. However, unlike experiment 2, participants could recognize the base pairs at the end of the experiment. These experiments suggest that visual statistical learning does not affect the basic units of VSTM. If visual statistical learning affected VSTM's units, then performance should have been better on structured arrays in experiment 3. Thus, these findings suggest that information in long-term memory can supplement limited capacity VSTM, as long as enough time is available to access VLTM.

26.452 **Unexpected events, predictive eye movements, and imitation learning**

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W. Schulz proposed that prediction errors can facilitate the learning of sequential behaviors. We assessed Schulz's proposal, asking how prediction errors alter the fidelity with which a remembered motion sequence was reproduced. Subjects viewed a sequence five times, each time reproducing what they had just seen. Each sequence comprised six quasi-randomly directed motions. Because eye movements are influenced by cognitive factors such as learning and expectation, we supplemented measures of reproduction fidelity with measures of eye movements made while subjects viewed each sequence of motions. Beginning with the second viewing of a sequence, tracking eye movements showed clear anticipation of the upcoming motions. Thus, eye movements provide a sensitive indicator of subjects' knowledge of and expectations for complex, quasi-random sequences of motions. To determine the influence of prediction errors, a novel motion direction was occasionally injected into a well-learned sequence. This unexpected, deviant motion transiently disrupted eye movements, requiring large, corrective saccades for catch-up. However, reproduction of this motion sequence was equivalent to that of well-learned, non-deviant sequences, and was greatly improved over reproduction of entirely novel sequences. These results undermine claims that eye movements provide a substrate crucial to visuomotor learning. Immediately after a perturbed sequence, a final presentation either reinstated the original, well-learned sequence, or preserved the deviant motion. On this final presentation, eye movements anticipated the reappearance of the deviant motion component; when this anticipation was correct, catch-up saccades were smaller and velocity of smooth pursuit was higher. Motion sequence reproduction was more accurate when subjects' expectation was violated and the original sequence appeared than when this expectation was confirmed. So, one presentation of an unexpected, deviant motion produces strong learning for that component, and violating expectations improves subjects' ability to reproduce a motion sequence.

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26.453 **Neural basis for monitoring of multiple features-location binding: an event-related functional magnetic resonance imaging study**

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Functional magnetic resonance imaging (fMRI) studies using a multiple object permanence tracking task (MOPT; Saiki, 2003) or a multiple object tracking task have reported the involvement of the frontoparietal network and inferior precentral sulcus (infPreCS) in the monitoring of location or feature-location binding. In general, many objects have multiple features; therefore, coherent object representation requires monitoring multiple features-location binding. To investigate whether the enhanced activities in the previously reported neural network or activities in additional regions contribute to the monitoring of multiple features-location binding, we used event-related fMRI with an MOPT paradigm and compared brain activities among different tasks using the same visual information. Visual objects were defined by 4 sets of a tilted black bar embedded in a colored circle. We prepared 3 change types: color (2 colored circles were replaced with each other), orientation (2 tilted bars were replaced with each other), and conjunction (2 colored circles and tilted bars were replaced with each other). Depending on the change type to be monitored, we prepared 2 types of tasks: single feature-location binding (monitoring only single feature-location binding) and triple conjunction tasks (monitoring the binding of 2 features and location). The former group consisted of color (to detect either color or conjunction change) and orientation (to detect either orientation or conjunction change) tasks, whereas the latter was the conjunction task (to detect only conjunction change). Behavioral data showed no significant difference between tasks. In the search for regions showing selective activation in monitoring of triple conjunction, we identified a network comprised of the superior parietal lobule, superior frontal gyrus, middle frontal gyrus, and infPreCS. In the monitoring of triple conjunction, infPreCS cooperated with subregions of the frontoparietal network, suggesting the contribution of enhanced activities in the neural network reported in previous studies in the monitoring of object representation.

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26.454 **Neural response dynamics in parietal cortex for an algebraic processing task**

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Introduction. Neural signals exhibit a wide variety of temporal characteristics, but in human brain studies it is difficult to derive the neural response time courses for local cortical regions of interest. A biophysically-based forward optimization procedure for the BOLD fMRI waveforms was constrained by a plausible parametrized model of local neural population responses. This paradigm allowed us to determine the temporal dynamics of the local neural populations during the various phases of the mental calculation process within the sequence of processing regions in the intra-parietal sulcus (IPS), which is well known to be involved in this visuo-cognitive activity. Methods. BOLD responses were measured throughout the human brain using a 3T scanner with a 1 s sampling rate and a jittered event-related design for stimuli consisting of temporally sequenced numeric equations together with a trial solution and error feedback about response correctness. The responses to the visual number presentations in each component were fit by a model with three waveform parameters for the neural response and three for the BOLD response, plus an overall scaling parameter. Results. The pattern of response dynamics differentiated bilateral areas corresponding to the angular gyrus and IPS regions 1-5 along the intraparietal sulcus. While the responses to the initial number and operator presentations were typically brief throughout retinotopic cortex, the angular gyrus showed prolonged responses that could support the number memory. Typically, IPS1-4 showed strong involvement in the calculation phase, while IPS5 was predominantly active during evaluation and response selection for the trial solution. Conclusion. This novel optimization technique allows estimation of the neural signal dynamics underlying the BOLD waveforms in an

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algebraic processing task, allowing the differentiation of distinct functional components and their causal roles in the information flow among cortical response areas lying along the IPS.

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26.455 **A computational model for change detection in familiar environments**

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Detecting visual changes in environments is an important computation that has applications both in the study of human and computer vision. Additionally, task oriented descriptions of visual cognition [1] could use such a mechanism for switching between ongoing tasks and updating internal visuospatial memory representations. We conjecture that the number of environments in which people spend most of their time is limited (out of the set of possible visual stimuli), that the environments do not frequently undergo major changes between observations and that over time subjects learn distributions of spatial and visual features. These assumptions can be exploited to reduce computational complexity of processing visual information by utilizing memory to store previous computations. A change detection technique is then required to detect when predictions deviate from reality. Baldi and Itti [2] provided a Bayesian technique, however they did not incorporate spatial location of features and require a commitment to a distribution of features a priori. We propose a mechanism that instead uses a low dimensional representation of visual features to generate predictions for ongoing visual stimuli. Deviations from these predictions can be rapidly detected and could be used as a reorienting attentional signal. The model we present is computationally fast and uses a compact descriptions of complex visual stimuli. Specifically, the model encodes color histograms of naturalistic visual scenes captured while exploring an environment. It learns a spatial layout of visual features using a self-organizing map on location data and color data, compressed using the matching pursuit algorithm. We present tests of the model on detecting changes in a virtual environment, and preliminary data for human subjects' change detection in the same environment.

[1] Sprague and Ballard, Proceedings of the 18th IJCAI, August 2003

[2] Baldi and Itti, ICNN&B 2005.

26.456 **Using objects as symbols: Associative learning improves when confusable items serve as cues rather than as associates**

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Recent research in adult word learning has shown that associative learning performance depends on the temporal order of the learned pairs: associations between novel objects and labels are learned more successfully when objects precede labels than when labels precede objects (Ramscar, Yarlett, Dye, Denny, & Thorpe, in press). Here we investigated whether this effect may be driven by labels being less confusable than objects, and whether the effect can be replicated in a non-linguistic domain if this asymmetry in confusability among cues and associates is preserved. To test this hypothesis, we constructed two-tone shapes to serve as either labels or objects depending on their level of confusability. Specifically, two pairs of visually similar "F" shapes served as objects with confusable Features and two pairs of visually dissimilar shapes "L" shapes served as easily discriminable Labels. Each F shape was arbitrarily assigned an L shape. Thirty-two subjects passively observed sequential presentation of these cue-associate pairs in an unsupervised learning paradigm. We manipulated the temporal order across pairs so that each subject learned two pairs in the F-L order and two in the L-F order. After 8 minutes of unsupervised learning, we tested whether subjects had learned the associations in a 4-AFC task: On each trial, subjects were prompted with a target shape and asked to pick the appropriate associate from amongst the four possible complementary shapes. Subjects demonstrated better associative learning on pairs learned in the F-L order compared to the L-F order, regardless of the order in which they were tested, analogous to the result observed in the linguistic domain. This provides preliminary evidence that the ordered learning effect found in word-learning may be the result of a domain-general mechanism. We frame our finding in terms of error-driven learning and explore the theoretical implications for recent word-learning research.

26.457 **Another look at mindsight**

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Whenever a change occurs in a visual display, some observers occasionally sense it (i.e., feel that something is happening) for several seconds before they are able to see it (i.e., form a visual picture of the event). Given the difference in phenomenological experience, and various behavioral dissociations between these two forms of experience, Rensink (2004) suggested that sensing and seeing involved different modes of perception; the mode enabling sensing was termed "mindsight". Alternatively Simons et al. (2005) suggested that both experiences were due to a single mode (i.e., regular sight), with sensing simply a verification stage when perception of change is weak. During the past few years, new studies have brought to light new evidence in favor of the mindsight hypothesis. However, the controversy about the existence of this mode of perception still remains. It is therefore time to collect and confront the various experimental results in order to draw a clear picture of the state of experimental evidence for and against a distinct mode of visual perception. We review the different arguments on both sides of this debate, clearly define the notions at stake, present some new results and several considerations (both conceptual and experimental) to help settle this issue.

Acknowledgement: Fyssen Fondation

26.458 **Speed-accuracy tradeoffs in cognitive tasks in action game players**

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Three speeded-choice reaction time tasks were used to assess different cognitive functions in action gamers: (i) Proactive Interference, which measures the ability to suppress familiar but irrelevant information in memory, (ii) The Posner Ab task, which measures the speed with which information is retrieved from long term memory and (iii) an N-back task, which measures working memory efficiency.

Action video game players (VGPs) displayed faster reaction times (RTs) than individuals who do not play fast paced video games (NVGPs). Such a difference in baseline RTs is known to complicate evaluation of cognitive effects across populations. Indeed, cognitive effects are typically defined in terms of differences between conditions, and it is unlikely that a 100ms difference between two conditions has a similar meaning given a baseline RT of 800ms versus a baseline RTs of 400ms (see Madden, Pierce, and Allen, 1996 for an extensive discussion of this problem). In addition, faster RTs in VGPs were accompanied, at times, by a small but significant decrease in accuracy preventing any straight-forward interpretation of the cognitive effects.

We present two different ways of analyzing the data that have been proposed in the field to address this issue. When applying such corrections, VGPs and NVGPs displayed comparable cognitive effects. The outcome of such between-groups study is weakened however by the use of paradigms in which accuracy is fixed and typically near ceiling. We present a new cognitive decision making task that allows to sample the full chronometric and psychometric curve. VGPs presented a very clear speed-accuracy tradeoff, but overall were found to perform more correct decisions per units of time.

Acknowledgement: This research was supported by grants to D. Bavelier from the National Institutes of Health (EY016880) and the Office of Naval Research (N00014-07-1-0937).

26.459 **The efficiency of encoding - how to get most images into visual memory**

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The ability of humans to extract meaningful visual information from briefly presented images and to remember them is astonishing. But what is the most efficient way of presenting visual information to achieve maximum performance in terms of remembered items? To address these questions we tested participants in a memory task for natural images where we varied the number of items presented simultaneously, the viewing time and the interstimulus interval (ISI). The viewing phase was followed by a test phase consisting of a 2-AFC recognition task of the images. Performance in terms of percentage of correct answers for the various conditions was

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then converted into capacity estimates, under consideration of the guessing probability and the number of items presented. This capacity estimation was then scaled to a fixed time unit to be able to compare performance under the different conditions. It proved to be more efficient to only show one object per trial very briefly rather than to show more objects simultaneously for a longer time period. In the final version of our experiment, we combined four presentation times (50, 100, 200, 300 ms) and four interstimulus intervals (0, 50, 100, 200 ms) resulting in 16 conditions. Performance increased significantly with longer trial durations from about 55% to 75% correct. Increases in the presentation time had a larger impact than increases in the ISI. Performance in all conditions was above chance level. When considering memory capacity for a given time unit, in all conditions about 1.3 objects were remembered per second. Thus, in terms of efficiency, variations in presentation time and ISI did not matter very much.

26.460 **Similar Scenes Seen: What are the limits of the visual long-term memory fidelity?**

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The capacity of long-term memory (LTM) for pictures is outstanding: observers distinguish thousands of distinct pictures from foil exemplars after seeing each item only once (Standing, 1973; Brady et al., 2008). In contrast, change blindness shows that, even in short term memory, two versions of the same picture are difficult to distinguish when they differ by only a few objects. Clearly, there are limits to the resolution of visual LTM. Here, we investigated the fidelity of LTM by using foil images representing similar versions of a scene. During a learning phase, 312 color photographs of different categories were displayed for 2 seconds each. Observers performed an N-back task to encourage sustained attention. Importantly, observers were explicitly informed prior to learning about the testing conditions. At test, they performed a 2-AFC task with one old image and a foil whose resemblance with the target was manipulated: the foil could be a mirror image of the same scene, the same scene zoomed in or out by 25 %, or a nearby scene cropped from a larger panoramic image. The control condition, a foil from a novel category, led to 93% recognition accuracy, as in related previous studies. The fidelity of memory was poorest (54%, chance level) when the foil depicted a “zoom-out” version of the old image. Participants performed well (84%) with foils depicting a translated non-overlapping version, and were moderately accurate (79%) with foils image overlapping by 50%, a zoom-in (69%) or a left-right mirror of the old image (72%). In a broader context, these results contribute to understanding the nature of stored visual representations. LTM representations have been shown to be sensitive to changes in scene viewpoint. Nevertheless, our results suggest that visual long-term memory is “open-minded” about certain kinds of viewpoint transformations: it does not mind a step backward.

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Object recognition: Features and categories

Vista Ballroom, Boards 501–515

Saturday, May 8, 2:45 - 6:45 pm

26.501 **Similarity-based multi-voxel pattern analysis reveals an emergent taxonomy of animal species along the object vision pathway**

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We present an account for how the structure of the representation of living things emerges in the object vision pathway, investigating three regions: medial occipital (MO), inferior occipital (IO), and ventral temporal cortex (VT). We investigated the similarity structure for patterns defined by responses to a variety of animate categories using functional magnetic resonance imaging (fMRI). Participants (N=12) viewed photographs of six animal species—two species each of insects, birds, and primates. Pair-wise dissimilarities between condition patterns were used to construct similarity spaces for each region within each subject. The similarity structures revealed how categorical representations emerge along the visual pathway. Patterns in early visual cortex (MO), as compared to those in IO and VT, are less differentiated and do not have a clear category structure. IO reveals differentiation between vertebrates and insects, while in VT each category becomes clearly defined. Individual differences multi-dimensional scaling (INDSCAL) showed how similarity structures transform from one region to the next. Thirty-six similarity structures from three brain regions—MO, IO, and VT—in each of 12 subjects were used to find a common multidimensional scaling solution where weights on dimensions varied between similarity structures. Differences in dimension weights reveal a reliable translation from MO through VT in similarity spaces organized according to low-level visual features in MO to semantic categories in VT. Similarity structures were highly stable and replicable both within and between subjects—especially in VT with an average between-subject correlation of r=.91. The consistency of similarity structures in IO and MO was also high, albeit not as strong as in VT (IO, r=.75; MO, r=.65). Similarity-based pattern analysis reveals a categorical structure in VT that mirrors our knowledge about animal species, providing a window into the structure of neural representations that form the basis of our categorical knowledge of the living world.

26.502 **In search of functional brain atlases: Deriving common categorical representational patterns across individuals in ventral visual pathway**

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Category information represented in activation patterns can be decoded using multivariate pattern analysis of functional MRI (fMRI) measures. Cross-subject registration of brain anatomy aligns only coarse structure leaving fine-scale variability in representational patterns. This is a major challenge in building a functional brain atlas that can store common representational activation patterns. We have developed a new functional alignment method, ‘hyperalignment’, that aligns each individual’s multi-voxel representational space to a common space that generalizes across experiments. We studied 14 subjects in two different imaging centers using different MRI scanners. We derived our alignment parameters using fMRI data that we obtained from ventral temporal cortex while subjects watched a movie. We then used these parameters to align fMRI data from two different experiments, in which ten subjects were shown images of seven categories of objects and faces in a block design and the other four were shown images from the same seven categories in a slow event-related design in a different scanner, into the same common space. A classifier trained on the hyperaligned face/object block design experiment data to classify these seven categories predicted the categories in the hyperaligned slow event-related data from the other four subjects with a mean accuracy of 52.7%. This between-subject classification (BSC) performance was equivalent to mean within-subject classification accuracy (WSC) for those four subjects (55.4%) and was significantly higher than BSC after anatomical alignment (BSCA) (35.8%). Mean BSC accuracy of hyperaligned data for subjects scanned in block design study was 61.3% (WSC=60.3%, BSCA=47.8%). These results demonstrate that hyperalignment provides a better way of deriving common representational patterns than does anatomical registration. Moreover, these common representational patterns can be mapped back into the brain of any reference subject opening doors for a new type of functional brain atlas that can store the high-dimensional patterns that are specific to an unlimited variety of neural representations.

26.503 **The Relationship between Multivariate Pattern Classification Accuracy and Hemodynamic Response Accuracy in Visual Cortical Areas**

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Traditional univariate analysis of fMRI data identifies differences in the average activity of specific brain regions under different conditions. In contrast, Multi-Variate Pattern Analysis (MVPA) classifies patterns of fMRI activity under different conditions. Both methods infer neural activity based on a hemodynamic response following the onset of a stimulus. It is an open question whether peak classification accuracy using MVPA occurs at, before, or after the peak in the BOLD signal level. Because neuronal activity is fast, it is possible that pattern classification accuracy is high within hundreds of milliseconds, even when the BOLD signal level is low. In other words, even very low average levels of hemodynamic activity, such as that which occurs during the initial negative dip in BOLD signal level, might produce highly informative activation patterns classifiable using MVPA. Alternatively, it is possible that the peak in MVPA classification accuracy occurs at the same temporal lag as the peak in BOLD signal level. To assess these possibilities, we performed an fMRI experiment with a slow event-related design, using faces and houses as stimuli, and explored the activity within functionally defined regions of interest from striate cortex to object-selective temporal cortex. We compared the average hemodynamic response to the classification accuracy over time. Our results suggest that there is a correlation between BOLD signal level and classification accuracy such that the peak in classification accuracy occurs at approximately the same temporal lag from stimulus onset as the peak in the BOLD signal level following stimulus onset.

26.504 **Detrimental effect of head motion covariates on GLM and multivoxel classification analysis of FMRI data**

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Head movements, or other global nuisance signals, can be a severe problem in FMRI analyses, yielding artefactual activations. To reduce this problem, the first step of data preprocessing is spatial alignment of the collected brain volumes over time, and the voxel wise removal of BOLD signal components correlated with the nuisance signals. We investigated the influence of the removal of nuisance signals on GLM and support vector machine analyses by creating simulated data sets and removing nuisance regressors of varying correlation with the stimulus time course. We report that for both types of analyses, false positive and false negative rates increased with increasing similarity between regressor and stimulus. Additionally, crossvalidated classification performance became ever more strongly biased downward as the correlation between nuisance regressor and stimulus increased, down to a performance level of 0%, where every instance was misclassified in crossvalidation. On the other hand, when the nuisance regressor was uncorrelated with the stimulus, classification performance was artefactually biased upward when a small number of time points was used. Overall, these results highlight the problematic nature of any signal that correlates with the stimulus pattern in FMRI experiments. Head motion is a particularly relevant example, but other signals could include respiration, heartbeats, and eye movements. These problems are particularly serious in the context of multivoxel analyses, which - due to their high sensitivity - are also especially sensitive to global nuisance signals as well as biases introduced by their attempted removal.

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26.505 **The neural representation of spatial relationships by anatomical binding**

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Visual spatial relations can be signaled implicitly with cells sensitive to conjunctions of features in particular arrangements. However, such hardwired circuits are insufficient for explaining our ability to visually understand spatial relations, e.g. top-of. A neural binding mechanism (Malsburg, 1999) is required that can represent two (or more) objects simultaneously while dynamically binding relational roles to each. Time has been suggested as the binding medium--either through serial attentional fixations (Treisman, 1996) or synchronous firing (Hummel & Biederman, 1992). However, using time is problematic for several reasons, not the least of which is that such representations are no longer simple vectors of neural firing but would require circuitry for decoding and storage beyond traditional associative memory models. An alternative is that the visual system uses "anatomical binding" in which one set of neurons is used to encode features of object#1 while a separate set encodes object#2. A series of fMRI experiments designed to test predictions of these various models provides evidence for anatomical binding in a manner consistent with Object Files/FINST theory (Kahneman et al., 1992; Pylyshyn, 1989). Based on these results, we propose a Multiple Slots Multiple Spotlights model: connections within the ventral stream hierarchy are segregated among several semi-independent sets of neurons creating, in essence, multiple parallel feature hierarchies each having its own focus of attention and tracking circuitry (FINST) and each having its own feature list output (Object File). When viewing a brief presentation of a single object all ventral stream cells would respond to its features (agreeing with existing single unit and speed of recognition results). However when viewing multi-object scenes (or multi-part objects) under extended processing times (>100ms) different spotlights could be allocated to different objects (or parts) producing a final neural representation that explicitly binds feature information with relational roles.

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26.506 **Voxels in LO—but not V1—distinguish the axis structures of highly similar objects**

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Many theories of object recognition assume that the representation of an object specifies its axis structure (e.g., Marr, 1982). Can LO (an area critical for shape recognition) distinguish between highly similar objects, all with the same shaped parts, that differ only in the relative positions of their parts, i.e., in their axis structures? We tested the issue using fMRI multivoxel pattern analysis. Our stimuli consisted of nine images, generated from three views (rotations in depth and in the plane) of each of three different novel objects, all composed of the same three geons, but differing in the arrangement of those parts. Unlike several prior studies, which used diverse sets of colored photos of familiar objects that differed greatly in many attributes, the images were all highly similar line drawings with no shading or familiar interpretation, and thus represent a theoretically clear test of shape selectivity per se. While viewing single presentations of the nine images, subjects identified each object by button press (1, 2, or 3), ignoring the object's orientation. A support vector machine classifier was trained and tested on independent splits of the data in different regions of interest. In V1, the classifier performed more accurately at separating groups of images of similar global orientation, and more poorly at separating groups of images based on the identity of the objects. In LO, this effect was reversed: greater accuracy was achieved separating objects (that is, different axis structures) than different global orientations. We interpret this double dissociation between V1 and LO as a fundamental shift in the shape similarity space, and conclude that LO is more sensitive to the relative positions of an object's component parts—i.e., its axis structure—than to the global orientation of the object.

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26.507 **Categorical representation of visually suppressed objects in visual cortex**

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Functional imaging has been used to understand how visual objects of different categories are represented in the brain. However, the relationship between the fMRI-derived object representation and consciously experiencing a particular object remains poorly understood. Recent studies investigating BOLD responses to visually suppressed objects suggest that even in the absence of awareness, specific cortical regions differentially represent different objects categories. However, drawing strong conclusions about categorical representation within specific brain regions is difficult since these studies have focused only on pairs of object categories and constrained analyses to very restricted and/or loosely defined regions of cortex Here, we extend this past work using fMRI combined with continuous binocular switch suppression to simultaneously investigate representations of visually suppressed objects across occipital, parietal, and temporal cortex and include faces, houses, tools and scrambled objects in our analyses. Univariate and multivariate (MVPA) analyses were conducted (N=8) within functionally defined ROIs including retinotopic areas: V1, V2, V3, V4 and V3A/B, V7, IPS1-5, SPL1 and object category areas: OFA, FFA, PPA, LOC and EBA. In the invisible conditions, univariate analyses found no differences in BOLD signal across object category in any ROI. In contrast, the MVPA yielded above-chance performance classifying the four image categories within the FFA and PPA as well as IPS2, IPS3, IPS4 and IPS5. However, secondary pair-wise MVPA revealed that this performance was largely mediated by differentiating between intact and scrambled images in all but the FFA in which faces could be dissociated from houses. However, within the FFA the MVPA could not accurately classify faces versus tools or faces versus scrambled pictures. Although MVPA analyses could classify at above-chance levels visually suppressed faces, tools, houses and scrambled objects within several areas of ventral and dorsal visual cortex, we find no evidence that the underlying representations are specifically categorical in nature.

26.508 The basis of global and local visual perception revealed by psychophysical 'lesions'

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We can extract the gist of scenes and objects very rapidly. This ability to "see the forest before the trees" is known as the Global Precedence Effect (GPE). The GPE is affected primarily by three factors: the spatial frequency content of the stimulus, the global and local grouping properties of the visual cortex, and the tuning curves of the magnocellular (M) and parvocellular (P) neurons in the lateral geniculate nucleus of the thalamus. Global information is conveyed primarily by low spatial frequencies (LSF) and local information, by high spatial frequencies (HSF). Moreover, the M-pathway is thought to be tuned primarily to LSF, while the P-pathway is thought to convey HSF. Therefore, the M-pathway is assumed to mediate global processing (and GPE) and the P-pathway, to local processing. To examine whether this mapping is true, we employed psychophysical techniques to selectively 'lesion' the M and P pathways and examined the relationship between spatial frequencies, M and P pathways and global/local processing. In Experiment 1 (N=10), we used hierarchical stimuli that were either M-biased (achromatic, low luminance contrast), P-biased (chromatic, isoluminant), or unbiased (black-on-white, resolved well by M and P cells). In Experiment 2 (N=10), we used hierarchical stimuli that were either 'scrambled' (phase of low and mid-range spatial frequencies randomly redistributed in the image), or unbiased. In both experiments subjects were tested for global/local processing using a focused attention paradigm. Contrary to the prevailing view, we found that both M and P pathways contribute significantly to global and local processing. Interestingly, we found that P-biased stimuli show a stronger GPE than M-biased stimuli. Our data also suggests that LSF is necessary for the GPE and HSF is sufficient for local processing. These findings describe for the first time the relationship between spatial frequencies, visual pathways, and global/local visual processing.

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26.509 Perceiving the Center of Human Figures

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Perceptual estimation of a center of mass has been studied extensively using dot patterns and simple geometric shapes (Friedenberg & Liby, 2008). However, less work has examined center estimation for ecologically relevant shapes such as human figures. We have extensive perceptual and motoric experience with human forms. It is of theoretical interest to see if observers are as accurate with these biological forms and whether their estimates are biased by the same factors found in the literature. In this experiment, sixty undergraduates judged the perceived centers of male and female human figures with limbs extended to the left or right in a variety of configurations. In this way we could manipulate the location, orientation and length of elongation axes relative to the body's main vertical symmetry axis. The outer contours of these figures were presented in black against a white background. Participants indicated their responses by drawing in a dot. Errors were measured as the distance between the true and perceived center. The orientation of the responses in terms of angular deviation from the vertical was also recorded. There was a significant main effect of limb extension both for the error data $F(17, 998) = 4.0$, $p <0.01$ and for orientation skew $F(17, 998) = 6.3$, $p <0.01$. Accuracy was best for bilateral figures where the limbs were extended symmetrically to either side while orientation response distributions were skewed away from the direction the limbs pointed. The results are discussed in terms of a dynamic balance model.

26.510 Defining an object's micro-valence through implicit measures

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Arguably all objects possess a "valence", which implies that no object is truly neutral. A valence is the affective value attributed to visual objects that is automatically activated when the object is perceived by our visual system. Objects that have previously been thought of as neutral in fact possess a weak valence, termed "micro-valence", that is, they are slightly preferred or anti-preferred. Micro-valence is likely evaluated without conscious awareness or directed attention. In order to access this system of processing we obtained a measure of micro-valence using an implicit task. We predicted that objects would show some level of micro-valence when tested implicitly. In the first experiment, participants were instructed that on each trial they should pick the item they would most want to include in their wedding registry. On any given trial, participants were simultaneously presented with four objects of the same basic category (for example, 4 wine glasses) and asked to select one. This task involved rapid selection, because the four objects were presented for 250 ms and participants were only given 400 ms to respond. This task accessed subjects' preference for a particular object, relative to others, without asking participants to explicitly rank the objects. In order to gain a measure of internal consistency across participants, the same objects were repeated in a second explicit valence task where participants were presented with all exemplars from a one basic level category and rank ordered them from positive to negative. The results confirm that there are subtle affective properties associated with individual objects. Understanding these affective properties may be helpful for understanding object perception and recognition in that these processes might be influenced by micro-valence.

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26.511 Why women wear heels: a new size illusion?

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It is commonly said that tall people look thinner. We asked whether an illusion exists such that the taller of two equally wide stimuli looks thinner, and conversely whether the thinner of two equally tall stimuli looks taller. Participants were randomly assigned to one of four experimental conditions: (1) to judge the horizontal extent of two identical bodies that only differed vertically; (2) to judge the vertical extent of two identical bodies that only differed horizontally; (3) to judge the vertical extent of two images, one of the entire body and the other of half a body; and (4) to judge the vertical extent of two rectangles that only differed horizontally. In all conditions we found a misestimation of the dimension that was not varied. Specifically, subjects judged (1) the taller of two bodies with the same horizontal extent as being narrower on 80.71% of trials (no illusion would result in the taller body being chosen on 50% of the trials); (2) the narrower of two bodies with the same vertical extent as being taller on 72.02% of trials; (3) half a body with the same vertical extent as the entire body as being taller on 56.25% of trials; and (4) the narrower of two rectangles with the same vertical extent as being taller on 58.57% of trials. These data confirm the folk wisdom that being thin makes you look taller and being tall makes you look thinner. The results with the rectangle stimuli suggest, however, that this illusory effect is a more general perceptual phenomenon rather than specific to bodies. We tentatively interpret this effect as a kind of "area constancy": if two identical images differ on one dimension, then they must also differ on the other in order to maintain a constant area.

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26.512 Motion Context Modulates Backward Masking of Shape

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Backward masking is the reduction in the visibility of a shape (target) when followed closely by another pattern (mask). Recent research has focused on the modulation of masking by spatial attention and gestalt influences, suggesting that backward masking occurs as a natural consequence of the object formation and updating processes that occur whenever the visual system is confronted with rapidly changing input (Enns, Lleras & Moore, 2009).

Here we study how backward masking of shape is influenced by a motion sequence, comprised of visible shapes that precede and follow the masked target. On each trial, the target (34 ms shape, 34 ms blank, 34 ms mask) was

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preceded and followed by visible shapes (102 ms). Critically, the first and last shapes combined with the masked target to form (a) a linear motion path, (b) a curved motion path, or (c) incoherent motion. Participants discriminated between three possible masked target shapes under three different levels of mask intensity.

Visual sensitivity was strongly influenced by the motion sequence, with much greater visibility when the target shape was consistent with a linear motion path than with a curved or incoherent path. Increased mask intensity also reduced target visibility more strongly for curved and incoherent paths than for linear motion. More detailed analyses will quantify the unique influence of the preceding and subsequent context shapes on target visibility.

This methodology is offered as a new way to study the influence of spatial-temporal context on shape perception. Experiments are underway to extend it to speeded action tasks involving either indirect responses (i.e., key presses) or direct manual actions to the objects in motion (i.e., finger pointing).

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26.513 Chinese character recognition is limited by overall complexity, not by number of strokes or stroke patterns

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Purpose. Strokes in Chinese characters can sometimes be grouped into identifiable stroke patterns. Are Chinese characters recognized holistically, by strokes or stroke patterns? Here we address this question by studying recognition efficiency for Chinese characters of different overall complexities, number of strokes or number of stroke patterns. Methods. Three normally sighted young adults participated in each of the three experiments. Stimuli were Chinese characters categorized into three groups, four characters each, according to (1) perimetric complexity, (2) number of strokes, and (3) number of stroke patterns in Experiments 1, 2 and 3 respectively. Perimetric complexity was defined as perimeter2/ 'ink' area. Average complexities for the three groups in Experiment 1 were 198.9, 272.1 and 335.5. In Experiments 2 and 3, perimetric complexity was controlled across the three groups. Observers performed a 4AFC task with the character presented in uniform grey background or Gaussian noise (sigma = 75% of background luminance) for 200ms. Contrast thresholds for 62.5% accuracy were measured by method of constant stimuli with five RMS contrast levels. Human performance was compared to an ideal observer model to calculate efficiency. Results. Average recognition efficiencies were 39.99%, 8.09% and 2.95% for low, medium and high complexities; 1.64%, 1.71% and 1.35% for 11–12 strokes, 14–15 strokes, and 17–19 strokes; 1.14%, 1.24% and 1.01% for 2-pattern, 3-pattern, and 4-pattern groups respectively. Recognition efficiency of Chinese characters decreased as a function of characters' complexity, not of their number of strokes or stroke patterns. Conclusion. Chinese character recognition efficiency was limited only by characters' overall complexity, but not by number of strokes or stroke patterns. The results suggested strokes or stroke patterns were not the component features of Chinese characters. Previous findings supporting strokes or stroke patterns as featural components in Chinese characters may be confounded by characters' overall complexity.

26.514 Spatial Frequencies Mediating Music Reading

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The purpose of this study was to examine Spatial Frequencies (SFs) mediating music reading compared to text reading. The SFs Bubbles technique (Willenbockel et al., 2009), which consists in randomly sampling multiple SFs simultaneously on each trial, was used. A set of 70 piano excerpts selected from the unfamiliar piano repertoire was used for music reading and 50 sentences from MNRead Acuity Charts were used for text reading. The visual size of each letter and note was about 0.34°. Five pianists and five naïve observers took part in the experiments. The percentage of correctly produced pitches and 'ascii code' was used as a performance measure for music and text reading respectively. To find out which SFs drove the participants' correct responses for music and text reading, a multiple linear regression was performed. A statistical test (Chauvin et al., 2005) was then used to determine thresholds that selected the diagnostic SFs for accurate performance. The music reading results showed a significant SFs band (from 1 to 1.7 cycles per note (cpn)) peaking at 1.19 cpn, compared to two SF bands for text reading: the first SFs band (from 1.08 to 1.3 cycles per letter (cpl)) peaking at 1.2 cpl and the second SFs band (from 1.6 to 2.6 cpl) peaking at 1.8 cpl. In a control experiment, five new pianists were instructed to play the set of 70 excerpts, first sampled with the obtained diagnostic filter for music reading, and then without sampling. Pianist performances with the diagnostic filter (94%) were comparable (96%) to those without filtering ($P > 0.05$). The present findings show that music reading is mediated only partly by SF bands mediating text reading, which may explain why in some cases, difficulties in music reading are not necessarily accompanied by difficulties in text reading.

26.515 The Visual Perception of Correlation in Scatterplots

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A set of experiments investigated the precision and accuracy of the visual perception of correlation in scatterplots. These used classical psychophysical methods applied directly to these relatively complex stimuli.

Scatterplots (of extent 5.0 deg) each contained 100 normally-distributed values. Means were set to 0.5 of the range of the scatterplot, and standard deviations to 0.2 of this range. 20 observers were tested. Precision was determined via an adaptive algorithm that found the just noticeable differences (jnds) in correlation, i.e., the difference between two side-by-side scatterplots that could be discriminated 75% of the time. Accuracy was determined by direct estimation: reference scatterplots were created with fixed upper and lower values, and a test scatterplot adjusted so that its correlation appeared to be midway between these two. This process was then recursively applied to yield several further estimates.

Results show that $jnd(r) = k\ (1/b - r)$, where r is the Pearson correlation, and k and b are parameters such that $0 < k, b < 1$; typical values are $k = 0.2$ and $b = 0.9$. Integration yields the subjective estimate of correlation $g(r) = \ln(1 - br) / \ln(1 - b)$; this closely matches the results of the direct estimation method. As such, the perception of correlation in a scatterplot is completely specified by just two easily-measured parameters.

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Search: Neural mechanisms and behavior

Vista Ballroom, Boards 516–526

Saturday, May 8, 2:45 - 6:45 pm

26.516 Simultaneous neurophysiological measurement of perceptual and response selection stages of processing during visual search

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For centuries scientists have debated whether our brains complete perceptual processing of an object before preparing the appropriate behavioral response to it. To account for behavioral reaction time effects, some models propose that information transmission between perceptual and response selection stages of processing is discrete and that perception is completed before response selection. Other models propose that information flow is cascaded and that information begins to flow between processing stages before perception is complete. We distinguished between these models by simultaneously recording multiple electrophysiological responses that measure when attention is focused on and withdrawn from task-relevant objects and when the appropriate behavioral response to the target object begins being selected. Here we show that perceptual attention is withdrawn from target objects before the response to the stimulus is selected during visual search. This same pattern of neurophysiological results was obtained when we stressed speed over accuracy of the behavioral response. These findings show that during cognitive processing humans complete perceptual processing of target objects before preparing the correct behavioral responses to their appearance.

26.517 Neural correlates of visual search in natural scenes

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Introduction: There is growing interest in understanding the neural mechanisms mediating perception of natural scenes (Thorpe et al. 1996, Codispoti et al. 2006). Studies have demonstrated the presence of high-level task-related decision processes in natural scene categorization (VanRullen & Thorpe, 2001). Unlike previous studies restricted to limited categories including cars, people and animals, we can reliably detect the presence of arbitrary searched objects from neural activity (electroencephalography, EEG). Here we analyzed EEG signals using multivariate pattern classifiers (MVPC) to predict on a single trial basis the presence or absence of cued arbitrary objects during search in natural scenes. Method: Ten naive observers performed a visual search task where the target object was specified by a word (500ms duration) presented prior to a natural scene (100ms). Four hundred target present and four hundred absent images were presented. Observers used a 10-point confidence rating scale to report whether the target was present or absent. Results: The results revealed a positive deflection in the event-related potential (ERP) over parietal electrodes during the 300-700 ms post-stimulus time window that was larger for target present trials than absent trials ($p<0.05$). Classifier performance (area under the ROC) identifying whether the image contained the target from single trial EEG activity (ranging from 100-700 ms) was 0.69 ± 0.02 (stder). In addition, MVPC predicted reliably the trial-to-trial choices of observers (0.66 ± 0.03). Temporally windowed classifier analysis indicated that the neural activity predicting the choice of the observers was temporally distributed starting at 300 ms and sustained to 700 ms post-stimulus. Conclusion: Pattern classifiers can be used efficiently to predict the presence of arbitrary target objects in natural scenes from single trial EEG. Our analysis indicates that discriminatory neural activity is associated with late components related to observers' decision processes.

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26.518 Constancy of the functional visual field across natural scenes

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When an observer is engaged in visual search, the region within which detection of a target is possible is known as the functional visual field. The extent of this region can be affected by search conditions, such as the density of distractors in search arrays and whether eye movements are permitted [B. C. Motter and D.A. Simoni, Vis. Res., 48:2382-2393 2008]. This dependence suggests that the size of the functional visual field might also vary in search over natural scenes. To test whether this is so, observers' gaze was monitored with a video eye tracker while they searched, with free eye movements, for a neutral grey target (Munsell N7) randomly located in a natural scene presented on a calibrated colour monitor, angular subtense 17x13 deg. The mean luminance of the target was matched to its local surround. Each trial lasted one second, after which the observer signalled with a mouse whether they had detected the target, and each image was viewed a total of 260 times, with the target present in half of the trials. Five observers participated and they viewed 20 near and far natural scenes. The closest fixation made to the target during trials in which the target was undetected was used to define an upper limit on the functional visual field. A routine ANOVA suggested systematic effects of both scenes and individual observers. But there was limited variation in the actual value of the average upper limit on the functional visual field i.e. from 4.9 to 6.2 deg over observers and from 5.1 to 6.2 deg over scenes. Although a more detailed analysis of observers' search patterns revealed marked individual differences, it seems that, despite the variety of visual attributes in the scenes, the size of the functional visual field was almost constant from fixation to fixation.

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26.519 Direct Current Polarization of macaque area V4 reversibly affects saccadic reaction times in a visual discrimination task

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Purpose: Macaque area V4 is important for object identification. Lesions of area V4 affect an animal's ability to select an odd target in an array. Transcortical direct current stimulation (tDCS) is a reversible method that allows bi-directional polarization of cortex. Application of surface anodal current tends to be stimulating, increasing spontaneous firing rates, while surface cathodal current tends to suppress activity. Here we used tDCS to explore the function of area V4. Methods: A monkey was trained to perform a visual discrimination task where he had to select, with a saccade, a distinct target disc from several distracters arranged in a circular array around a fixation spot. At display onset, current pulses of 6mA with Gaussian profiles (sigma=150ms) were applied to the dura using Ag/AgCl electrodes (1mm diameter x 3mm long rod). Trials with surface positive, negative, and zero current were mixed randomly within a block. Results: The results show that application of tDCS above the dura of macaque area V4 affects the saccadic response times reversibly, on the timescale of a single trial. Response times were shorter with cathodal (surface negative) current, and were increased for anodal current. Conclusions: Thus performance in a visual discrimination task can be modulated using direct current polarization of area V4. The trial-by-trial modulation will be a useful tool for studying the function of visual cortical areas.

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26.520 Independent Influence of Luminance and Color on Saccade Initiation During Target Selection In the Superior Colliculus

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One of the main functions of the superior colliculus (SC) is to orient visuospatial attention towards behaviorally relevant stimuli on the basis of visual features such as color. However a longstanding view has held that visual activity in the SC arises exclusively from achromatic pathways. Recently we (White et al., 2009) reported evidence that the SC also receives a significant contribution from chromatic pathways, supported by the fact that the arrival time for color was significantly delayed relative to luminance. Here we explored consequences of this shift in visual arrival time on target selection processes in the SC. Monkeys were trained to perform a color-oddball search task under three conditions: 1) Isoluminance-easy ("pink" target amongst "yellow" distractors, isoluminant with the background), 2) Luminance-easy (luminance pedestal added to all items), and 3) Isoluminant-difficult (distractor chromaticity shifted closer to target chromaticity). These conditions allowed us to formulate predictions based on three parameters, visual response onset latency (ROL), neural discrimination time (DT), and saccadic reaction time (SRT). We predicted longer SRTs in the isoluminance-easy relative to the luminance-easy condition because of the delay in ROL for the former. In contrast, we predicted longer SRTs in the isoluminance-difficult relative to the isoluminance-easy condition because of reduced target-distractor discriminability for the former. Results showed that SRTs were prolonged in the isoluminance-easy relative to the luminance-easy condition due to the delay in ROL, while DT remained relatively fixed. In contrast, SRTs were prolonged in the isoluminance-difficult relative to the isoluminance-easy condition due to prolonged DT, while ROL remained fixed. The results support the idea that during search for a color singleton, task irrelevant luminance signals associated with the stimuli can directly trigger the accumulation of SC neuronal activity towards response threshold independent and in advance of the arrival of the task-relevant color component of the stimuli.

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26.521 What, when and how of target detection in visual search

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When and how do we decide whether the target is present in the scene or not? There are surprisingly few quantitative models that address this question. We propose a generative model of visual search. First, the observer obtains stimulus information (corrupted by additive white noise of variance σ) at each location and time instant. Second, information across scene locations is combined using optimal Bayesian inference to compute the instantaneous evidence for target presence in the scene (log likelihood ratio of target presence vs. absence at time t). Third, the observer accumulates evidence over time and decides 'yes' if the accumulated evidence exceeds criterion $\zeta+\Delta$, 'no' if the evidence falls below criterion $-\zeta+\Delta$, and otherwise continues to observe the scene. Δ is a criterion-shift which depends on the target frequency, and the reward for different responses. This model has only 2 free parameters (noise σ, criterion ζ), compared to many parameters in drift diffusion models.

The model can explain several search phenomena including how accuracy and RT are affected by set-size, target-distractor discriminability, distractor heterogeneity, target frequency and reward. It can capture the shape of the RT distribution in target present and absent trials for different tasks like feature, conjunction and spatial configuration search.

It explains that rare targets are missed (Wolfe et. al, 2005) because decreasing target frequency (e.g., from 50% to 2%) shifts the starting point of the decision process closer to 'no' than 'yes' criterion, leading to high miss error rates, and fast abandoning of search. Our model predicts that increasing penalties on miss errors will decrease these errors and increase RTs. We validated these predictions through psychophysics experiments with 4 human subjects.

To summarize, we have proposed a generative model of visual search that with only 2 free parameters, can explain a wide range of search phenomena.

Acknowledgement: NSF, NGA

26.522 **Covert and overt selection on visual search**

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Purpose: Two experiments were conducted to investigate the effect of covert selection (attentional selection) and overt selection (oculomotor selection) in visual search tasks when the relevant stimuli (target and distractors) were presented among irrelevant stimuli (background). Methods: In the first experiment participants were required to make a visual search for a target accompanied by a variable number of distractors (5, 10, 15) presented among a uniform background with different luminance. The target was a "+" sign with the vertical segment displaced to the right or left of the center of the horizontal segment. In half of the trials an element with the same characteristics as the target, but with the same luminance as the background and with the vertical segment displacement in the opposite direction, was presented (intruder element). Targets, distractors and the intruder element were presented in random positions within the matrix. In the second experiment the same procedure was adopted, but the relevant stimuli (target and distractor) and irrelevant stimuli (intruder and background) differed along a colour dimension with equiluminance. Reaction time and percentage of eye fixations were measured. Results: The presence of the intruder played a role during attentional selection (covert selection) and caused a reaction time cost but did not show a significant effect in oculomotor selection (overt selection), evidenced by a non-significant percentage of fixations on intruder element. Conclusions: The results support the independent selection model and are discussed in terms of stimulus-driven activity and goal-driven control on visual search.

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26.523 **Gaze capture by task-irrelevant, eye of origin, singletons even without awareness during visual search**

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The eye of origin of inputs is barely encoded in cortical areas beyond primary visual cortex. Thus human observers typically fail to perceive ocular distinctiveness - as when an item (an ocular or eye of origin singleton) is presented to one eye among a background of all other items presented to the other eye. Nevertheless, I recently showed (Zhaoping, 2008) that such singletons behave as exogeneous cues for attention. Visual search for an orientation singleton target bar among uniformly tilted distractor bars was easier (harder) if the target (or respectively a distractor) bar was also an ocular singleton. Using eye tracking (via electro-oculography or video tracking), I now confirm that this ocular singleton indeed automatically attracts gaze. Observers searched for an orientation singleton among hundreds of uniformly tilted distractor bars to quickly report whether the target was in the left or right half of the display spanning about 40x30 degrees. All bars were presented monocularly, and the gaze started at the center of the display at stimulus onset. If the ocular singleton was present, the first saccade after stimulus onset was typically directed to the lateral side of the display containing it, whether or not the ocular singleton was associated with the true (orientation-defined) target or with a distractor bar on the opposite lateral side from the target. In a second experiment using the greater accuracy of video eye tracking (albeit in a smaller display), observers had to quickly find and gaze at the orientation singleton target, an ocular singleton was present as a distractor bar in half the trials. The search display was masked once observers' gaze arrived at the target. Observers were often unable to report after mask onset whether they had seen the ocular singleton during search, even if they had directed their gaze to it.

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26.524 **Non-parametric test to describe response time and eye movement distributions in visual search**

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Visual search is one of the most common paradigms used to study attention, and the three main tasks that have emerged to study visual search include feature, conjunction and spatial-configuration. It is well documented that for the spatial-configuration tasks response times are twice as long when there is no target compared to the target present condition. Further, for both target absent and present conditions, response time increase as the number of distracters increases. The objective of the present study is to investigate two gaps in this literature. Little to nothing is known about the role of eye movements in this relationship. Second, the current statistical analyses used to study these response times rest on the assumption of a normal distribution; that is not the case for the distribution of response times in this task, which are known to be skewed. The present study measured response times, the number of fixations and fixation duration in a group of 20 adults by means of a spatial-configuration visual search task consisting of Gabor. The results indicate that eye movements are dispersed for conditions, in which the target was absent, and consistent, almost pattern like, when the target was present. Response time results varied according to the fixation maps, but fixation duration measures did not. In agreement with previous reports, we found that response time was greater in the target absent condition and increased systematically as the numbers of distracters increased. The Kolmogorov-Smirnov test showed a similar pattern of results, where the differences between the two slopes increased as the number of distracters increased, but plateau after 8 distracters. The typical slope difference, at the 50% threshold, was found to be smaller than 2:1, suggesting that the difference between target present and target absent search tasks might not be as large as previously expected.

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26.525 **Visual Similarity Predicts Categorical Search Guidance**

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How a target category is represented and used to guide search is largely unknown. Of particular interest is how categorical guidance is possible given the likely overlap in visual features between the target category representation and different-category real-world objects. In Experiment 1 we explored how the visual similarity relationships between a target category and random-category distractors affects search guidance. A web-based task was used to quantify the visual similarity between two target classes (teddy bears or butterflies) and random-object distractors. We created displays consisting of high-similarity distractors, low-similarity distractors, and "mixed" displays with high, intermediate, and low-similarity items. Subjects made faster manual responses and fixated fewer distractors on low-similarity displays than on high-similarity displays. In mixed trials, first fixations were more frequently on high-similarity distractors (bear=49%; butterfly=58%) than low-similarity distractors (9%-12%). Experiment 2 used the same high/low/mixed similarity conditions, but now these conditions were created using similarity estimates from a computational model (Zhang, Samaras, & Zelinsky, 2008) that ranked objects in terms of color, texture, and shape similarity. The same data patterns were found, suggesting that categorical search is affected by visual similarity and not conceptual similarity (which might have played some role in the web-based estimates). In Experiment 3 we pit the human and model estimates against each other by populating displays with distractors rated as similar by: subjects (but not the model), the model (but not subjects), or both subjects and the model. Distractors ranked as highly-similar by both the model and subjects attracted the most initial fixations (31%-41%). However, when the human and model estimates conflicted, more first fixations were on distractors ranked as highly-similar by subjects (28%-30%) than the highly-similar

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distractors from the model (14%-25%). This suggests that the two different types of visual similarity rankings may capture different sources of variability in search guidance.

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26.526 Graphical comparison of means in within subject designs

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In vision sciences it is common to have study designs with many within subject conditions. The data are often presented in bar graphs with standard error bars. Non-overlapping standard error bars do not necessarily mean statistically significant difference. Similarly, overlapping 95% confidence intervals do not necessarily mean lack of a significant difference. We reviewed the literature that suggests a confidence interval can be derived that allows comparison between all means on a single chart. We then provide a simple graphical method in Excel that uses stacked bar graphs to create 84% confidence intervals in which non-overlapping bars are significant at an unadjusted p<.05. The bars can also be constructed using a Bonferonni adjustment considering (n-1)! comparisons. As an example we provide the results of a reaction time detection task using PowerPoint slides with 8 emphasis conditions (Bold, Italic, Underline, CAPS, red, yellow, green, blue) on 3 backgrounds (white, black, dark blue). We propose a method of estimating the standard error from the output of a maximum likelihood mixed model analysis of variance (SPSS 17, IBM Corp). Specifically we perform a one way analysis of variance and use the largest standard error of the differences (SED) from the paired comparisons output. The SEM is estimated as the square root of SED2/2. SEDs vary across comparisons if there is missing data, so our estimate uses the largest value. The degrees of freedom are n-1. The non-overlapping bars are virtually identical to the ANOVA paired comparisons. Because our example had heterogeneity of variance across groups, we also estimated the means and standard errors directly with a Bayesian Monte Carlo Markov Chain analysis (AMOS 18, IBM Corp) and computed the same confidence interval. In this example both analyses provided very similar results.

Search: Attention

Vista Ballroom, Boards 527–545

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26.527 Top-down and bottom-up controls in visual search: Evidence from a large task-irrelevant salient distracter

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In this study we explore how a salient line irrelevant to the task affects visual search. The search display was a lattice of regularly spaced short horizontal bars covering the entire screen. The target was a small oriented gap in one of the bars, always located on the same horizontal line in the middle of the display. The task was to discriminate a leftward vs. rightward slant of the gap. The salient line was formed by rotating the texture bars in one vertical column by 90 deg. It thus was orthogonal to the texture. The location of the target and salient line varied independently from trial to trial. Therefore the salient line did not predict target location. Reaction time was used as a dependent variable. In Experiment 1, a target presented directly on the salient line was discriminated less quickly and less reliably, suggesting that the salient line impaired visual search. In Experiment 2, the impairment caused by the salient line became progressively less by decreasing the line length. The impairment persisted, however, even when the salient line was shortened to a single vertical bar. In Experiment 3, the salient line continued to impair visual search despite extensive practice. In Experiment 4, the salient line actually facilitated visual search when it was defined by color, rather than orientation. Both the length and practice effect suggest that the search was, in part, under bottom-up control, whereas the facilitation due to color suggests a top-down effect on target detection.

26.528 Guidance of Attention During Visual Search: Can Multiple Attentional Templates Operate Concurrently?

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Previous research has demonstrated that monkeys and humans can form an attentional template in visual working memory (VWM) that specifies the features of a target and can be used to guide attention toward matching items. VWM has a capacity of 3-4 items and could presumably store multiple templates, but it is not clear whether multiple VWM representations can simultaneously guide attention. To test this, we recorded eye movements during a visual search task in which observers searched for a Landolt-C target in an array containing 32 items, with 8 in each of four colors: red, yellow, green, and blue. A cue indicated which two colors might be the color of the target; observers were instructed to either search one color and then the other, or to search both colors simultaneously. Some of the cue color pairs were more similar in hue (e.g., red-yellow) and others were dissimilar (e.g., red-green). Searching for two similar colors could potentially be achieved by means of a template with a single intermediate color. When instructed to search one color at a time, observers exhibited no RT difference between similar and dissimilar color pairs, indicating that only one template was active at a time. However, when participants were instructed to search the two cue colors concurrently, RTs were longer when they searched the dissimilar color pairs than the similar color pairs, and they were more likely to direct gaze toward items that were not one of the two possible target colors. Thus, it is difficult (although not impossible) to simultaneously use two templates to guide attention.

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26.529 Further evidence on dimension-specific lateral inhibition in visual search

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Last year, we reported preliminary evidence that suggests that representations of neighboring search items on the same perceptual dimension inhibit each other (Chan & Hayward, VSS 2009). This year, we report further results from 4 experiments to strengthen and refine this notion. To tease apart a distance effect from a hemifield effect, we always put the target and the singletons in the same hemifield. We studied dimension-specific spatial interaction between two 'special' search items – a target and a singleton in Experiments 1 and 2, and two singletons in Experiments 3 and 4, by manipulating inter-item distance. For the target-singleton experiments, since mutual inhibition between target and singleton reduces target signal, search should be slowed and result in a stronger "attentional capture". For the two-singleton experiments, mutual inhibition between singletons reduces their distractions, causing a weaker capture. As such, inter-item inhibition can be measured in terms of capture. In the experiments, we found stronger signs of mutual inhibition for close items than for mid/far items, when they were defined by the same dimension. No such signs were found for different-dimension items. This confirms that lateral inhibition occurs on a dimension-specific map. However, even at mid/far distances where lateral inhibition was at floor, capture was still larger for two singletons of different dimensions. This suggests that the lack of spatial inhibition across dimensional maps is not the only reason that two singletons of different dimensions produce stronger capture. We speculate that non-spatial dimension-specific inhibition also takes place, so that signals of irrelevant dimensions are inhibited. However, inhibition is limited to one dimension at a time, and so is not effective for avoiding capture from two dimensions simultaneously.

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26.530 Inhibitory tagging of individual items is only found in very difficult visual search tasks

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Several theories and models of visual search assume that search efficiency is improved by the use of inhibitory tagging. Hulleman (2009) found no difference in search slopes between search amongst static items and amongst moving items. So, if there is indeed inhibitory tagging of items, it would seem that the tag travels with the item. This hypothesis was tested in two experiments. In the first experiment, where participants had to search for a T amongst L's, there was again no difference between search amongst static (0.0 deg/s) and amongst moving items (7.2 deg/s) in either search slopes or error rates for displays with up to 36 items. In the second experiment participants searched for a square with a notch in the top left corner amongst squares with a notch in one of the other corners. This is a very difficult search task. Although search slopes for static (0.0 deg/s) and for moving (7.2 deg/s) item displays were again very similar, there was now a clear difference in error rates: there were more errors for the moving items. Critically, the maximum display size in this experiment was 18 items; only half the size used in the first experiment. Taken together, these two experiments suggest that there is a fundamental difference in the processes involved in very difficult visual search tasks on the one hand and easier visual search tasks on the other. Whereas the former operate at an item by item level, with only limited robustness against motion, the latter operate above the level of individual items and offer extensive robustness against motion. A theoretical framework that encompasses these findings will be presented.

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26.531 **Independent and additive effects of repetition of target and distractor sets in active visual search**

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Priming of pop-out is a well known phenomenon in the literature on visual attention, where the repetition of features from a previous trial facilitates a response to the same feature on the next trial. While such effects have mostly been studied by measuring key-press responses, priming from target repetition has also been found to facilitate saccadic eye movements to targets containing repeated features. Much less studied is priming from repeated context, or distractor-sets. Priming of context is presumably driven by inhibition mechanisms speeding rejection of non-targets. In order to investigate any facilitatory effects of target and context repetition upon latencies of saccadic eye movements, and any interactions between the two, we measured saccades in a color-singleton task where the target color and the color of the distractors varied independently of one another. The task was an "active" visual search where observers had to make a speeded saccade to the center of the singleton target. Repetition of target color and distractor-set color both resulted in decreased saccadic latencies, but the effect was larger for repetition of context than target. In contrast, target repetition had a larger effect upon search accuracy. Because of these discrepancies we calculated inverse efficiency (saccadic latency/percentage correct) to control for possible trade-offs between latency and accuracy. The inverse efficiency analyses showed highly significant effects of repetition of both target and context, with no hint of an interaction between the two. The tight link between attention shifts and eye movement preparation is well documented, and our analyses of priming show that the repetition of both target and distractor-sets has a strong influence upon attention shifts and eye movements and that these effects are independent of one another.

Acknowledgement: University of Iceland Research Fund

26.532 **Prediction prevents rapid resumption from being disrupted after the target's location has changed**

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Recent studies of rapid resumption (RR)—an observer's ability to quickly resume a visual search after an interruption (Lleras, Rensink and Enns, 2005)—suggest that implicit predictions underlie visual perception (see Enns and Lleras, 2008) because observers seem to construct implicit predictions about what information they expect to see after each interruption. The nature and content of a prediction (or perceptual hypothesis) can be explored by subtly changing the information to be presented after an interruption. Changes to the target's relevant features such as location and identity disrupt RR (Jungé, Brady and Chun, 2009; Lleras et al., 2005, 2007). These findings suggest that if the perceptual hypothesis about the target cannot be confirmed, processing of the display (and the target) must start anew when the display reappears, leading to slower response times. Here, we manipulated the location of the target between looks at the display to investigate whether predictable changes in location could be learned by observers and thereby incorporated into the test and confirmation of the perceptual hypothesis. Specifically, in a subset of trials (location-change trials), on each presentation of the search display targets cycled through a set of 5 predetermined locations, either in clockwork fashion (Experiment 1) or jumbled (Experiment 2) fashion, although the starting location in the sequence changed from trial to trial. On control trials, the target did not change location between presentations. Both experiments showed significant RR in the control condition. Interestingly, we obtained significant RR on location-change trials and this effect increased throughout the experiment, suggesting that sequence learning occurred and was slowly incorporated into the testing of perceptual hypotheses. These findings confirm that an interrupted visual search can be rapidly resumed even if the content of the hypothesis has changed, when the observer is given the possibility to predict the forthcoming change.

26.533 **Perceptual load corresponds to known factors influencing visual search**

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One recent account of the early versus late selection debate in attention proposes that perceptual load determines the locus of selection. Attention selects stimuli at a late processing level under low-load conditions but selects stimuli at an early level under high-load conditions. Despite the successes of so-called 'load theory,' the notion of perceptual load remains poorly defined. We investigated the factors that influence perceptual load by using manipulations that have been studied extensively in visual search, namely target-distractor similarity and display heterogeneity. First, using visual search, we examined the search slopes as participants discriminated two target letters. Consistent with previous work, search was most efficient when targets and distractors were dissimilar and the displays contained homogeneous distractors; search became less efficient when target-distractor similarity increased and when the displays contained heterogeneous distractors. Importantly, we next used these same stimuli in a typical perceptual load task that measured attentional 'spill over' to a task-irrelevant flanker. We found a correspondence between search efficiency and perceptual load; stimuli that generated efficient searches produced flanker interference effects, suggesting that such displays involved low perceptual load. Flanker interference effects were reduced in displays that produced less efficient searches, and both high target-distractor similarity and heterogeneous displays were required to abolish flanker effects. These results suggest that 'perceptual load' might be defined in part by well-characterized factors that influence visual search.

26.534 **Modulating the attentional saliency of object onsets in natural scenes**

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One of the most powerful events for capturing a viewer's attention and gaze is the appearance of a new object in the visual scene: attention and gaze shifts to the new object's location occur within 100-200 ms after object appearance. Previous research has identified determinants of this capture effect at various levels of the visual processing hierarchy: the transient associated with the onset, the appearance of new contours, the appearance of a new spatio-temporal entity, semantic category membership of the object, and semantic object-scene consistency. That immediate attentional capture by object onsets can be influenced by semantics is a controversial issue, and the purpose of our present set of studies was to determine whether this controversy might be resolved by looking at attentional capture effects from a fixation-contingent perspective. Specifically, is it possible that the attentional effect of object onsets is determined in the interplay of feed-forward feature analysis and re-entrant object recognition processes, and that the relative contribution of these two processing streams is modulated by the object's peripheral position, its visibility, and its time of appearance relative to the position and duration of the current fixation? We report a series of eye-tracking experiments in which latency of oculomotor reactions to object onsets is examined as a function of the object's categorical and contextual semantics, its eccentricity, contrast, orientation and time of appearance relative to the ongoing fixation. In addition, to determine whether object onsets have a special attentional status, onset effects were compared against effects of unobtrusive attentional cues presented inside of critical objects that were present throughout the scene's exposure. Attentional capture by object onsets was shown to be shaped by an interaction of featural, semantic, positional and temporal properties of the object onset thus documenting the existence and the boundary conditions of semantically modulated attentional capture.

26.535 Saliency enhances perceived contrast but degrades detection

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Numerous studies have shown that saliency has a large influence on visual search. In contrast, very little is known about how salient objects are perceived in typical search displays. We measured the perceived contrast of a Gabor stimulus that either had the same orientation as the surrounding distractors or a different orientation. Observers were shown a circular array of eight Gabors and two Gabors were marked as relevant. The task was to judge which of the Gabors in the marked locations had a higher contrast. We observed that the perceived contrast of Gabors with a contrast different from the context increased slightly. In another experiment, we investigated whether contrast enhancement, which we observed for above-threshold Gabors, would help observers to determine the location of a Gabor at contrast threshold. Observers were asked to indicate the position of the Gabor in one of two marked locations while the same six task-irrelevant Gabors as in Experiment 1 were shown. We found that it was more difficult to localize a Gabor that had an orientation different from the surrounding Gabors. Saliency may harm detection for stimuli at threshold while boosting contrast of above-threshold stimuli.

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26.536 Real-world Statistical Regularities Guide the Deployment of Visual Attention, Even in the Absence of Semantic Scene Recognition

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Previous research has shown that the contextual information in real-world scenes helps guide visual attention when searching for a target within the scene (Torralba et al., 2006). However, it is unknown whether such contextual guidance can occur in the absence of semantic scene recognition. To address this question, we generated texture patterns that were unrecognizable as real-world scenes, yet preserved the statistical regularities of real-world scenes (i.e., the global pattern of orientation and spatial frequency information). In each texture, we imbedded the image of a pedestrian at a location where a pedestrian was likely to appear with either a low probability or a high probability (based on an independent set of rankings using the original, real-world images). On each trial, observers were instructed to locate the pedestrian and indicate, as quickly and accurately as possible, the direction in which the pedestrian was facing. Response times for the high probability trials (M = 1989 ms) were reliably faster than the low probability trials (M = 2593 ms) ($t(8) = 7.09$, $p < .001$). This difference could not be explained by differences in absolute screen position: the low-probability and high-probability locations were matched across images (i.e., the low-probability location for one image was the high-probability location for another). This difference also could not be explained by differences in local visibility, because a control experiment showed that when the background is erased, except for a local window around the pedestrian, there was no difference in reaction time for high and low-probability locations ($p > .05$). Thus, the advantage for the high-probability locations arises from the global context of a particular image. Combined, these results suggest that the statistical regularities of real-world scenes can guide the deployment of visual attention, even in the absence of semantic scene recognition.

26.537 Knowing what not to look for: Difficulty ignoring irrelevant features in visual search

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Foreknowledge of target-relevant information can be used to guide attention in visual search. However, the role of ignoring in visual search - that is, having foreknowledge of information related to nontargets - remains relatively unexplored. In a recent paper, Munneke et al. (2008) demonstrated that participants could ignore the location of an upcoming distractor if that location was cued prior to the display. In a series of experiments using a similar design, we explored whether participants could ignore a specified feature. Participants were asked to identify which of two possible uppercase letters was present in a display consisting of four differently colored letters. On "Distractor-Cued" trials, participants were also told that the target would not be a specific color (e.g. "ignore red"). Participants were unable to successfully use these cues to speed search - in fact, they were slower to find the target on Distractor-Cued Trials even though the cue contained relevant information and was 100% valid. We also measured compatibility effects of the cued distractor (a lowercase letter either compatible or incompatible with the target). There were stronger compatibility effects on Distractor-Cued Trials later in the experiment, suggesting that participants were not learning to suppress the irrelevant feature. Taken together, these data suggest that while knowing where not to look facilitates visual search (Munneke et al., 2008), knowing what not to look for hinders visual search. In subsequent studies we show that while establishing an attentional set to ignore a feature prior to a given trial results in less efficient visual search, if a set is established, search can be more efficient when the to-be-ignored feature appears than when it doesn't. This is consistent with Woodman and Luck's (2007) "template for rejection." Ongoing experiments are investigating whether there are cases for which knowing what feature to ignore facilitates visual search.

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26.538 Probabilistic information influences attentional process

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Purpose: Resent studies in visual attention have reported that attention is guided by the probabilistic information including the experimental tasks. In addition, some of these studies have suggested that the probability of the target appearance is available as an attentional cue without explicit knowledge regarding the probabilistic information. It is, however, unclear what kind of information participants can exploit as an attentional cue. In the present study, we investigated whether the probabilistic information implicitly defined by spatial location or symbolic cue was available for participants. Methods: Participants were conducted the visual search task. They were instructed to discriminate the target orientation presented in the left or right placeholder as quickly and accurately as possible. In the experiment 1, the spatial probability of the target appearance was manipulated. In 60% of trials, target stimuli were presented in one placeholder (high probability condition), in 20% of trials, they were in another placeholder (low probability condition), and in the rest of 20% trials, no target stimuli were presented. In the experiment 2, cue validity was manipulated. The cues were colors of the center fixation. In 60% of trials, the color cues were valid (valid condition), in 20% of trials, the cues were invalid (invalid condition), and in the rest of 20% trials, no target stimuli were presented. Results & Conclusion: In the experiment 1, the target discrimination in the high probability condition was faster than the low probability condition. On the other hand, in the experiment 2, there is no difference in the reaction times between valid and invalid condition. These results suggest when probabilistic information is defined by spatial locations, it leads attentional guidance despite that participants do not notice the information. In contrast, when probabilistic information is defined by symbolic cues, it does not lead attentional guidance.

26.539 Bound to guide: A surprising, preattentive role for conjunctions in visual search

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According to Guided Search (and similar models), features are only conjoined once an object is attended. This assertion is supported by many experiments: e.g. conjunctions of features do not pop-out in visual search and observers are poor at judging proportions of different types of conjunctions in displays. Thus, observers appear to be insensitive to the preattentive conjunctions of features. Now, consider two versions of a triple conjunction search for red, vertical rectangular targets among distractors that could be red, green, or blue; vertical, horizontal, or oblique; and rectangular, oval, or jagged. In one condition, all 26 possible distractor types are present on each trial (set sizes: 27 and 54). In the other condition, only three distractor types are present (e.g., red oblique ovals, jagged green verticals, and blue horizontal rectangles). Critically, in each condition, each feature is evenly distributed in the display: i.e. 1/3 of items are red, 1/3 green, 1/3 blue, and similarly for orientation and shape. Since the preattentive feature maps are identical in both conditions, search performance should not differ. However, RTs are faster for the condition with only three distractor types (Grand means: 625msec vs. 835msec). How can we explain this? Perhaps the easier search was done by selecting one feature (e.g. red items) and looking for an oddball in that subset. However, in a control experiment, when the target was defined as the oddball in the otherwise

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homogeneous red subset, search was ~200msec slower than in the three distractor condition. Alternatively, it may be possible to reject groups of identical items even if the group is defined conjunctively. Regardless of the explanation, these data show that the preattentive conjunction of basic features speeds search even though explicit appreciation of conjunctions requires attention.

26.540 **Spatio-temporal mapping of exogenous and endogenous attention**

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The spatial distribution and the temporal dynamics of attention have been studied countless times. Although these two factors are well understood in isolation, their interaction remains much less clear. How does the shape of the attentional focus evolve across time? To answer this question we measured a quantitative space-time map of both endogenous and exogenous attention in humans. To sample attention effects in the space-time domain we tested the visibility of a low contrast target presented at different distances and delays from a cue in a noisy background. For exogenous attention we used a non-informative high-contrast peripheral cue at a random location 5° from fixation. In the endogenous condition we used a central informative arrow cue pointing left or right. We sampled the spatial domain as the Euclidean cue-target distance, locating the target randomly on the screen in the exogenous condition, and randomly along the horizontal midline in the endogenous condition. As an indirect measure of attention, we determined, for each distance and delay from the cue, the background contrast compensation required to keep performance at 75% (adjusted with a staircase procedure). After more than 94,000 trials in 13 subjects, the space-time mapping of exogenous attention revealed a progressive enhancement from 50 to 275 ms, extending up to 8° from the cue. Endogenous attention maps (over 40,000 trials in 8 subjects) showed an early (100 ms) enhancing effect centered on the cue, with a later deployment at the cued side peaking between 8 and 10° at 400 ms after cue onset. Finally, we measured the interdependency between the spatial pattern of visual attention and its temporal dynamics: most of the data could be explained by a constant spotlight shape, independent of time. Our results represent the first detailed space-time maps of both endogenous and exogenous visual attention.

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26.541 **The Dynamics of Top-Down and Bottom-Up Control of Visual Attention during Search in Complex Scenes**

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The interaction of top-down and bottom-up control of visual attention is of central importance for our understanding of vision, and most of its extensive study has employed the paradigm of visual search. However, little is known about the dynamics of top-down and bottom-up mechanisms during demanding search tasks in complex scenes that guide our attention so efficiently in everyday situations. Here, we present and apply a novel method to estimate the time course of visual span, that is, the area around gaze fixations from where visual features can exert top-down or bottom-up control of attention. The method assumes that a larger visual span allows larger areas of relevant information to attract eye movements for its inspection within a single, central fixation (center-of-gravity effect, Findlay, 1982). Indeed, the distribution of gaze fixations can be predicted by convolving the distribution of relevant information with a Gaussian kernel whose size matches the visual span (Area Activation Model, Pomplun et al., 2003). In this study, we computed separate top-down (Hwang et al., 2009) and bottom-up saliency maps (Itti & Koch, 2001) for 160 real-world search displays and convolved each of them with Gaussian kernels of different sizes. Those sizes that resulted in the best predictors of the positions of 15 subjects' search fixations were taken as estimates of visual span. We used this method to estimate the strength and visual span of top-down and bottom-up control of attention by display features during different phases of the search process. Top-down control was found to be weak initially but to quickly dominate search while narrowing its focus, whereas bottom-up control revealed slowly diminishing influence and a constantly large visual span. These results suggest that, throughout the search process, accumulating scene knowledge determines the dynamics of attentional control, which is not reflected in current models.

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26.542 **The salience of absence: when a hole is more than the sum of its parts**

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An item can be conspicuous against a uniform background either by possessing a feature other items lack, or, typically to a lesser degree, by lacking a feature the others share. It has always been assumed that the conspicuity of feature absence arises from the saliency at its location. However, if the salience of a location is determined by the largest neural response from primary visual cortex (V1) that it inspires, as suggested by a recent theory, then the only way an absence or a hole could become conspicuous is if the saliency of its surrounding stimuli attracts attention to its vicinity (Li, 2002); it would lead to no V1 activity by itself. Specifically, the absence of input at the hole reduces suppression of the V1 responses to the stimuli surrounding it, in a way that depends on spatial- and feature-specific suppression between nearby V1 neurons, making the surrounding stimuli more salient. If this enhanced saliency of the surround determines the conspicuity of the hole, then altering the visual input strength to those surrounding stimuli should alter the reaction time (RT) for finding the hole in a visual search task, in a way that is predictable from V1 interactions. We test this prediction by measuring observers' RTs for finding a target among distractor crosses when the target consists of just one of the two bars of a cross. When the target bar has sufficiently low contrast, the RT does not increase when its contrast is reduced further, indicating that the V1 response it evokes is immaterial to its conspicuity. Meanwhile, changing the contrast of various bars in the surrounding crosses alters the RTs according to the feature and spatial specificities of V1 interactions. The saliency of a hole may only be a subsequent impression inferred from our perceptual experience.

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26.543 **Performance Costs and Benefits for Simultaneous Dynamic Events in Visual Search**

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Attention capture is not only measured in terms of reaction time (RT) benefits to find a certain target, but also in terms of RT costs produced by certain distractors. Thus, one would expect that if the number of such distractors is systematically increased, RT costs would be even higher. The present study looked at cumulative interference effects from multiple dynamic events on target detection. In Experiment 1 the search display consisted of a combination of static, abrupt-onset (onset) and moving items which could all be target or distractors with an equal probability. In line with previous studies, participants were faster when the target was an onset than when it was a static item and slowest when it was a moving item. Surprisingly, the type of distractor(s) did not have any effect on search performance nor did it depend on the type of target. In Experiment 2, motion was replaced by an onset of motion (motion-onset). Based on previous studies (Abrams and Christ, 2003), which have shown that motion-onset captures attention, we expected that the competition between onset and motion-onset items would lead to a distractor-type effect. Again, motion-onset targets did not capture attention, and there was no effect of distractor type. In Experiment 3, the display size was increased from three to eight items and the number of onsets was systematically varied between zero and eight. Results showed the typical advantage for onset targets in comparison to static targets. Furthermore, RTs to an onset target increased as a (power) function of number of onsets, while RTs to a static target were unaffected by the number of onsets. Thus, the cost of having multiple onset distractors did occur with eight-item, but not with three-item displays, suggesting that a limited capacity bottleneck might be involved in the attentional prioritization process.

26.544 **Neural mechanisms underlying active ignoring in the ageing brain**

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Saturday PM

There is evidence to suggest that we actively ignore information that is irrelevant to our current goals. This is demonstrated using the preview search paradigm. Here half of the distracters in a visual search task are presented briefly before the addition of the remaining distracters (and target) to the display. Results for young adults show that the time taken to find the target in these "Preview" trials is reduced in comparison to a "Full" condition where all distracters are presented simultaneously. This preview benefit suggests that observers exclude the previewed distracter items from search. fMRI studies reveal enhanced neural activation in posterior parietal cortex in response to preview trials, reflecting a distinct active ignoring process.

Ageing is associated with various cognitive costs including the ability to inhibit processing. Thus, older adults may show less preview benefit because they are unable to ignore the previewed items. There is some evidence that older adults do not benefit from the preview display in a similar manner to young adults. A key aim of our study was to compare neural activation during active ignoring between old and young participant groups to investigate how ageing affects ignoring. We found that old (M = 71.8 years) and young adults (M = 21.8 years) who demonstrated a clear behavioural preview benefit showed similar areas of neural activation to each other. Contrasting preview trials against full trials revealed activation in the precuneus and superior parietal lobule (SPL), areas consistently activated in previous fMRI studies with young adults. Furthermore, activity in the SPL was significantly greater for older adults. These results show that 1) older adults are able to ignore previewed distracter items and, 2) the function of the posterior parietal cortex, an area implicated with distracter suppression, can be retained in older adults.

26.545 The effects of feature preview history and response strategy on inter-trial suppression of selective attention

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In a color-oddball search task, when a target's color in the current search display has been passively viewed in a preceding target-absent display (TAD), the response time (RT) to the target is slower than when the distractor's color in the current search display was passively viewed. The RT difference between the target-color preview and the distractor-color preview is known as distractor previewing effect (DPE). Four experiments were conducted to investigate the effects of target appearance predictability on the DPE by distributing trials in a blocked and a random fashion, in which the number of TAD presentations was fixed and varied within each block, respectively. Simultaneously, we examined history effects of multiple previews of target and distractor features (ranging from 0 to 2 in Exps. 1A and 2A; from 0 to 5 in Exps. 1B and 2B) on target response in the blocked (Exps. 1A and 1B) and random (Exps. 2A and 2B) designs. For the consecutive 2 TAD presentations a single (target or distractor) color was repeated twice, or target and distractor colors were alternated prior to the search display in Exps. 1A and 2A. In Exps. 1B and 2B, either a target or a distractor (not both) color was repeated in consecutively presented TADs. We found: (a) the size of the DPE increased as the number of TADs increased, with that increase more consistent in the random than in the blocked design; (b) the DPE occurred in both the 2 and 1 TAD conditions in the blocked design, but only in the 2 TAD condition in the random design; (c) the color previewed in the immediately preceding TAD (i.e.,one-back) influenced the RT more than the color in the two-back. These results demonstrate cumulative history effects with more emphasis on recent events and top-down response strategy on target selection.

Spatial vision: Mechanisms and models

Vista Ballroom, Boards 546–557

Saturday, May 8, 2:45 - 6:45 pm

26.546 Locating the functional vertical midline with a motion probe

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The vertical midline splits the visual fields into two halves that are represented in contralateral hemispheres. While space is retinotopically encoded across most visual areas within each hemisphere, the vertical division between hemifields necessarily disrupts this topological organization. We are interested here in measuring the functional consequences of the vertical split. In particular, we investigate how crossing the vertical midline impairs motion sensitivity.

Observers were engaged in a motion speed change detection that occurred midway along the trajectory of a rotating dot. Two dots diametrically opposed on a virtual circle travelled each a quarter of the circle. Only one of the dots changed speed for a brief duration and observers had to report which dot presented the speed change (the one above or below fixation). The speed change could occur just before or just after the dot crossed the vertical midline. Viewing was monocular.

Observers were significantly worse in detecting the speed change when it occurred after crossing the midline than before. In addition, the range over which motion sensitivity was impaired increased with the speed of the stimulus.

On the theoretical side, the loss of motion sensitivity after the vertical midline possibly reflects an impairment to predict the future location of the moving dot, or an impairment to communicate this prediction across hemispheres. On the practical side, this phenomenon is useful to estimate the location of the functional midline and to determine the extent to which the area around the vertical midline is represented in both hemispheres.

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26.547 Modeling the representation of location within two-dimensional visual space using a neural population code

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Although the representation of space is as fundamental to visual processing as the representation of shape, it has received relatively little attention. Here we develop a neural model of two-dimensional space and examine how the representation is affected by the characteristics of the encoding neural population (RF size, distribution of RF centers, degree of overlap, etc.). Spatial responses of the model neurons in the population were defined by overlapping Gaussian receptive fields. Activating the population with a stimulus at a particular location produced a vector of neural responses characteristic for that location. Moving the stimulus to n locations along the frontoparallel plane produced n response vectors. To recover the geometry of the visual space encoded by the neural population, the set of response vectors was analyzed by multidimensional scaling, followed by a Procrustes transform. The veridicality of the recovered neural spatial representation was quantified by calculating the stress, or normalized square error, between physical space and this recovered neural representation. The modeling found that large receptive fields provide more accurate spatial representations, thus undermining the longstanding idea that large receptive fields in higher levels of the ventral visual pathway are needed to establish position invariant responses. Smaller receptive field diameters degrade and distort the spatial representation. In fact, populations with the smallest receptive field sizes, which are present in early visual areas and, at a single cell level, contain the most precise spatial information, are unable to reconstruct even a topologically consistent rendition of space. Development of this neural model provides a general theoretical framework not only for understanding neurophysiological spatial data, but also for testing how various neuronal parameters affect spatial representation.

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26.548 Faster periphery and slower fovea for coherent perception

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Central vision, the fovea, is thought to be processed differently from the peripheral parts of the visual field, relying on different physiological streams. However, because usually both fovea and periphery are simultaneously stimulated, one would expect mutual modulations between the two representations in order to achieve a unified percept. We measured ERP responses to different sizes of Gabor patches, occupying from strictly foveal (0.4 degrees) to a combined foveal and peripheral parts of the visual field (up to 14 degrees). Annuli (rings produced from a Gabor with the foveal opening filled with mean-luminance background) were used to stimulate the surround. The results show 3 main components representing the foveal and the peripheral processing. 1) P1-amplitude increased with increasing

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absolute area of stimuli, similarly to our findings for increasing contrasts. Moreover, it reflected a linear summation of sensory representation of complementary center and surround stimuli. However, surprisingly, the latency showed a faster processing in periphery than in the fovea. 2) P2-amplitude showed no linear summation between the two parts. However, latency showed significant additional gains in the speed of processing for the combination of center and surround, compared to the parts in isolation, suggesting that the periphery accelerates the processing of the fovea. 3) N2-amplitude showed no linear summation, but a step change from the strictly foveal to peripheral stimulation, despite the linear shortening of latencies with increasing stimulation area. Moreover, the difference in the amplitude for the peripheral stimulus vs. the one combining both fovea and periphery support our earlier suggestions that N2 reflects lateral interactions from the fovea. Surprisingly, stimulation of periphery increases the speed of foveal processing. Our results suggest interactions between the representation of the fovea and the periphery, rather than an independent representation. Thus, faster peripheral processing compensates for spatial distance, resulting in a coherent percept.

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26.549 **Blur clarified**

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A review of the literature on blur detection and discrimination reveals a large collection of data, a few theoretical musings, but no predictive model. Among the key empirical findings are a “dipper” shaped function relating blur increment threshold to pedestal blur, as well as a nonlinear effect of luminance contrast. We have found that these phenomena and others are accounted for by a simple model in which discrimination is based on the energy of differences in visible contrast. Visible contrast is computed from the luminance waveform, as modified by local light adaptation and local contrast masking. The energy of the difference between two visible contrast waveforms, within a pooling aperture, determines threshold. This model can also predict detection thresholds for one dimensional waveforms such as Gabor signals. When fit to the ModelFest Gabors, it gives reasonable predictions for classic blur detection and discrimination data as well.

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26.550 **Extended depth of focus spectacles for full visual field presbyopia correction via brain adaptation**

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Extended depth of focus (EDOF) techniques was previously adapted for ophthalmic usage as a solution for presbyopia and astigmatism. The aim of this research is to use the brain adaptation ability in order to produce homogenous EDOF over the full visual field (VF), with EDOF engraving positioned in discrete positions in the optical system. A set of EDOF profiles was engraved every 3mm over the whole external surface of a spectacle lens. We studied 14 presbyopic patients aged 48-68 (average reading addition of 2.2 D., astigmatism of 0.50-1.00 D.). The VF was tested by examining the visual acuity at tens of random points within the VF of about 30 degrees by displaying various Snellen letters. Subjects had to identify the letters, with assigned scores from one to four for the responses: (1) identifying the letter displayed, (2) identifying a similar letter to the one displayed, (3) naming a letter not similar to the one displayed, or (4) not recognizing the letter. Results in LogMAR units: without the EDOF profile: Best corrected visual acuity (BCVA) was -0.01 and distance corrected near visual acuity (DCNVA) was 0.465. With the EDOF spectacle lens: BCVA=0.05 and DCNVA=0.079. Additionally, the EDOF lens overcame up to 1.00 D. astigmatism. Stereo perception, color vision, and contrast sensitivity remained unaffected. In 96% of the VF correct answer was recorded (category 1). In 2%, small errors were measured (category 2). In the remaining 2%, either large errors or no recognition were recorded. The high EDOF performance showed a solution for presbyopia that was obtained over the full VF, allowing good reading ability. This was achieved using brain adaptation process forcing the reader to gaze only through predefined directions that coincided with the discrete locations.

26.551 **Orientation and shape tuning of van Lier aftereffect**

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van Lier et al(2009, Current Biology) have reported an intriguing color aftereffect. They adapted observers with two differently colored, overlapping four-point stars sharing the center, but with a 45 deg relative rotation, and subsequently presented achromatic test outline of one of the stars. Perceived afterimage was stronger inside the test, and the color of aftereffect inside the test pattern extended to the central area where it was colored gray in adaptation phase. In the present study, we tried to evaluate orientation and shape selectivity of the phenomenon by using almost the same stimuli as they used. For orientation tuning, the test pattern was rotated relative to the up-right adaptor. The original phenomenon was reproduced when the adaptor and test overlapped exactly, but most observers see afterimage only within the test contour pattern. Afterimage was switched on and off altogether depending on test orientation. Similar afterimage was observed up to 15 deg of rotation, when the test pattern was rotated. Observers perceived a color afterimage including the central area that corresponds to the adaptor with nearer orientation. In addition, the after images in rotated conditions did not exactly fill-in the test contour, but it had original upright orientation with discrepancy to the rotated test contours. For shape tuning, the base width of the stars was manipulated, and similar after effects were observed up to 20% to the fatter side and more than 50% to the thinner side variations of the width of the test contour. Here again, discrepancies between afterimage and test contour similar to those found for rotation was observed. The afterimages were either thinner or fatter than test contour depending of the width relationship between adaptor and test. These results indicate that switching colors and spatial filling-in are mediated by separate mechanisms.

26.552 **Integration of visuospatial position information is modulated by retinal eccentricity and attention**

Jessica Wright[1](jessica@vision.rutgers.edu), Adam Morris[1], Bart Krekelberg[1]; [1]Center for Molecular & Behavioral Neuroscience, Rutgers University, Newark, NJ

Perception of spatial position is a basic function of the visual system, yet there are still many questions regarding how position is computed in the brain and how this information is integrated across space. The quantification of these processes is an important first step in elucidating the underlying neural mechanisms. We propose that spatial integration can be modeled as a weighted average of visual position information and that weights at particular locations in space are modulated by various factors including retinal eccentricity and spatial attention. The current study utilized psychophysical methods in human subjects to quantify the extent to which different regions of the visual field influenced performance on a centroid estimation task. Subjects located the centroid of briefly presented one-dimensional and two-dimensional arrays of dots positioned randomly within a large region of the visual field. To probe the effects of endogenous and exogenous spatial attention, a central or peripheral cue was used to bias attention toward one side of the display. Using statistical models, we generated maps of weights that described the influence each region of the visual field had on the centroid determinations in each of the conditions. The data suggest that 1) subjects estimate centroids reliably, but with some degree of idiosyncratic bias; 2) spatial locations are not utilized equally when determining the centroid, with most subjects prioritizing foveal regions over peripheral regions and 3) endogenous and exogenous attention modulate the contribution of spatial locations to the overall percept with higher weights typically allocated to attended areas. Taken together, these results suggest that subjects prioritize information at different regions of space based on the reliability of the information or signal associated with that region. Reliability depends not only of the level of acuity due to retinal eccentricity, but also on cognitive influences such as attention.

Acknowledgement: Pew Charitable Trusts and the National Health and Medical Research Council of Australia

26.553 **Comparing properties of the spatial integration of local signals into perceived global structure**

Andrew Meso[1](andrew.meso@mcgill.ca), Robert Hess[1]; [1]McGill Vision Research, Dept. of Ophthalmology, McGill University

Sensitivity to global structure was investigated using a stimulus containing perceived vertical or horizontal bands generated by superimposing a pair of narrowband noise images modulated by two out of phase periodic functions (Watson & Eckert, 1994 JOSA, A(11)496-505). We probed a moving version of the stimulus in which components making up the pair of noise images have opposite directions of motion and then a static analogue in which the pair of components have orthogonal directions of carrier orientation. The stimuli contain local signals characterised by the carrier frequency which have to be integrated over a larger spatial extent determined by the modulation frequency, which we therefore considered a global parameter. We obtained threshold luminance and modulator contrast sensitivities using a two interval 2AFC psychophysical detection task. We found that the motion stimulus showed band-pass tuning of the ratio of carrier to modulation frequency with a peak corresponding to an optimum sensitivity where the modulator is of a scale of ten times the carrier. This optimal sensitivity was found to be scale invariant over a range of retinal image sizes varied up to a factor of 10 with a fixed number of modulator cycles. This result suggests a coupling between the spatial frequency of local motion detection stages and the integration process, which happen at a larger scale. In the case of the static orientation stimulus, a much broader tuning was found, which showed an optimum at a higher ratio (<50). Observers were more sensitive to carrier orientation in the cardinal axes that the obliques, with the broader optimum ratio also shifted slightly in the two cases. Our results suggest that there is substantial spatial pooling of local signals which exhibits different properties for moving stimuli compared with orientation stimuli.

Acknowledgement: This work is funded by an NSERC grant #46528-06 to R. F. Hess

26.554 **Does size matter more in the same eye?**

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Our perception of objects depends not only on their physical characteristics but also on the context in which they appear. In the Ebbinghaus illusion, two physically identical circles, one surrounded by large circles and one by small circles, appear perceptually different in size. This illusion has long been used as a means to study the neural pathways involved in perception and action. However, the neural mechanisms of this illusion remain largely unexplored. Here we compared monocular, binocular and dichoptic versions of the Ebbinghaus illusion to begin investigating the cortical stages at which it arises. Two circles (targets) and two groups of surrounding circles (inducers) were separately presented to the two eyes. The inducers were presented to one eye, and the targets were presented to either the same eye (monocular), or the opposite eye (dichoptic), or to both eyes simultaneously (binocular). We found that the illusion was strongest when inducers and targets were both presented to the same eye (monocular). The illusion also persisted when inducers and targets were presented to different eyes (dichoptic or binocular). The strength of the illusion for fully monocular presentation, coupled with incomplete interocular transfer, may be consistent with the Ebbinghaus illusion being at least partially mediated by monocular neurons in the primary visual cortex.

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26.555 **Visual sensitivity can scale with illusory size changes**

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Retinal image size is fundamental to human vision. It can place a necessary limit on sensitivity, as the retina is the instrument that transforms physical input into neural signals. However, retinal image size does not predict the apparent size of associated objects. Rather, images of the same physical dimensions can appear to represent different sized objects, as viewing distance is taken into account when determining apparent size. Here we take advantage of this to examine the relationship between visual sensitivity and the scaling processes involved in determining apparent size. We assess the impact of illusory size changes, induced by apparent viewing distance changes, on judgments concerning clearly visible stimuli and on the ability to detect low contrast inputs. We find that sensitivity to slight orientation changes, between successive and clearly visible stimuli, can scale with illusory size changes. However, illusory size changes do not impact on the ability to detect low contrast inputs. When considered in conjunction with recent brain imaging, our data suggest that visual sensitivity is linked to the spread of activity across primary visual cortex which, for clearly visible stimuli, is shaped by the scaling processes involved in the determination of apparent size.

Acknowledgement: Australian Research Council

26.556 **Explaining the Time Order Effect**

Thom Carney[1](neurometrics@speakeasy.net), Stanley Klein[1]; [1]School of Optometry, University of California at Berkeley

In two interval forced choice (2IFC) tasks it has been known since Fechner's time (1860) that the stimulus in the second interval is perceived as being stronger for weight discrimination. Not only is there a response bias, the thresholds (JNDs) are systematically lower in one interval than in the other. Recent studies by Nachmias (Vision Res. 2006) implicate the role of a memorized reference as being responsible for this asymmetry whereby when the test is in the first interval it perturbs the magnitude of the reference.

Our recent experiments were designed to test some of the hypotheses for explaining this Time Order Error (TOE). Our new intervention was that for each 2IFC adaptive staircase trial on a contrast discrimination task we introduce a small contrast increment or decrement (jitter) to both intervals of a given trial. If observers based their judgment on the difference of the two intervals the sign of the jitter would be irrelevant. If observers compared the 2nd interval to a weighted average of the 1st interval and a memorized reference, they would have lower JND values when the test was in the 2nd interval. We interleaved four 2IFC separate staircases for the two intervals and the two signs of jitter.

The results for two subjects on a Gabor contrast discrimination task (30% reference) were nearly identical. There was a strong bias effect whereby interval 2 seemed stronger than interval 1 about 70-75% of the time. The JND was significantly lower in interval 2, similar to that reported by Nachmias on very different tasks. The jitter parameter demonstrated that both observers paid more attention to the 2nd interval, by about 13+/-6%. Although our jitter manipulation explains only a small part of the TOE, it provides a powerful tool for assessing the decision process in 2IFC tasks.

Acknowledgement: EY004776

26.557 **Testing hypotheses regarding psychometric functions: Robustness to violations of assumptions**

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The likelihood ratio test (LRT) may be used to compare statistically any two nested models defined by the constraints they place on the parameters of psychometric functions (PFs). As such the LRT provides for a flexible method of testing a wide variety of research questions (e.g., are the thresholds and/or slopes in conditions A and B statistically different? Is the lapse rate significantly different from 0?). However, such statistical comparisons between models are valid only insofar the assumptions that are made by both models are correct. For example, when testing the equivalence of the threshold parameters between two conditions both models might assume that the slopes are identical between conditions. Here, using Monte Carlo simulations, the robustness of the LRT for a variety of violations of assumptions is investigated in the context of different possible model comparisons. Results indicate that statistical p-values associated with model comparisons are robust against many violations of assumptions even if these violations result in biased parameter estimates. For example, though it has been well established that threshold and slope estimates might be seriously biased when the assumed lapse rate differs from the actual (generating) lapse rate, here it is shown that such violations have a negligible effect on statistical decisions regarding the equivalence of either the thresholds or slopes of PFs across multiple datasets. Also shown is that an inflation of type-I-error rates in situations where violations of assumptions do affect statistical p-values (e.g., violations regarding assumptions of a PF's slope parameter) may be successfully avoided by performing a goodness-of-fit test of the fuller (less constrained) model and allowing rejection of the simpler model only when the fuller model fits well. Also considered are the effects of violations of assumptions on model comparisons made using the AIC and BIC information criteria.

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Sunday Morning Talks

Color and light

Sunday, May 9, 8:15 - 10:00 am
Talk Session, Royal Ballroom 1-3
Moderator: Qasim Zaidi

31.11, *8:15 am*

Chromatic variations suppress suprathreshold brightness variations

Frederick Kingdom[1](fred.kingdom@mcgill.ca), Jason Bell[1], Gokhan Malkoc[2], Elena Gheorghiu[3]; [1]McGill Vision Research, Department of Ophthalmology, McGill University, Montreal, Canada, [2]Laboratory of Experimental Psychology, University of Leuven, Belgium , [3]Dogus University, Faculty of Arts and Sciences, Department of Psychology Acıbadem, Kadıköy 34722 Istanbul-Turkey

Aim. To determine the relative perceptual saliencies of suprathreshold color (chromatic) and luminance variations when the two are combined. Method. The stimulus was similar to that used by Regan & Mollon in their study of the relative saliencies of the cardinal color directions (in Cavonius, ed., Colour Vision Deficiencies XIII, 1997). It consisted of left- and/or right-oblique modulations of color or luminance defined within a lattice of circles, with each circle ringed by a black line to minimize any impression of transparency when the different modulations were combined. There were two conditions. In the 'separate' condition, the color and luminance contrasts were presented separately in a 2IFC procedure and the subject indicated on each trial the interval containing the more salient modulation. In the 'combined' condition, the two modulations, which were orthogonal in orientation, were added together and the subject indicated on each trial whether the dominant perceptual organization was left or right oblique. For each color direction and for each condition, the relative color to luminance contrast at the PSE was calculated. Results. For all color directions, PSEs for the 'separate' and 'combined' conditions were significantly different: more luminance contrast relative to color contrast was required to achieve a PSE in the 'combined' compared to 'separate' condition, suggesting that in the combined condition the luminance variations were being masked by the color variations. Conclusion. Suprathreshold color variations mask suprathreshold brightness variations.

Acknowledgement: Canadian Institute of Health Research grant #11554 given to F.K.

31.12, *8:30 am*

Uncovering multiple higher order chromatic mechanisms in cone contrast space

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Despite good psychophysical and physiological evidence, the number and nature of multiple higher-order chromatic mechanisms is still under debate. This is mainly due to several studies that defined their stimuli in cone contrast space (CCS) and failed to find support for higher order mechanisms. We measured detection thresholds for chromatic directions in cone contrast space using a noise masking paradigm (Hansen & Gegenfurtner (2006), Journal of Vision, 6(3):5, 239–259). Our choice of masking directions (38 and 47 deg) was guided by an analysis of the nonlinear mapping of angles between cone contrast space and a post-receptoral color space (DKL). When the noise contrast was sufficiently high (40% rms cone contrast), we found clear evidence for selective masking, indicating multiple mechanisms tuned to these directions. Why did earlier studies in CCS fail to find evidence for higher order chromatic mechanisms? First, the noise directions in CCS tested in previous studies (90 deg $\Delta M/M$, 135 deg isolum) map to almost identical angles in DKL space (7.1 and 1.6 deg), implying that effectively only one higher order mechanisms (L−M) was stimulated. Second, the masking contrast in these studies was generally very low (<10%), resulting in insufficient power to differentially activate higher order mechanisms. We conclude that CCS as a receptoral color space is not well-suited for the study of higher order mechanisms. Rather, these higher-order mechanisms seem to be evenly distributed in post-receptoral DKL color space. DKL color space is a natural choice to study higher order mechanisms because it reflects the input signals arriving in visual cortex. Higher order mechanisms exist in CCS, but are more difficult to find.

31.13, *8:45 am*

Interaction Between S-cone and Luminance Signals in Surround Suppression

Bei Xiao[1](bei.xiao@gmail.com), Alex Wade[1,2]; [1]The Smith-Kettlewell Eye Research Institute, San Francisco, [2]Department of Neurology, University of California San Francisco

Introduction: Neural signals driven by achromatic and S-cone isolating stimuli are processed in relatively independent early visual pathways. Although some interactions between these two types of stimuli are observed when they are presented in the same spatial location, the degree of long-range interaction is less well understood. To examine this, we measured surround suppression in spatially-separated luminance-driven and S-cone-driven signals using both behavioral psychophysics and source-imaged EEG.

Methods and Results: Appearance matching: We used a psychophysical asymmetric appearance-matching task to measure perceived contrast of a central Gabor patch with a spatially-separated annular surround. We found strong suppression measured in this manner when the surround and the probe were driven by stimuli having the same chromaticities (within-channel). Suppression was absent when signals had different chromaticities (across-channel), suggesting little long-range interaction between luminance and S-cone signals for this task. Within-channel surround suppression was tuned for relative orientation and temporal frequency.

Source-imaged EEG: We measured surround suppression in retinotopically-defined V1 using high-density source-imaged EEG. The neural data showed orientation tuned within-channel surround suppression. However, in contrast to the psychophysical results, we also observed weak but significant cross-channel suppression for S-cone driven centers with achromatic luminance surrounds. We hypothesized that the cross-channel interaction in the EEG might be due to indiscriminate pooling of neural responses that included neurons weakly tuned for chromaticity.

Contrast modulation detection: To test this, we measured surround suppression using similar stimuli but a different psychophysical task (contrast modulation detection) that isolated a different subset of the neural population. With this task we found cross-channel interactions similar to those in the EEG.

Conclusion: Luminance signal and S-cone signals are processed relatively independently in early visual system. Some neural populations experience more long-range cross-channel interactions than others and the degree of independence measured psychophysically depends on the task of choice.

Acknowledgement: NIH EY018157-02, NSF BCS-0719973

31.14, *9:00 am*

Decoding foveal stimulus chromaticity using the peripheral V1 BOLD response

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Introduction: Although much is known about chromatic properties of classical receptive fields, the effect of chromatic stimuli on extraclassical suppressive surrounds is less well-understood. If extraclassical receptive fields are chromatically-tuned, neurons outside directly-stimulated regions might carry information about stimulus chromaticity. Here we show that fMRI BOLD signals in peripheral regions of V1 carry significant information about the color of a foveal stimulus.

Methods: Subjects fixated 5 degree diameter contrast-reversing gratings defined by chromatic contrast along the three different color directions in MacLeod-Boynton space in a block-design fMRI experiment. Data from directly stimulated cortical regions and from a peripheral 'surround' in retinotopically-defined V1 were analyzed both by univariate analysis and by a multivariate pattern classification algorithm.

Sunday AM

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Results: The univariate analysis showed little difference in central response amplitudes but distinct differences in the surround for all three color directions: Luminance stimuli created a large negative BOLD response while S-cone and (L-M)-cone isolating isoluminant stimuli did not. Although isoluminant stimuli did not generate a mean activity change in the surround, it was possible they caused changes in small-scale patterns of voxel responses in this region. By removing periphery mean responses, we used the classification routine to ask whether we could predict the color of foveal targets based on responses of peripheral cortical neurons. We found that we could discriminate all three color directions using a multivariate pattern classifier operating on peripheral voxels as well as central ROIs.

Conclusions: The spatially-extended negative BOLD effect is largely generated by luminance stimuli. This is consistent with single studies showing the largest suppression from extraclassical receptive fields in magnocellular neurons of the early visual system. However, our ability to classify isoluminant stimuli based on peripheral population responses confirms that some V1 neurons must have large, chromatically-tuned suppressive surrounds.

Acknowledgement: NIH EY018157-02, NSF BCS-0719973

31.15, *9:15 am*

Effects of image dynamic range on perceived surface gloss

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One of the defining characteristics of glossy surfaces is that they reflect images of their surroundings. High gloss surfaces produce sharp reflections that show all the features of the surround, while low gloss surfaces produce blurry reflections that only show bright "highlight" features. Due to the presence of light sources and shadows, the illumination field incident on a glossy surface can have high dynamic range. This means that the reflections can also have high dynamic range. However, in a conventional image of a glossy object, the high dynamic range reflections are compressed through tone mapping to make the images fit within the output range of the display. While the utility of conventional images demonstrates that the general characteristics of glossy objects are conveyed by tone-mapped images, an open question is whether the tone mapping process distorts the apparent gloss of the imaged object. We have conducted a series of experiments to investigate the effects of image dynamic range on perceived surface gloss. Using a custom-built high dynamic range display, we presented high dynamic range (HDR) and standard dynamic range (tone mapped, SDR) images of glossy objects in pairs and asked subjects to choose the glossier object. We tested objects with both simple and complex geometries and illuminated the objects with both artificial and natural illumination fields. We analyzed the results of the experiments using Thurstonian scaling, and derived common scales of perceived gloss for both the HDR and SDR object renderings. Our findings are that 1) limiting image dynamic range does change the apparent gloss of depicted objects - objects shown in SDR images were perceived to have lower gloss than identical objects shown in HDR images; 2) gloss differences are less discriminable in SDR images than in HDR images; and 3) surface geometry and environmental illumination modulate these effects.

31.16, *9:30 am*

Interaction of diffuse and specular reflectance in the perception of object lightness and glossiness

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Purpose. To judge object surface properties, the visual system must estimate reflectance from the light signal arriving at the eyes. We ask to what extent observers are able to do this under geometrically varying light fields, and focus on the interaction between two distinct reflectance properties: diffuse and specular. These are physical correlates of the percepts of lightness and glossiness. If the two reflectance attributes are processed independently, future experiments can be simplified by studying each in isolation, while interactions require continued joint measurement. Methods. Observers adjusted the diffuse and specular components of one grayscale sphere to match the appearance of second, reference, sphere. Spheres were rendered using the Debevec (SIGGRAPH98) light fields and presented on a high-dynamic-range display. For symmetric matches, both spheres were rendered using the same light field. For asymmetric matches, a different light field was chosen for each sphere. Matches were collected for different combinations of reference sphere diffuse and specular reflectance. Surface roughness was held constant across the two spheres; the measurements were repeated for two levels of roughness. Performance was quantified by the slope of regression lines of matched versus reference reflectance. Results. Symmetric matches were close to veridical (average slopes 0.99 diffuse component; 1.00 specular). Asymmetric matches deviated systematically from veridical (average magnitude of slope deviation 0.06 diffuse; 0.31 specular), showing an effect of light field on perceived lightness and glossiness. The matched diffuse component decreased with increasing reference sphere specular component. In contrast, the matched specular component was roughly independent of reference sphere diffuse component. Matches were similar for the two levels of roughness (r = 0.94). Conclusions. The spatial structure of the illumination affects the perceived lightness and glossiness of 3D objects. Specular component matches were independent of the diffuse component, but not vice-versa. Changing surface roughness had little effect.

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31.17, *9:45 am*

Roles of color & 3-D information in recognizing material changes

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Chemical and physical properties of objects provide them with specific surface patterns of colors and 3-D textures. Endogenous and exogenous forces alter these colors and patterns over time. The ability to identify these changes can have great utility in judging the state and history of objects. To evaluate the role of color and 3-D texture cues, we used calibrated images acquired from 15 different viewpoints of 26 real materials undergoing changes (Courtesy of Shree Nayar and Jinwei Gu). Materials included fruits, foods, woods, minerals, metals, fabrics and papers, and changes included drying, burning, decaying, rusting, oxidizing and heating. Observers were asked to identify materials and types of changes for color and gray-scale images. Observers obtained 3-D information by varying the viewing angle of the image (deformation of the frame provided estimates of the slant and tilt of the material with respect to the observer). The images were shown in three sets of trials: one image of the surface, two images of the same surface at the beginning and end of a natural change, and image sequences of the time-varying appearance (number of time samples varied from 10 to 36). The presence of color cues improved performance in all conditions but most dramatically in the organic category. This may be because certain color patterns occur only in organic fruits and vegetables. Identification of materials improved if observers saw two states of the material, but the complete image sequence did not improve performance if images were restricted to fronto-parallel view-points. The ability to examine the material surface from several viewpoints improved performance, thus showing the importance of the 3-D micro-structure of the surface texture. The role of color in object recognition has been controversial, but this controversy may be resolved as color's role in material perception becomes clearer.

Acknowledgement: Grants EY07556 & EY13312 to QZ.

Perceptual learning: Mechanisms and models

Sunday, May 9, 8:15 - 10:00 am
Talk Session, Royal Ballroom 4-5
Moderator: Paul Schrater

31.21, *8:15 am*

Learning shapes the spatiotemporal dynamics of visual processing

Zoe Kourtzi[1](z.kourtzi@bham.ac.uk), Sheng Li[1,2], Stephen Mayhew[1]; [1]School of Psychology, University of Birmingham, UK, [2]Department of Psychology, Peking University, China

Perceptual decision making has been suggested to engage a large network of sensory and frontoparietal areas in the human brain. However, relatively little is known about the role of learning in shaping processing in these regions at different stages of decision making from sensory analysis to perceptual judgments. Here, we combine psychophysical and simultaneous EEG-fMRI measurements to investigate the spatiotemporal dynamics of learning to discriminate visual patterns. Observers were instructed to discriminate between radial and concentric Glass pattern stimuli that were either embedded in different noise levels (coarse discrimination) or varied in the spiral angle between radial and concentric patterns (fine discrimination). Our behavioral results showed that training enhanced the observers' sensitivity in the coarse task, while changed the internal decision criterion (i.e. categorical boundary) in the fine task. Information theory-based analyses of EEG single-trials revealed two temporal components that contained discriminative information between radial and concentric patterns: an early component (120 ms post-stimulus) associated with the analysis of visual stimuli and a later component (240 ms) related to the global pattern discrimination. Further, using multivariate pattern classification analysis we tested whether we could predict learning-dependent changes in the observers' choices from fMRI signals related to these EEG components. We observed learning-dependent changes in prefrontal circuits at the later EEG component for both tasks. In contrast, learning-dependent modulation in higher occipitotemporal areas (LO, KO/LOS) differed between tasks: for the coarse discrimination learning-dependent changes were associated with the first EEG component, while for the fine discrimination with the later component. These findings demonstrate that learning shapes the dynamics of neural processing in visual areas in a task-dependent manner. In particular, learning shapes sensitivity in early detection and integration processes for coarse discrimination tasks, while later decision criteria processes for fine categorical judgments.

Acknowledgement: BBSRC: D52199X, E027436

31.22, *8:30 am*

Adaptive Sequencing in Perceptual Learning

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Question: In real-world perceptual learning (PL) tasks learners come to extract distinguishing features of categories, enabling transfer to novel instances. This kind of learning can be accelerated by structured interventions involving a series of classification trials (e.g., Kellman, Massey & Son, 2009, TopiCS in Cognitive Science). Little is known about practice schedules that optimize PL, nor their relation to laws of learning for factual items. Method: We tested an adaptive sequencing algorithm for PL that arranged spacing for categories as a function of the individual learner's trial-by-trial accuracy and reaction time. Participants learned to classify images from 12 butterfly genera. Each genus contained 9 exemplars from 3 species (Experiment 1) or 9 exemplars from 1 species (Experiment 2 - low variability categories). 1 of the 9 exemplars was not presented in training and was used as a test of novel transfer. Training trials were 2AFC where participants matched one of two images to a genus label. During training participants received either: 1) random presentation, 2) adaptive sequencing, or 3) adaptive sequencing with sets of 3 sequential category exemplars (mini-blocks). Participants completed pre and post-tests immediately before and after training, and an additional post-test after a 1-week delay. Results: Learning efficiency (accuracy per learning trials invested) was reliably greater for adaptive sequencing. Effects persisted over a 1-week delay and were larger for novel items. In experiment 2 where the variability of category exemplars was lower, adaptive sequencing resulted in even greater learning efficiency gains. Mini-blocks hurt efficiency in both experiments, especially for novel items. Conclusion: Results suggest that, across a range of category distributions, adaptive sequencing (but not blocking) increases the rate of learning and benefits novel transfer – key components of PL and fundamental aspects of learning in many domains.

Acknowledgement: Supported by US Dept. of Education, Institute for Education Sciences (IES) Grant R305H060070 to PK.

31.23, *8:45 am*

Augmented Hebbian Learning Accounts for the Complex Pattern of Effects of Feedback in Perceptual Learning

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A complex pattern of empirical results on the role of feedback in perceptual learning has emerged: Whereas most perceptual learning studies employed trial-by-trial feedback, several studies documented significant perceptual learning with block, partial, or even no feedback, and no perceptual learning with false, random, manipulated block, and reversed feedback (Herzog & Fahle, 1997). Shibata et al (2009) showed that arbitrary block-feedback facilitated perceptual learning if it is more positive than the observer's actual performance. At high training accuracies, feedback is not necessary (Liu, Lu & Dosher, 2008), and significant learning was found in low training accuracy trials when they were mixed with high accuracy trials (Petrov, Dosher, & Lu, 2006; Liu, Lu & Dosher, 2009). We conducted a computational analysis of the complex pattern of empirical results on the role of feedback with the Augmented Hebbian Reweighting Model (AHRM; Petrov, Dosher & Lu, 2005), in which learning occurs exclusively through incremental Hebbian modification of the weights between representation units and the decision unit, by simulating existing feedback studies in the literature. The Hebbian learning algorithm incorporates external feedback, when present, simply as another input to the decision unit. Without feedback, the algorithm uses observer's internal response to update the weights. Block feedback was used to modify the weights of the bias unit in the model. The simulation results are both qualitatively and quantitatively consistent with the data reported in the literature. Augmented Hebbian Reweighting accounts for the complex pattern of results on the role of feedback in perceptual learning.

31.24, *9:00 am*

Changes induced by attentional training - capacity increase vs. allocation changes

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Attentional blink (AB) is a phenomenon in which identification of the second visual target (T2) is impaired in rapid serial visual presentation (RSVP) when it is presented within half a second after the appearance of the first target (T1). Even though AB has been thought to reflect the limited capacity of visual systems, we found that this robust phenomenon was removed after a single day of attentional training with a modified RSVP task in which T2 was spotlighted red while both T1 and all the distractors were white. Thereafter AB was continually not observed at least for a few months (Choi & Watanabe, 2009 VSS). How was the attentional training able to overcome this kind of capacity limitation? Training could have increased the overall attentional capacity of our visual system, or it could have simply changed the allocation of attentional resources. To address this question, in the current study we measured AB before and after the training at various SOAs (stimulus onset asynchrony) between T1 and T2 while a 200ms fixed SOA was employed during the training. If the training simply changed the allocation of attentional resources, a certain tradeoff (AB occurring at another SOA) should be observed. After 2 days of training with a spotlighted T2 at the fixed SOA, AB effects were eliminated at multiple SOAs that had AB effects prior to training. Training also increased the performance of identifying T1. When T2 was presented immediately after T1 without any distractors, AB did not occur (lag 1 sparing) but the performance in detecting T1 was poor. However, after training the performances in identifying T1 were significantly improved with no change in performance of identifying T2. These results thus indicate that attentional training increases the attentional capacity rather than changing the attentional resource allocation.

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31.25, *9:15 am*

Accounting for speed-accuracy tradeoff in visual perceptual learning

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In the perceptual learning literature, researchers typically focus on improvements in accuracy, such as proportion correct or dprime. In contrast, researchers who investigate the learning, or practice, of cognitive skills focus on improvements in response times (RT). Here, we argue for the importance of accounting for both accuracy and RT in perceptual learning experiments, due to the phenomenon of speed-accuracy tradeoff: at a given level of discriminability, faster responses tend to produce more errors. A formal model of the decision process, such as the diffusion model (Ratcliff & McKoon, 2008), can explain the speed-accuracy tradeoff. In this model, a parameter known as the drift rate represents the perceptual strength of the stimulus: higher drift rates lead to more accurate and faster responses. We applied the diffusion model to analyze responses from a yes-no coherent motion detection task. Participants were trained for 5 days and completed 500 trials per day. On each trial, participants were shown a field of moving dots for 200 ms within a 14-degree aperture. On "signal" trials, 15% of dots moved coherently in a specific direction at a constant speed, while the remaining dots were replotted at random locations. On "noise" trials, all dots were replotted randomly. The results showed a significant range of individual differences in speed-accuracy tradeoff. When accuracy and RT measures were analyzed separately, inconsistent patterns of learning were observed across sessions. However, the diffusion model analysis indicated that drift rates improved consistently across sessions. These results suggest that part of the variability typically observed in perceptual learning experiments may be attributed to speed-accuracy tradeoff, and that drift rates offer a promising new index of perceptual learning. We discuss further advantages of diffusion modeling in perceptual learning, including the ability to dissociate decision time from non-decision time, and perceptual bias from response bias.

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31.26, *9:30 am*

Learning internal models for motion extrapolation

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Prediction and extrapolation form key problems in many perceptual tasks, as exemplified by tracking object motion with occlusion: an object moves along a variable path before disappearing and a prediction of where the object will reemerge at a specified distance beyond the point of occlusion is made. In general, predicting the trajectory of an object during occlusion requires an internal model of the object's motion to extrapolate future positions given the observed trajectory. In recent work (Fulvio, Maloney & Schrater, VSS2009), we showed that people naturally adopt one of two kinds of generic motion extrapolation models in the absence of feedback (i.e. no learning)- a constant acceleration model (producing quadratic extrapolation) or a constant velocity model (producing linear extrapolation). How such predictive models are learned is an open question. To address this question, we had subjects extrapolate the motion of a swarm of sample points generated by random walks from two different families of dynamics - one periodic and one quadratic. For both motion models, the ideal observer is a Kalman filter, and we compute normative learning predictions via a Bayesian ideal learner. Simulation results from the ideal learner predict that learning motion models will depend on several factors, including differential predictions of the motion models, consistency of the motion type across trials and limited noise. To test these predictions, subjects performed a motion extrapolation task that involved positioning a "bucket" with a mouse to capture the object as it emerged from occlusion, and feedback was given at the end of each trial. While subject performance was less than ideal, we provide clear evidence that they adapt their internal motion models toward the generative process in a manner consistent with statistical learning.

Acknowledgement: ONR N 00014-07-1-0937

31.27, *9:45 am*

Attention mediates learned perceptual bias for bistable stimuli

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Long-lasting biases in the appearance of ambiguously rotating stimuli can be induced by stereo-disambiguated training stimuli (Haijiang et al., 2006). Does this learning depend on visual attention? Methods: Observers (N=13) participated on three consecutive days. Each session consisted of 480 trials. Each trial contained a 2-sec movie of a rotating Necker cube. Observers fixated a central square, verified by a gaze-tracking camera. An arrow (750 ms) at fixation indicated one of four possible task locations. Two locations were assigned an "attended rotation direction" (ARD) of clockwise and two locations were assigned an ARD of counter-clockwise. On Test trials (128/session) an ambiguous cube appeared at one location. On Training trials (352/session), stereo-disambiguated cubes appeared at all four locations. Training stimuli always rotated according to the ARD when observers attended to them (25% of Training trials). In Experiment 1, equal numbers of ARD and anti-ARD stimuli were shown at each location. Thus, 75% of Training trials at a given location were unattended, of which 1/3 had ARD and 2/3 had anti-ARD. In Experiment 2 the unattended cubes always rotated anti-ARD. On Day 3 the ARDs were reversed at all locations (both experiments) to assess long term learning. Results: In Experiment 1, 81±6% (mean ± SE across observers) of Test trials agreed with the ARD on Day 1, increasing by 6±3% (to 87±6%) on Day 2. These learned biases were robust, dropping by only 9±2 % (to 77±6%) with reverse Training on Day 3. In Experiment 2, however, only 41±3% of Test trials agreed with the ARD on Day 1, increasing to 44±2% on Day 2, dropping 12±5% to 32±5% on Day 3. Conclusions: Long term bias for 3D rotation can be learned with or without attention, but 2-3 unattended trials are needed during training to counteract a single attended trial.

Acknowledgement: NIH R01-EY-013988, HFSP RPG 3/2006, NSF BCS-0810944

Development: Mechanisms

Sunday, May 9, 11:00 - 12:45 pm
Talk Session, Royal Ballroom 1-3
Moderator: Daniel Dilks

32.11, *11:00 am*

Components of attention in normal and atypical development

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Neuropsychological and neuroimaging studies of attention indicate that the human brain contains distinct networks for selective attention, sustained attention, and attentional (executive function = EF). However, attention test batteries designed to analyse these separate attention functions have not hitherto been available for developmental ages less than about 6 years.

We have designed, pilot-tested, and validated an Early Childhood Attention Battery (ECAB) whose subtests can be understood by children aged between 3-6 years. Normative data on 156 children in this age range showed that a three factor model based on the hypothesised distinct attention networks fitted the data well for children over 4.5 years, but younger children's data was equally well fit by a two factor model with substantial cross-loading. These results suggest that the differentiation of attention networks emerges over the tested age range, perhaps because more general constraints limit performance in the younger children.

We have used the ECAB to analyse and compare groups of 32 children each with two developmental disorders showing distinct cognitive profiles, Williams Syndrome (WS) and Down Syndrome (DS), with developmental ages too low for other attention tests (e.g. TEA-Ch). In relation to test norms for their mental age, the results provide evidence for syndrome-specific patterns of impairment. Both syndrome groups performed relatively well on tests of sustained attention and poorly on aspects of selective attention and EF. The DS group showed a specific strength in auditory sustained attention, whilst the WS group showed a particular deficit in visuo-spatial EF tasks.

We discuss these results in relation to the interaction of attention mechanisms with the dorsal cortical stream, neuroimaging [Meyer-Lindenberg et al, Neuron, 2004] and behavioural [Atkinson et al, NeuroReport 1997; Dev Neuropsychol, 2003] evidence for dorsal stream deficits in WS, and consider how they relate to the broader concept of "dorsal stream vulnerability" in developmental disorders.

Acknowledgement: Research Grants G0601007 from the Medical Research Council & RES-000-22-2659 from the Economic & Social Research Council

32.12, *11:15 am*

The Convexity Assumption: Infants use Knowledge of Objects to Interpret Static Monocular Information by 5 Months

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The adult visual system uses top-down information to interpret ambiguous images. When the 2D contours of a cube are presented to the retina, for example, adults generally perceive a 3D cube. In the absence of information to the contrary, the adult visual system assumes that objects are convex. Our question is, when do infants begin to form and use such assumptions to interpret visual input? We presented a wire half-cube, with its vertex pointed away, to 5- and 7-month-old infants (n = 17 and 20 respectively), and observed the infants' reaching behavior under monocular and binocular viewing conditions. For adults, the cube's vertex appears closer than the outer edges when the display is viewed monocularly; but the cube's actual layout is perceived when viewed binocularly. In the monocular condition, the infants in both age groups reached significantly more often to the central region of the display than to the outer edges (5 months, p=0.009; 7 months, p=0.016). Furthermore, infants reached more often to the center of the display in the monocular condition than the binocular condition (5 months, p<0.0001; 7 months, p=0.016). These results suggest that the infants perceived the cube as convex under monocular viewing conditions and as concave under binocular conditions. By 5 months of age, infants use their knowledge of 3-dimensional objects to interpret ambiguous 2-dimensional displays. This knowledge is provided by mechanisms that recognize a form and supply information, in a top-down fashion, to early visual projection areas. Further work will be needed to investigate this ability in younger infants.

Acknowledgement: NIH Grant # T32 HD007151, Center for Cognitive Sciences - U of Minnesota

32.13, *11:30 am*

The innate "face" representation is more broadly tuned: 4-month-old infants individuate upright but not inverted horses

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Evidence of remarkable face discrimination abilities in neonates, perceptual narrowing and a critical period converge to argue for an innate representation that supports face individuation from birth. Previous studies have shown this initial representation encompasses monkey as well as human faces, but it has implicitly been assumed that it is of a face. Here, we consider the possibility that it is even broader. We tested individual level discrimination of whole animals (bay thoroughbred horses, shown in side view), at an age before any narrowing has been observed for faces (4-month-olds). Horses and human faces were equated for visual similarity as demonstrated by matched discrimination performance for the inverted orientation in adults. Using a novelty-preference procedure, results for 4-month-old infants (with no horse experience) then showed the babies discriminated individual upright horses; moreover, they did so at least as well as they discriminated upright human faces, and these findings were obtained despite adults showing the expected pattern of poor discrimination of upright horses relative to upright faces. Infants did not discriminate inverted horse stimuli. Together, the results imply that the innate representation capable of supporting individuation of upright biological stimuli is much broader in form than the previously proposed innate primate face representation. We argue the representation encompasses at least other mammal heads (in profile view), and possibly full bodies of all animals.

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32.14, *11:45 am*

Texture-defined Figure/Ground Segmentation In Human Visual Development: A High-Density Electrical Mapping Study

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The human visual system uses texture discontinuities and grouping mechanisms to segment visual scenes in objects and supporting background. To study the development of these processes, we used synthetic images portraying simple texture-defined figures and high-density VEP recording in 3-5 month old infants and in adults. We compared responses in two conditions: in one condition a set of disk-shaped regions appeared and disappeared from a uniform background. The uniform background consisted of horizontal 1-dimensional dynamic noise. The figures were created by rotating the texture within 9 small disk-shaped regions from horizontal to vertical at 1 Hz. In a control condition, the texture within the disks also rotated between horizontal and vertical at 1 Hz, but the disks remained segmented when the texture was horizontal. A difference in response profile between these two conditions was used to isolate responses that are sensitive to the global organization of the stimulus. We recorded strong, but delayed segmentation-related responses in the infants: their initial segmentation response started at about 200 msec after the onset of the figures versus 70-90 msec in adults. The infant response waveform was much simpler than that of the adults and their responses were restricted to the occipital midline at all latencies. This pattern contrasted strongly with that of the adults: after an initial peak at the occipital pole, the adult response spread to lateral electrodes over right and left lateral cortex by 150 msec. Activity over frontal electrodes occurred by 200 msec, followed by later activity on lateral sites at 250-300 msec. While infants are sensitive to the global organization of our stimulus, they process this information in a much more restricted range of cortical areas. In particular, we found no evidence of activity in lateral occipital and frontal areas that is prominent in the adult evoked response.

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32.15, *12:00 pm*

Fusion of disparity and texture cues to slant is not mandatory in children

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Integrating sensory cues can lead to "fused" percepts in which the ability to judge the component cues is lost. In recent studies, children did not integrate cues across modalities until 8 years or later. One hypothesis for this late development is that keeping cues separate and avoiding fusion is adaptive in allowing senses to be calibrated against each other while the body is growing. To test whether children do keep cues separate, we studied development of integration and fusion within the single modality of vision. We measured discrimination (d') in 6-year-olds (n=20) and adults (n=20) for whether two discs were of same or different slant, given single or combined interocular disparity and texture cues. Observers judged slant differences of 12.5° (adults) or 25° (children), which made single-cue stimuli equally discriminable for the two groups. In combined-cue conditions, differences in discs' slants were either in the same direction in terms of both disparity and texture, or in opposite directions. "Integration" predicts better slant discrimination given two cues in the same direction than either cue alone. "Fusion" predicts worse discrimination given two cues in opposite directions than either cue alone. Adults showed significantly better slant discrimination (d') given two consistent cues ("integration") and significantly worse discrimination given two inconsistent cues ("fusion"). Six year olds showed neither effect, but had combined-cue discriminations intermediate to those for single cues, consistent with following one or other cue on each trial. Thus, while combining cues confers an advantage on adults when the cues agree, not combining cues confers an advantage on 6-year-olds when the cues disagree. Six-year-olds' ability to keep disparity and texture information separate enables them to detect a type of cue conflict that adults cannot. Such conflicts may provide the error signals needed for sensory recalibration as interocular distance changes in childhood.

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32.16, *12:15 pm*

Sensitivity to Biological and Global Motion: Similar in their Protracted Development but Different in Susceptibility to Visual Deprivation

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We used a staircase procedure to test sensitivity to biological and global motion in normally developing children aged 6-9, 9-12, and 12-15 years, and adults (n = 20 per group), as well as in eight patients treated for bilateral congenital cataracts (11-30 years old). In the biological motion task, participants discriminated biological motion from scrambled displays, with the number of added noise dots varied across trials. Thresholds were defined as the maximum number of noise dots tolerated for accurate discrimination. In the global motion tasks, participants discriminated upward from downward motion in random-dot kinematograms moving at 4 and 18 deg/sec in separate blocks. Thresholds were defined as the minimum percentage of signal dots required to accurately determine the overall direction of motion. Results revealed a similar, long developmental trajectory for sensitivity to biological and global motion (ps<0.0001). Only the 12- to 15-year–olds showed adult-like performance, suggesting that the extrastriate mechanisms that integrate local motion cues over time and space take many years to mature. Although global motion thresholds were lower for faster than slower speeds at every age (ps<0.0001), developmental trends did not differ across the two speeds (p>0.10). In contrast, early bilateral

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deprivation had different effects on the two types of motion perception. Z-scores based on age-appropriate norms indicated a large deficit in processing both speeds of global motion (mean Z-score = -4.21 and -5.85 for fast and slow speeds, $ps<0.01$) but no abnormality for processing biological motion (mean Z-score = -0.19, $p>0.70$). The adverse effect of visual deprivation was equivalent at the two speeds of global motion ($p>0.20$) and greater than the (non-significant) effect on biological motion ($ps<0.01$). The spared sensitivity to biological motion might be explained by a neural network that is stimulated by body movements during the period of visual deprivation.

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32.17, *12:30 pm*

No Change in the Size of the Right Fusiform Face Area between Age Five and Adulthood

Daniel D. Dilks[1](dilks@mit.edu), Eyal Dechter[1], Christina Triantafyllou[1], Boris Keil[2], Lawrence L. Wald[2], Matthew D. Tisdall[2], Andre van der Kouwe[2], Bruce Fischl[2], Rebecca Saxe[1], Nancy Kanwisher[1]; [1]McGovern Institute for Brain Research, MIT, [2]Athinoula A. Martinos Center for Biomedical Imaging, MGH, Harvard Medical School

Studies of the development of face recognition reveal a conflict between behavioral findings – which show that all classic signatures of adult face recognition are present very early in development (by 4 years of age) – and neural evidence for continuing enlargement of the right 'fusiform face area' (rFFA) well into adolescence. Here we addressed this conflict by developing i) new pediatric neuroimaging methods including a new 32-channel coil optimized for five-year-olds, ii) dynamic movie stimuli designed to engage the interest of children and adults alike, and iii) novel pulse sequences that reduce the effects of subject motion. Eight children between the ages of 5 and 6 were scanned while viewing movies of faces and objects. One child moved more than 6 mm, and was omitted from further analyses. Each of the seven remaining children was matched on subject motion and residual error from the general linear model to an adult subject run on the same protocol with an adult 32-channel coil. Six out of the seven children showed clear, adult-like rFFAs. No significant differences were found between the children and adults in either the volume of the functionally defined rFFA, or in the total number of face-selective voxels in the anatomically defined fusiform gyrus. Thus, we find no change in the size of the rFFA between age 5 and adulthood, consistent with the behavioral data suggesting face processing is present early in development.

Acknowledgement: This work was supported by NIH grant EY13455 and a grant from the Ellison Medical Foundation.

Sunday AM

Attention: Brain imaging

Sunday, May 9, 11:00 - 12:45 pm
Talk Session, Royal Ballroom 4-5
Moderator: Yaoda Xu

32.21, *11:00 am*

Decoding feature-based attentional priority signals in human cortex

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Attending to visual features causes modulations of neuronal activity in early visual cortex. Although the effect of such modulation on sensory cortex is relatively well understood, the nature of the their control signals remains unknown. We examined the attentional control signals for motion and color in two fMRI experiments. Subjects viewed a compound stimulus containing two superimposed motion directions (or colors), while alternating their attention between the two directions (or colors). They performed an attention-demanding change detection task on the attended stimulus. We found different attentional states (e.g., attending to red vs. green) did not produce reliable differences in fMRI response amplitude. However, using multi-voxel pattern analysis of fMRI data, we were able to decode subjects' attentional state in multiple brain regions. These regions include early visual areas (V1 to MT), as well as parietal and frontal areas (IPS and FEF) that are commonly associated with spatial attention. These results thus demonstrate that IPS and FEF are also responsible for attending to specific features, in addition to spatial locations. Our results provide the first evidence regarding the control signals associated with maintaining attention on a non-spatial feature value.

32.22, *11:15 am*

Response profiles of macaque dorsolateral prefrontal cortex neurons during a rule-guided target selection and sustained attention task

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We investigated the role of primate dorsolateral prefrontal cortex (dlPFC) neurons in target selection and sustained attention by recording single-cell activity within the area in behaving macaque monkeys. The animals were presented with two colored moving random dot patterns (RDPs), the target and the distracter. The target was defined using a color rank selection rule: turquoise > red > blue > green > pink > grey. All colors were approximately isoluminant and randomly assigned to the stimuli. The animals were required to select the target, sustain attention to it, and detect a transient change in its motion direction. We recorded the activity of 222 neurons, of which 147 (66%) showed an increase in activity during task trials relative to baseline. Out of the 147, 68% reliably encoded the position of the target. This latter group was subdivided into three distinct populations: one group encoded target position transiently, starting ~150ms after color cue onset (21%, 'selection neurons'), a second group signaled target position in a sustained manner, starting ~350 ms after cue onset (42%, sustained attention neurons), and the third group combined features of the aforementioned groups (37%). Using ROC (receiver operating characteristic) analysis we found that these neurons effectively discriminated target and distractor through their firing rate as early as ~150 ms after cue onset. Moreover, immediately following color cue onset, discrimination occurs earlier for greater distance between target and distractor position in the color-rank scale. This finding follows the animals' behavioral performance; proportion of correct discriminations was higher the greater the distance between target and distractor in the color scale. Overall, our results indicate that different populations of dlPFC neurons may be involved in target selection and sustained attention and that the neurometric performance of these units closely follows the one of the animals.

Acknowledgement: CIHR

32.23, *11:30 am*

A neural pooling rule for attentional selection in human visual cortex

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To characterize sensory and decisional processes enabling attention to enhance behavioral performance, human observers performed contrast discrimination judgments following two types of attentional cues, while cortical activity was measured with fMRI. Four sinusoidal gratings were presented, one in each visual quadrant, at 8 different "pedestal" contrasts. Stimuli were shown in two 600-ms intervals separated by a 200-ms blank interval, one of which (randomized across trials) had a near threshold contrast increase across the 2 intervals. After stimulus offset, an arrow at fixation indicated the target location. Observers maintained central fixation and pressed 1 of 2 buttons to indicate the interval with higher contrast. The three non-target locations had different contrasts that remained unchanged across intervals. Half the trials were preceded by a focal attention cue (arrow at fixation indicating target location), and half were preceded by a distributed cue (4 arrows indicating four possible target locations). fMRI response amplitudes were measured in each of several visual cortical areas, separately for each visual quadrant, pedestal contrast, and attentional condition and then combined across quadrants.

Robust increases in fMRI responses and behavioral performance improvements were observed with focal versus distributed attention cues. The changes in fMRI responses could account for the improved behavioral performance only assuming that focal cues caused a 4-fold noise reduction. Whereas sensory noise reduction could account for part of this effect, neither our data nor previous studies support the full 4x reduction we found.

Rather, the data were well-fit by a model in which most of the ostensible noise reduction was attributed to the selection and pooling of sensory signals into a decision, utilizing a max-pooling decision rule. We conclude that increases in neural activity with attention in early visual cortex enhance performance by selecting relevant sensory signals for decision.

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32.24, *11:45 am*

Gain in the most informative sensory neurons predicts task performance

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Traditional accounts hold that selective attention facilitates perception by increasing the gain of sensory neurons that are maximally responsive to task relevant stimulus features. In contrast, recent theoretical and empirical work suggests that attention strives to maximize performance on the current perceptual task, even if this means applying sensory gain to neurons tuned away from the relevant features (Navalpakkam and Itti, 2007; Scolari and Serences, 2009). For example, when discriminating a 90° oriented line from a set of distractors oriented at 92°, sensory gain should be applied to neurons tuned to flanking orientations because they undergo a larger change in firing rate in response to the target and distractors. Given the high-density of orientation-selective neurons in primary visual cortex, we hypothesized that such "off-channel" gain in V1 should predict performance on a difficult orientation discrimination task. We used fMRI and voxel tuning functions to determine if correct trials were associated with more off-channel sensory gain when compared to incorrect trials. Subjects completed a 2AFC task in which a grating (sample stimulus) was presented at one of 10 possible orientations for 2s, followed by a 400ms delay, and then a second grating which was rotated clockwise or counterclockwise from the sample (the size of the offset was determined on a subject-by-subject basis, and ranged from 1-4.75°). Subjects exhibited a larger BOLD response in V1 in the most informative voxels (e.g., ±36° offset from the sample) on correct trials than on incorrect trials; this pattern was not observed in other visual areas (V2v, V3v, and V4v). These results indicate that performance on demanding perceptual tasks is not always predicted by the gain of the maximally responsive sensory neurons. Instead, the magnitude of gain in the most informative neurons predicts perceptual acuity, even if these neurons are tuned away from the relevant feature.

Acknowledgement: National Institutes of Health Grant R21-MH083902 (J.T.S.)

32.25, *12:00 pm*

Feature-based attention in the human thalamus and superior colliculus

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Feature-based attention is known to enhance the responses of cortical neurons tuned to the attended feature, but its control mechanisms remain poorly understood relative to those of spatial attention, which involve a network of cortical and subcortical structures. Subcortical structures are thought to serve as important control points in the flow of information, but while feature-based attention has been observed in the cortex, it is not known whether its effects also can be observed in the subcortex. We therefore functionally imaged the human subcortical visual nuclei while subjects detected changes in separate fields of moving or colored dots. We found that when the fields were disjoint, spatially attending to one field enhanced hemodynamic responses in the superior colliculus (SC), lateral geniculate nucleus (LGN) and two retinotopic pulvinar nuclei. When the two dot fields were spatially coincident, feature-based attention to the moving versus colored dots enhanced the responses of the pulvinar and voxels located along the ventromedial surface of the LGN, corresponding to the location of the magnocellular layers, while voxels along the dorsolateral surface of the LGN, corresponding to the location of the parvocellular layers, showed the opposite effect; the SC was inconsistently modulated among subjects. These feature-based attentional modulations could not be explained by differential allocations of spatial attention. All of the subcortical nuclei demonstrated enhancement in hemodynamic activity preceding the attentional switches between the features; however, suppression was observed in voxels along the lateral edge of the LGN, perhaps corresponding to the thalamic reticular nucleus, and voxels in what appeared to be the superficial layers of the SC. We conclude that feature-based attention operates throughout the visual system via modulation of activity in neurons that encode the attended feature.

32.26, *12:15 pm*

The flipside of object individuation: Neural representation for object ensembles

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Imagine you are in a supermarket looking for apples. You need to first find the right fruit pile by representing collections of objects without encoding each object in the collection in great detail. After you locate the apple pile, you can proceed to pick out the best-looking apples by encoding individual objects with their detailed features. While a huge amount of research effort has been dedicated to understanding how we represent specific objects, our knowledge of the cognitive and neural mechanisms underlying object ensemble representation is still incomplete. Using the fMRI-adaptation paradigm, we showed participants a sequence of three images that were either all identical, all different, or shared object ensemble statistics (e.g. three different non-overlapping snapshots of the same apple pile). Using an independent localizer approach, we found that the lateral occipital complex (LOC) showed a significant release from adaptation (i.e. a rise in activation compared to the 'identical' condition) in both the 'shared' and 'different' conditions (which did not differ from each other). In contrast, ventral medial visual cortex including areas in the collateral sulcus and the parahippocampal place area (PPA) showed statistically equivalent levels of repetition attenuation (i.e. a reduction in activation compared to the 'different' condition) in both the 'identical' and 'shared' conditions (which did not differ). These results indicate that while the LOC is involved in encoding specific object features (which is consistent with previous findings), the ventral medial visual cortex may be involved in representing ensemble statistics from object collections. Notably, although our stimuli contained minimal amount of 3D scene information, the PPA exhibited adaptation when ensemble statistics were repeated. This suggests that the PPA may contribute to scene representation by extracting ensemble statistics rather than the 3D layout of a scene.

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32.27, *12:30 pm*

Neural signatures of shape discrimination decisions at threshold

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The lateral occipital cortex (LOC) is known to selectively activate to intact objects versus scrambled controls, to be selective for figure-ground relationship, and to exhibit at least some degree of invariance for size and position. Because of these features, it is considered to be a crucial part of the object recognition pathway. Here we determined if the LOC is involved in shape discriminations. High-density EEG was recorded while subjects performed a threshold-level shape discrimination task on figures segmented by either phase or orientation cues. Our paradigm allowed us to separate responses due to the figural cue from the responses corresponding to the discrimination of shape. The appearance or disappearance of a figure region in the stimuli generated robust visual evoked potentials localized throughout retinotopic cortex. Contrasting responses from trials containing a shape change (hits) with trials in which no change occurred (correct rejects) revealed activity preceding the subject's response in the LOC that was selective for presence of the target shape change. Task-dependent activity that was time-locked to the subjects' response was found in frontal cortex. Activity in the LOC was determined to be related to shape discrimination for several reasons: Shape-selective responses were silenced when subjects viewed identical stimuli but their attention was directed away from the shapes to a demanding letter discrimination task; shape-selectivity was present across all cues used to define the figure; shape-selective responses were present under conditions where stimulus-locked activity was absent. These results indicate that decision-related activity is present in the LOC when subjects are engaged in threshold-level shape discriminations.

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Sunday AM

Spatial vision: Crowding and eccentricity

Royal Ballroom 6-8, Boards 301–317

Sunday, May 9, 8:30 - 12:30 pm

33.301 The mechanism of word crowding

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Word reading speed in peripheral vision is slower when words are in close proximity of other words (Chung, 2004). This word crowding effect could arise as a consequence of interaction of low-level letter features between words, or the interaction between high-level holistic representations of words. We evaluated these two competing hypotheses by examining how word crowding changes for five configurations of flanking words: the control condition — flanking words were oriented upright; vertical-flip — each flanking word was the up-down mirror-image of the original; horizontal-flip — each flanking word was the left-right mirror-image of the original; letter-flip — each letter of the flanking word was the left-right mirror-image of the original; and scrambled — letters in each flanking word were scrambled in order. The low-level feature interaction hypothesis predicts similar word crowding effect for all the different flanker configurations, while the high-level representation hypothesis predicts less word crowding effect for all the alternative flanker conditions, compared with the control condition. Six young adults read sequences of six random four-letter words presented one at a time, using the rapid serial visual presentation paradigm. Words (2° print size) were presented at 10° in the nasal field of the left eye of each observer. For each flanker configuration, reading speed was determined when the target words were presented alone, or flanked above or below by other words at one of four vertical word spacings (0.7×, 1×, 1.5×, and 2× standard line spacing). Across observers, the reading speed vs. spacing functions were very similar for all flanker configurations. Reading speed was unaffected by flankers until the word spacing was reduced to 0.7× ($p<0.0005$) when reading speed dropped by an average of 34%, compared with the unflanked reading speed. The remarkably similar word crowding effect irrespective of the flanker configurations suggest that word crowding arises as a consequence of interaction of low-level letter features.

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33.302 Semantic and identical word priming reduces peripheral word crowding and reaction times

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Visual crowding dramatically reduces the perception of word form and meaning in peripheral vision. Previous research demonstrates that crowded letters and shapes can be “demasked” when the same form is simultaneously presented at the fovea, provided the central and peripheral figures are similar in orientation and contrast (Geiger, Lettvin, Perception, 1985). The present study explored whether a briefly presented, but visible, identical or semantically related foveal prime word would “uncrowd” flanked peripheral words compared to an unrelated prime condition. We tested eighteen observers across three target eccentricities (fovea, 4°, and 8°) and three prime-target relationships (unrelated, identical, or semantically related). Using a dual-task design, participants first discriminated target words from non-words in a 2 AFC peripheral lexical decision task (LDT). In the second task, observers gave a letter-by-letter account of the target, providing a more detailed report of the deleterious effects of crowding. Across all eccentricities, LDT percent correct and discriminability (d’) improved modestly, but not significantly, on identical and semantically related trials compared to the unrelated prime condition. However, the letter-by-letter analysis revealed that identical and semantically related word trials reduced crowding and reaction times. Subjects correctly reported all letters of the crowded word more often in both the identical and semantically related conditions ($F(2,34)= 15.6$, $p<0.01$). Further, on correct LDT trials, reaction times were reduced for both identical and related word pairs across all eccentricities ($F(2,34)= 12.2$, $p<0.01$). Taken together, these results suggest that LDT does not provide the most sensitive measure of semantic influences on word crowding. More importantly, these results demonstrate that semantic priming at the fovea can reduce peripheral word crowding and facilitate reaction times. This adds to a growing body of research demonstrating that the resolution of vision in crowded scenes can be modified by learning and prior experience.

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33.303 Two locations are better than one: Improving peripheral reading speed by reducing spatio-temporal interactions of words

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Interaction between objects in close proximity could occur spatially and/or temporally. The purpose of this study was to investigate whether peripheral reading speed could improve by reducing the spatio-temporal interaction between successive words of a sentence. We hypothesized that presenting words at alternating spatial locations would reduce the spatio-temporal interaction of successive words and thus enhance reading performance. Eight observers with normal vision (aged 20 to 24) read aloud single sentences, presented one word at a time, using rapid serial visual presentation (RSVP). Testing was conducted at the fovea and 10° eccentricity in the inferior visual field. Print sizes were larger than the critical print size at each eccentricity. Words of each sentence were presented at the same location on the display (0 separation: control), or alternated between two vertically separated locations (1×, 1.4×, 2×, 2.6×, 3.6×, 5.2× the x-height). For each condition, the number of words read correctly was measured for six RSVP word exposure durations that spanned approximately 1 log unit, with six sentences per duration. Reading speed was calculated based on the duration that yielded 80% accuracy. At the fovea, the geometric mean reading speed for the eight observers ranged between 676 and 799 wpm and did not vary with vertical separation. At 10° eccentricity, however, reading speed did depend on vertical separation ($p<0.0005$). The geometric mean reading speed was 242 wpm for the control (zero-separation) condition, but was fastest at a vertical separation of 1.4× x-height (14% improvement, $p = 0.042$) and slowest at a vertical separation of 5.2× x-height (15% reduction, $p = 0.003$). Our results suggest that presenting words at two slightly separated spatial locations can reduce the spatio-temporal interaction between successive words and enhance reading speed in the periphery. These findings have important rehabilitative implications for patients with central vision loss.

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33.304 Effects of dioptric blur on foveal acuity and contour interaction for noisy Cs

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Contour interaction for visual acuity has been found to dissipate with imposed dioptric blur of +1.50D using standard luminance letters and bars (Simmers et al, 1999). It is unclear how dioptric blur affects visual acuity or contour interaction for letters imbedded in noise. We examined the effects of dioptric blur on luminance-modulated and contrast-modulated noise Cs with and without surrounding contours. Stimuli were constructed from random dot dynamic noise, added or multiplied to a square-wave profile. We measured foveal acuity for a square-shaped C with and without four flanking bars separated by 0 to 2 letter widths under different levels of dioptric blur (0-2D with flanks; 0-4D without). Acuity was measured using a method of constant stimuli and 4AFC paradigm for approximately equally visible luminance-modulated and contrast-modulated noisy Cs. Acuity thresholds for isolated contrast-modulated Cs are about 0.3 logMAR higher than for luminance-modulated Cs at all blur levels. The effect of increasing blur on acuity is ~0.3 logMAR/D (from 0 to 4D). The relative peak magnitude of contour interaction for the contrast-modulated C is greater (by ~0.1 logMAR) and more extensive, than for the luminance-modulated C. Dioptric blur up to 2D raises both types of isolated C acuity thresholds similarly, but affects their contour interaction parameters differently. The magnitude of the peak effect is directly related to the unflanked logMAR threshold (or letter size). However with increasing blur, the extent of interaction is maintained for the contrast-modulated C, but reduced significantly for the lumi-

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nance-modulated C (as for standard luminance letters; Simmers et al, 1999). For these blur levels, contrast-modulated Cs are more subject to contour interaction effects than luminance-modulated Cs. This could be a result of larger integration areas for contrast-modulated stimuli and a differential effect of blur on contrast and luminance modulation sensitivity functions.

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33.305 **Effects of contrast on foveal acuity and contour interaction using luminance and contrast modulated Cs**

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The effects of flanker contrast on contour interaction have been investigated for large letters (e.g. Chung et al, 2001). However, except from clinical studies of crowding using fixed letter separation (eg. Kothe and Regan, 1990; Simmers at al, 1999), it is not known how foveal acuity thresholds and contour interaction are affected by decreased target and flanker contrast.

We measured gap resolution thresholds for a luminance-modulated and contrast-modulated square C in isolation and in the presence of flanking bars. Stimuli were created by adding or multiplying binary noise to a square-wave signal. The modulation depths of the target and the flankers were either (1) equal and changed in unison or (2) different, in a ratio of ~0.5 to ~1.5.

Gap resolution thresholds increase with a decrease in contrast (or modulation depth), at a slightly faster rate for luminance-modulated than contrast-modulated Cs. For both types, the peak magnitude and extent of the interaction decreases as the contrast of the C and the bars is reduced. The relative peak magnitude is greatest when the flankers abut the target, saturates at high contrasts, and at saturation is higher for contrast-modulated (~logMAR 0.2) than for luminance-modulated (~logMAR 0.1) stimuli. When the contrast of the flankers is higher than that of the target, the magnitude of the interaction is greater than when the flankers are of similar or lower contrast.

The reduction of contour interaction with lowered contrast is in agreement with the findings of clinical studies that used noiseless letters. The lack of scaling of the extent of interaction with resolution threshold (letter size) suggests that contrast masking cannot fully explain foveal contour interactions. The effects of relative contrasts show that, like the interaction observed with large letters in peripheral vision (Chung et al, 2001), foveal contour interaction is not grouping by contrast.

Acknowledgement: MIH holds a PhD Scholarship funded by the Government of Malaysia

33.306 **Crowding and Multiple Magnification Theory**

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Background: Although uniform stimulus magnification often compensates for eccentricity dependent sensitivity loss, crowding is frequently cited as a refutation of magnification theory. However, if one assumes multiple sources of eccentricity-dependent sensitivity loss then changes in crowding with eccentricity may be characterized simply in terms of non-uniform magnifications with eccentricity (Latham & Whitaker, 1996, OPO). Method: In three experiments we measured size thresholds for relative target/crowder separations of 1.25, 1.70, 2.32, 3.16, 4.31, 5.87, 8.00 and ∞ times target size. The sizes of target and crowders were varied uniformly to find the size eliciting threshold-level performance. Thresholds were measured at 0, 1, 2, 4, 8 and 16° in the lower visual field. The three tasks were grating orientation discrimination (Latham & Whitaker, 1996), T orientation discrimination (Tripathy & Cavanagh, 2002, VR) and letter identification (Pelli et al. 2007, JoV). We plotted target size at threshold as a function of separation at threshold. Results: In all cases size thresholds at fixation were independent of target/crowder separation. In other words, there was no effect of crowding at fixation. At all other eccentricities log(threshold size) decreased roughly linearly as log(separation) increased until asymptote was reached, at which point size thresholds were independent of separation. However, the rate at which threshold size decreased with separation increased with eccentricity and in some cases reached a point at which a critical separation was achieved; i.e., separation at threshold was independent of target size (Pelli, 2008, COIN). Conclusions: Although there are systematic changes in the size/separation curves from fovea to periphery there seems to be a qualitative change between fixation and periphery: at fixation size thresholds are separation independent and at the furthest eccentricities separation thresholds approach size independence. Contrary to our expectations multiple linear magnifications seem inadequate to characterize the data.

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33.307 **Position and orientation are bound in crowding**

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The recognition of complex objects, like letters, requires the encoding of multiple visual attributes, such as orientation and position, and their binding into features. While the encoding of individual attributes is impaired by clutter, a process known as crowding, it is unclear whether crowding is driven by interactions between these attributes or between features (i.e. conjunctions of attributes). To test this idea, we investigated the interaction between crowding effects on two feature attributes: position and orientation. Stimuli were crosses composed of two near-orthogonal lines, presented 15deg. in the upper visual field. When crowded, the target cross was flanked to the left and right by flanker crosses (with 2.25deg. separation). Observers were required to judge either the orientation (clockwise/counterclockwise) or position (up/down relative to the stimulus centre) of the near-horizontal target feature. We first confirm the effects of crowding on the discrimination of orientation and position separately. For each feature attribute, crowding induces both threshold elevation (i.e. impaired discrimination) and a systematic bias in target identification towards the identity of the flanker features (i.e. responses are biased towards either the flanker feature-positions or orientations). We next examined the interaction between these crowding effects by requiring conjoint judgements of both the orientation and position of the near-horizontal target feature. If crowding occurred independently for each feature attribute, errors in target identification should be equally likely in either orientation or position, with a lower probability of combined errors for both attributes. In contrast, when targets and flankers differed in both orientation and position, errors were significantly more likely to occur for both attributes simultaneously (matching flanker identities) than for either attribute in isolation. This suggests that crowding takes place either after, or during, binding of the position and orientation of features within objects.

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33.308 **Visual acuity and contour interaction for luminance-modulated and contrast-modulated Cs in normal foveal vision**

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Interactions between suprathreshold luminance-modulated and contrast-modulated stimuli have been found for letter contrast detection (Chung et al, 2007) and Gabor contrast matching (Ellemberg et al, 2004) however it is not known how they interact for the classical visual acuity task (Flom et al, 1963). Luminance-modulated and contrast-modulated square Cs and bars were constructed by adding or multiplying square-wave modulating signals to dynamic binary noise. C gap acuity thresholds were obtained using a 4AFC paradigm with the method of constant stimuli. Bar separations varied from abutting to two letter widths. Cs were either equated in their visibilities (~3.5x above contrast thresholds) or presented at maximum producible modulations. Threshold versus separation data were fit with a Gaussian to objectively determine magnitude and extent of contour interaction. When the C and bars are of the same type, typical patterns of contour interaction are observed. Acuity threshold elevation for abutting bars is significantly larger for the contrast-modulated C (0.2 logMAR) than for the luminance-modulated C (0.1 logMAR); $p<0.05$; the lateral extent of interaction (2sd of Gaussian) is also larger (4.37±1.4 gap widths versus 3.25±0.4 gap widths) but not significantly different ($p>0.1$). When the luminance-modulated C is flanked by contrast-modulated bars (212), acuity is adversely affected in similar fashion to same-type contour interaction but with peak magnitude: 0.15 logMAR. Reduced bar visibility significantly reduces the effect ($p<0.05$). When contrast-modulated C is flanked by luminance-modulated bars (121), a similar pattern of results occurs with peak magnitude: 0.15 logMAR. Increasing bar visibility significantly increases contour interaction ($p<0.05$). The similar effects of flanks of different type on C visual acuity suggest that luminance and contrast modulations are not treated independently at the level of resolution processing.

Acknowledgement: MIH holds a PhD scholarship funded by the Government of Malaysia

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33.309 **Size illusion and crowding**

Jungang Qin[1](jungang.qin@usc.edu), Bosco S. Tjan[1,2]; [1]Department of Psychology, [2]Neuroscience Graduate Program, University of Southern California

Crowding represents an essential bottleneck for form vision in the peripheral field (Levi, 2008). The severity of crowding depends on the center-to-center spacing between target and flankers and the critical spacing corresponds to a 6 mm separation on V1 cortex (Pelli, 2008). The perspective cue of a scene can induce changes in both the perceived object size and spacing. An increase in the perceived size leads to a corresponding increase in the spatial extent of fMRI activation in V1 (Murray, et al., 2006). Do the perceived object size and spacing affect crowding? We examined this question by presenting letters against a computer-rendered hallway scene with strong perspective cue. Letters of constant size appeared larger when presented at 3/8 the screen height measured from the top of the display ("far" condition) than at 6/8 the screen height("near" condition). Contrast thresholds were measured for identifying a target letter when it was presented either alone or flanked by other letters. The letters were presented either at the "near" or "far" location, each with its own fixation to ensure a target eccentricity of 10°. In the control conditions, the hallway scene was replaced with a local patch of the scene covering the "near" or "far" letter area with a 1.43 x-height margin. Contrast thresholds were normalized with respect to the corresponding local-patch conditions. We found that the normalized threshold elevation due to crowding was reduced by an average of 0.24 log units at the "near" position (where letters appeared smaller) compared to the "far" position (where letters appeared larger). This counterintuitive finding suggests that the smaller perceived size might induce a narrower distribution of spatial attention or reduced positional uncertainty, which in turn reduces crowding.

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33.310 **Effects of Kanizsa's illusory contours on crowding strength**

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Purpose: Crowding is the detrimental effect of surrounding objects on the identification of a target object. The cortical locus of crowding remains a controversy. Processing of Kanizsa's illusory contours has been shown to start at V3. Here we attempt to localize crowding relative to V3 by asking if illusory contours influence crowding. Methods: Five normally sighted young adults participated. Target stimulus was a Kanizsa's square inducer (0.5° diameter) presented at 4.5° eccentricity in the lower right visual field for 200ms. Subjects identified the target orientation in a 4AFC task. In the 4-flanker condition, 3 inducers were positioned to form a Kanizsa's square with targets of 1 orientation. Center-to-center distance between the target and the lower right inducer was 1°. The fourth flanker was another inducer placed at 1° radially from the target on the fixation side. In the 2-flanker condition, the upper right and lower left inducers were removed. Discrimination index (d') for each target orientation was calculated from 60 trials for both conditions. Results: Illusory contours (IC) could be perceived only in 1 of the 4 target orientations in the 4-flanker condition. The 4-flanker condition had lower d', indicating strong crowding, than the 2-flanker condition for all target orientations. Average differences in d' between the 4-flanker and 2-flanker conditions for the IC-present and IC-absent trials were 0.50+0.16 and 0.72+0.16 respectively. IC-present trials resulted in significantly smaller d' difference than IC-absent trials ($t(4) = 2.60$, $p = .03$, one-tailed), indicating higher resistance to crowding from 2 additional flankers. Conclusion: Effect of additional flankers was reduced by the formation of illusory contours. The results suggest that illusory contour processing occurs before crowding, and thus, the cortical locus for crowding would be after V3. Preliminary results from a follow-up experiment with classification image supported the utilization of illusory contours in our task.

33.311 **Temporal crowding with normal observers and its interplay with spatial crowding**

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Spatial crowding refers to cases in which a target is flanked by other stimuli presented simultaneously with the target, and temporal crowding refers to cases in which the target is surrounded in time by other stimuli (i.e., stimuli that appear before and after the target). Recently, Bonneh, Sagi and Polat (2007) have demonstrated that temporal and spatial crowding in amblyopic observers are interrelated. However, only low crowding was found for their normal group, possibly due to foveal presentation. This study examined whether similar relations between temporal and spatial crowding can be found for normal observers with peripheral presentation. To measure simultaneously both temporal and spatial crowding, a rapid sequence of 3 displays was presented on a given trial at 9° of eccentricity. Each display included 3 letters. In one of these displays, the central letter was an oriented T, and the observers had to indicate the T's orientation. The spatial distance between the T and its flankers and the temporal spacing (ISI) between the displays was systematically manipulated to determine the extent of spatial and temporal crowding when measured concurrently. As expected we found spatial crowding: accuracy improved as the target-flankers spacing increased. This spatial crowding emerged regardless of the target temporal position but it significantly interacted with ISI: the effect was more pronounced at shorter ISIs. We also found temporal crowding: accuracy increased as the ISI between the displays increased, though this effect was considerably smaller than the spatial effect. Interestingly, the extent of this temporal crowding was larger for smaller target-flankers spacing and was more pronounced when the target appeared at the first temporal position. Hence, when the stimuli are presented at peripheral locations both spatial and temporal crowding can be demonstrated with normal observers. Moreover, as with amblyopic observers, these two types of crowding interact.

33.312 **Symmetry and Crowding Across the Visual Field**

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Background: There is a consensus that crowding is a property of peripheral (but not foveal) vision and that crowding zones are elliptical and oriented towards the fovea. However, Latham and Whitaker (1996) found evidence of crowding at fixation and suggested that multiple linear magnifications were required to explain the changes in crowding from fixation to the periphery. Past studies of crowding have involved gratings (e.g., Latham & Whitaker, 1996, OPO) or alphanumeric characters (e.g., Cavanagh, 2002, VR; Pelli et al. 2007, JoV). Here we ask whether the basic characteristics of crowding apply to biologically relevant stimuli; specifically, symmetry. Furthermore, we ask whether multiple linear magnifications explain the changes in crowding from fixation to the periphery. Method: We measured size thresholds for target/crowder separations of 1.25 to 8.00 times target size, as well as a no-crowder condition, in a symmetry discrimination task. Thresholds were measured with the target at fixation and 8° below or to the right of fixation. In one condition the crowders flanked the target vertically and in another they flanked the target horizontally. In all cases we plotted target size at threshold as a function of separation at threshold. Results: At fixation, size thresholds were independent of target/crowder separation. At all other eccentricities threshold size decreased as separation increased until asymptote was reached, at which point size thresholds were independent of separation. As well, crowding was stronger when flankers were presented parallel to the fixation-to-target axis, consistent with the suggested structure of crowding zones. Conclusions: Consistent with previous literature it appears that there is a qualitative difference in crowding across the visual field; symmetry appears to behave like previously studied stimuli. Therefore, contrary to our expectations, and previous data (Latham & Whitaker, 1996), multiple linear magnifications seem inadequate to characterize the data.

Acknowledgement: NSERC and CIHR grants awarded to Rick Gurnsey

33.313 **Size Pooling**

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Does crowding affect apparent size? Korte (1923) and Liu & Arditi (1999) reported that a crowded string of letters appears shorter in length, possibly abbreviated, with letters missing. We present three rectangles, a target between flankers, all 1 deg high arranged horizontally, 10 deg to the right of fixation. The flankers are 1 deg wide. We tested several target widths: 0.75, 1.0 and 1.25 deg. Target-flanker spacing is 1.25 deg, center to center. We also tested without flankers. A reference rectangle is always present 5 deg above the target object, beyond the range of crowding. While maintaining fixation, the observer adjusts the width of this reference to match the apparent width of the target object. Relative to the unflanked condition, flankers decreased the apparent width of the target by 19% when the flank-

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ers were narrower and increased by 9% when the flankers were wider than the target. Thus, the apparent width of the target is a weighted average that includes the flankers. This is size pooling.

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33.314 **Pool party: objects rule**

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To recognize an object we first detect features and then combine or "pool" them. Crowding, the inability to identify a peripheral object surrounded by flankers, is thought to be a breakdown of feature pooling. Thus, it has been widely used to study object recognition. Features within objects are usually spatially distributed. How much do the flanker features furthest from the target affect crowding? Do features need to be part of an unbroken object to be combined with target features?

We create a set of six target objects consisting of jagged vertical sides attached by flat tops and bottoms. These objects differ only in the features on their jagged sides. All flankers are derived from this set. We use whole objects as flankers in one condition, and broken objects as flankers in others. We break an object by introducing a gap between its jagged sides, violating object closure. At various eccentricities, we present a target object between two flankers. We vary the width of the flankers by keeping the near jagged side a constant distance from the target while moving the far jagged side (for unbroken objects, top and bottom stretches, for broken objects, size of gap increases). We find that, in the whole object condition, as the flanker's far side moves closer to the target, crowding increases. However, for broken objects, moving the far side closer to the target does not affect crowding. Further, there was little crowding with broken objects. We ruled out target-flanker similarity as an explanation. Our finding that the far side of a flanker combines with the target object only when it is attached to the near side suggests that objects, not features, pool. We conclude that whether a flanking feature is combined with the target depends on what flanking object the feature belongs to.

33.315 **Object Crowding**

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Crowding occurs when stimuli in the peripheral field become harder to identify when flanked by other items within a spatial extent that depends on eccentricity (Korte, 1923; Bouma, 1970). Crowding has been demonstrated extensively with simple stimuli such as gabors and letters. Here we characterize crowding for everyday objects. We presented three-item arrays of objects and of letters, arranged radially and tangentially in the lower visual field. Observers identified the center object, and we measured contrast energy thresholds as a function of target-to-flanker spacing (center-to-center). We found that object crowding is similar to letter crowding in spatial extent, but is much weaker (~2.5x vs. ~11x in threshold elevation relative to an unflanked target). We also examined whether the exterior and interior features of an object, operationally defined, are differentially affected by crowding. We used a circular aperture to present either just the interior portion of an object or everything else but the interior (a 'donut' object). For both apertures and donuts, critical spacing and threshold elevation were similar to those of intact objects. To sum up, crowding between objects does not significantly differ from that between letters in terms of spatial extent and the anisotropy along the radial and tangential directions. However, crowding-induced threshold elevations for objects (intact, aperture, donut) are much lower than that for letters. Taken together, these findings suggest that crowding between letters and objects are essentially due to the same mechanism, which affects equally the interior and exterior features of an object. However, for objects, it is easier to compensate for the loss in performance by increasing contrast.

Acknowledgement: NIH R01-EY017707, R01-EY016093

33.316 **Objects crowded by noise flankers**

Kilho Shin[1](kilhoshi@usc.edu), Julian M. Wallace[1], Bosco S. Tjan[1,2]; [1]Department of Psychology, University of Southern California , [2]Neuroscience Graduate Program, University of Southern California

Crowding is a key limiting factor of form vision in the peripheral field. A prominent theory of crowding is that of inappropriate feature integration (Levi, 2008; Pelli & Tillman, 2008). However, it is not known what features are inappropriately integrated. Tjan and Dang (2005, VSS) addressed this question by flanking a letter target with different types of flankers. They found that a noise flanker obtained by phase-scrambling a letter crowded a letter target as effectively as a letter flanker. Here we repeated their experiment with gray-scale images of everyday objects in place of letters. We measured contrast threshold elevation for identifying a target object presented at 10° below fixation as a function of target-flanker spacing (center-to-center: 1°, 1.5°, 2.25°, 3.375°). At small spacing where the target and flanker stimuli overlapped, the target was made to occlude the flankers. We used four types of flankers: intact objects, anisotropic pink noise (phase-scrambled objects), isotropic pink noise (phase-scrambled and orientation-scrambled objects), and white noise. As with letters, we found that anisotropic pink noise flankers led to essentially the same threshold vs. spacing function as intact object flankers, with a maximum threshold elevation of about 0.7 log units. White noise flankers led to the least amount of crowding, with threshold elevation less than 0.2 log units. Isotropic pink noise flankers produced an intermediate amount of crowding, with a maximum threshold elevation of about 0.6 log units. Taken together, these results suggest that the features that are inappropriately integrated are those that are common to the intact and the phase-scrambled objects, thus strongly implicating narrowband Gabor-like features. Comparisons between the isotropic and anisotropic pink noise conditions further suggest that the orientations of these Gabor features are relevant for crowding.

Acknowledgement: NIH/NEI R01-EY017707, R01-EY016093

33.317 **Unconscious processing of emotion in crowded display**

Nathan Faivre[1](nathan.faivre@ens.fr), Vincent Berthet[1], Sid Kouider[1]; [1]Laboratory of Cognitive Sciences and Psycholinguistic, Ecole Normale Supérieure, Paris, FRANCE.

We present a new "gaze-contingent substitution" paradigm, aiming at characterizing unconscious processes in crowded displays. Crowding occurs when nearby flankers impede the identification, but not the detection, of a peripheral stimulus. The origins of crowding effects in the visual system are still only poorly understood. According to bottom-up proposals, hard-wired limitations in the primary visual cortex cause the information about the crowded stimulus to be lost very early, any information being pooled with that of the flankers. According to top-down proposals, however, the smallest region of the visual field that can be isolated by attention is much coarser than the smallest details resolvable by vision. Crowding would then reflect a partial conscious read-out of perceived information due to a lack of attentional resolution. In this work, we show that not only static but also dynamic emotional primes (i.e., videos of faces) rendered unconscious by crowding can bias a decision on subsequent preference judgments. Importantly, control experiments show that this unconscious transfer of valence does not occur with inverted faces. Other methods such as continuous flash suppression, during which stimuli are suppressed from awareness through binocular rivalry, are also studied. Comparison of the two methods reveals stronger unconscious effects in crowding. These results are discussed in light of current theories of crowding and favor a top-down explanation in which crowded stimuli are not lost in V1 but rather can bias decisions at an abstract level. These results motivate continued research on the unconscious processing of dynamic stimuli.

Perception and action: Navigation and mechanisms

Royal Ballroom 6-8, Boards 318–331

Sunday, May 9, 8:30 - 12:30 pm

33.318 **Perceiving pursuit and evasion by a virtual avatar**

William Warren[1](Bill_Warren@brown.edu), Jonathan Cohen[1]; [1]Dept. of Cognitive & Linguistic Sciences, Brown University, Providence, RI

How do we perceive the behavioral intentions of another pedestrian? In this study, a virtual avatar is programmed to pursue or evade the participant in an ambulatory virtual environment. The avatar is driven by our steering dynamics model (Fajen & Warren, 2007; Cohen, Cinelli, & Warren, VSS 2008, 2009). We investigate whether the perception of pursuit and evasion is based on the avatar's trajectory, which is contingent on the participant's movements, and on the direction of the avatar's head fixation. Participants wore a head-mounted display (63° H x 53° V) and walked toward an approaching avatar, while head position was recorded using an inertial/ultrasonic tracking system (70 ms latency). Avatars could (a) pursue or evade the participant, and (b) fixate or look straight ahead; pursuers fixated the participant and evaders fixated and walked to a point behind the participant. In Exp. 1, a single avatar appeared at 6, 7, 8, or 9 m, and participants reported whether it was pursuing or evading them. Mean d' was 2.5, and head fixation only contributed at 6 m. Mean RT was 2-3 s; head fixation provided a half-second advantage for pursuit at 7 and 8 m, but a half-second disadvantage for evasion at all distances. In Exp. 2, two, three, or four avatars appeared; one was a pursuer, and the others were evaders. The participant reported which avatar was pursuing them. RT increased with the number of distractors, and there were small improvements with fixation. The results indicate that pursuit/evasion is reliably perceived from the avatar's contingent trajectory alone, and that they are judged sequentially. Head fixation provides a modest additional advantage at close ranges.

Acknowledgement: NIH R01 EY10923

33.319 **Follow the leader: Behavioral dynamics of following**

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Can human crowd behavior be explained as an emergent property of local rules, as in flocking (Reynolds 1987) and fish schooling (Huth & Wissel 1992)? Here we derive one such possible 'rule:' a dynamical model of following another pedestrian. We collected position data from pairs of pedestrians walking in a 12m x 12m room, using an inertial/ultrasonic tracking system (IS-900, 60 Hz). The 'leader' (a confederate) walked in a straight path. After 3 steps at a constant speed, the leader would (a) speed up, (b) slow down, or (c) remain at the same speed for a variable number of steps (3, 4, or 5), and then return to his original speed. The 'follower' (a subject) was instructed to maintain a constant distance from the leader (1m or 3m). We evaluate several candidate following models, in which the follower's acceleration is controlled by (a) nulling change in distance, (b) nulling change in relative speed, or (c) more complex functions of these variables, drawing inspiration from studies of vehicle-following in traffic (Brackstone 1999). For each model, we cross-correlate the predicted acceleration of the follower with the observed acceleration in the tracking data. Future work will investigate the visual information that serves as input to the model. Once a control law for following is characterized, it can be integrated with other components for steering toward goals, avoiding obstacles, and intercepting moving targets (Fajen & Warren 2003, 2007). This will allow us to empirically determine whether human crowd behavior does indeed emerge from such local interactions.

Acknowledgement: NIH R01 EY10923

33.320 **Why does the rabbit escape the fox on a zig-zag path? Predator-prey dynamics and the constant bearing strategy**

Charles Z Firestone[1](charles_firestone@brown.edu), William H Warren[1]; [1]Department of Cognitive and Linguistic Sciences, Brown University

It is frequently observed that prey often evade predators by darting back and forth on a zig-zag path, rather than simply outrunning them on a straight path. What might account for this behavior? Previous work has shown that humans, dragonflies, and bats intercept moving targets by nulling change in the bearing angle of the target. The present research investigated whether a zig-zag escape path may be an effective countermeasure to this constant bearing strategy. Computer simulations randomly generated hundreds of thousands of 'prey' escape paths, each of which was tested against Fajen & Warren's (2007) dynamical model of the 'predator's' constant bearing strategy. Parameters included the angle and frequency of turns in the escape path, initial distance between predator and prey, relative speed of predator and prey, and the predator's visual-motor delay. Performance was measured as ground gained by 'prey' over 'predator.' Zig-zag paths emerged as the most effective escape route, and succeeded even when the prey was slower than the predator and a straight path would have failed. Analysis revealed a strong positive correlation between the variability in the bearing angle and the ground gained by the prey, suggesting that zig-zag paths succeed by disrupting the predator's efforts to hold the bearing angle constant. A rule of thumb for prey also emerged from the data: When the predator 'zigs,' you should 'zag.' We are currently collecting data on human 'predators' pursuing virtual 'prey' in an ambulatory virtual environment, to test the simulation predictions and to determine whether humans maintain the constant bearing strategy. Future work will test an interactive escape strategy in which the prey's 'zags' are contingent upon the predator's 'zigs.' The results suggest that zig-zag escape paths are common because they are effective countermeasures to the constant bearing strategy.

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33.321 **The influence of external landmarks, the sun, and cast shadows on learning a wormhole environment**

Jonathan Ericson[1](Jonathan_Ericson@brown.edu), William Warren[1]; [1]Cognitive & Linguistic Sciences, Brown University

In previous research, we created a non-Euclidean hedge maze by introducing two "wormholes" that seamlessly transported participants between locations, by means of rotating the virtual environment. Participants relied on the topological graph structure (route knowledge) to navigate, and were unaware of the radical violations of global Euclidean structure (rips and folds in space). Here we provide more information about maze orientation by adding external landmarks, a sun, and cast shadows. Participants actively walk in a 40 x 40 ft. virtual environment while wearing a head-mounted display (63° H x 53° V), and head position is recorded with a sonic/inertial tracker (70 ms latency). Participants learn the locations of nine objects (places) by freely exploring the maze in one of three conditions: (1) a control condition with uniform lighting and no external landmarks, (2) a test condition in which the light source and external landmarks rotate with the maze, and (3) a test condition in which the light source and external landmarks remain fixed with respect to the laboratory. We then probe their spatial knowledge in each condition using a shortcut task, in which participants walk from Home to object A, the maze disappears, and they are instructed to walk directly to the remembered location of object B. If participants use the cast shadow and landmark information to detect the maze rotation, they may report violations and walk to the metric location of object B more frequently than in the control condition. If participants rely on the graph structure of the maze despite the additional orientation information, they should walk through a wormhole to the alternative target location, B1, as they do in the control condition. Acknowledgments: NSF BCS-0214383, BCS-0843940

Acknowledgement: NSF BCS-0214383, BCS-0843940

33.322 **Learning a new city: Active and passive components of spatial learning**

Elizabeth Chrastil[1](elizabeth_chrastil@brown.edu), William Warren[1]; [1]Cognitive and Linguistic Sciences, Brown University

When arriving in a new city, how do you learn its layout? It seems that actively walking around would lead to better spatial knowledge than passively riding in a taxi, yet the literature is decidedly mixed. However, "active" learning has several components that are often confounded. We test the contributions of four components to spatial learning: visual information, vestibular information, motor/proprioceptive information, and cognitive decisions. Participants learn the locations of 10 objects in an ambulatory virtual maze environment, and are then tested on their graph and survey knowledge of object locations. Six learning conditions are crossed with two test conditions, for a total of 12 groups of participants: (a) Free Walking: participants freely explore the environment for 10 minutes, providing all components of active exploration. (b) Guided Walking: participants are guided along the same paths, removing the decision-making component. (c) Free Wheelchair: participants steer through the maze in a wheelchair by pressing buttons to indicate left and right turns, minimizing motor/proprioceptive information. (d) Guided Wheelchair: participants are wheeled through the maze along paths that match the Free Walking condition, removing motor/proprioception and decision-making, (e) Free Video: participants steer through a desktop VR maze by pressing buttons, removing motor/proprioceptive and vestibular information. (f) Guided Video: participants watch a participant's-eye video of the Free Walking condition, providing passive learning. In the test phase, participants are wheeled to object A and instructed to walk to the remembered location of object B: (i) Survey knowledge task: the maze disappears and participants take a direct shortcut from A to B. (ii) Graph knowledge task: participants walk from A to B within the maze corridors, with detours. We expect that active decisions will be sufficient for graph knowledge, whereas active motor/proprioceptive and/or vestibular information will be necessary for metric knowledge, and both will surpass passive learning.

Acknowledgement: NASA/RI Space Grant

 See page 3 for Abstract Numbering System

33.323 **Putting New Zealand on the map: Investigating cognitive maps in human navigation using virtual environments**

Diane M. Thomson[1](dmt9@waikato.ac.nz), John A. Perrone[1]; [1]The University of Waikato, Hamilton, New Zealand

The mechanisms underlying navigation in complex environments are currently not very clear, particularly the role of visual rotation information. We therefore examined the accuracy of human path integration abilities based on purely visual information (e.g., depth cues, optic flow information and landmarks), focusing mainly on the effects of self-rotation by the navigator. Participants navigated either actively or passively through realistic large-scale virtual environments in a driving simulator, along routes consisting of roads linked by a traffic circle. The environments were modelled on real New Zealand locations. Angular estimates of the starting point location were recorded for a number of different conditions. In the active mode, participants used a steering wheel, accelerator and brake pedals to control their simulated motion; whilst passive participants observed a pre-recorded route. The environments were varied between highly structured (urban) and less structured (rural) settings, in order to increase or reduce optic flow information and depth cues; and between those with landmarks present at the intersections, and those with no landmarks. Route layouts were manipulated to include different combinations of road-lengths and intersection exit-road angles. Participants were able to perform path integration using visual information, but with systematic errors. There was a clear effect of navigation mode: in all environments, participants in the active condition tended to be more accurate than those in the passive condition, except when the route consisted of a short approach road to an intersection followed by a long exit road. Clear effects of route layout were also observed: the pattern of errors (overestimation vs. underestimation of the direction of the starting location) depended on the angle-distance configuration. However, the presence of more structure and landmarks did not increase accuracy: the pattern of errors was similar between the urban and rural environments, and between environments with and without landmarks.

Acknowledgement: The New Zealand Road Safety Trust

33.324 **Learning relative locations in single and multiple- destination route planning in the real labyrinth**

Kayoko Ohtsu[1](id-ant@moegi.waseda.jp), Yoshihiro Oouchi[2]; [1]Graduate School of Education, Waseda University, [2]Teikyo-Gakuen Junior College

A few studies have examined the relation between route planning during wayfinding and spatial learning. Route planning often involves manipulation of spatial representation about a current space when one cannot see a destination directly. At an early stage of learning an environment, one has to retrieve some representation about a destination and estimate its direction relative to a current place to plan and choose a route. In other words, that is a process of knowing the relative location of the two places. We tested the hypothesis that a route planning would enhance spatial learning through the wayfinding task using a real environment. Incidental learning outcomes between two types of route planning were compared: (I) single destination (estimating one relative location at a time) and (II) multiple destinations (estimating a number of relative locations at a time). In the experiment, 50 participants explored the simple symmetric labyrinth (7 by 7 meters) freely and visited 4 targets (exploring phase), and then they were asked to revisit these targets in a predefined order (visiting phase). Half the participants were given (i) the next goal target every time after reaching the current one while the other half were given (ii) the next 3 goal targets and a order to make a round of visits. After the task, the participants judged 12 relative directions to and from the 4 target positions. Results suggest that performance in multiple destinations condition is better than that of single one. Since there was no difference in total task execution time and both conditions had brought about similar physical experiences (the amount of walking and a migration pathway), we conclude the manipulation of spatial representations about multiple destinations in the exploring phase would have formed more elaborated spatial knowledge.

33.325 **Investigating the potential impact of presence on the accuracy of participants' distance judgments in photo-realistic and non-photorealistic immersive virtual environments**

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The reported experiment seeks to provide insight into the impact of rendering style on participants' sense of presence in an immersive virtual environment (IVE). This work is motivated by recent findings that a) people tend not to severely underestimate distances in an immersive virtual environment when that IVE is a high-fidelity replica of the same physical space that they know they are concurrently occupying; but b) people will underestimate distances when the virtual replica environment is rendered in a minimalist, line-drawing (NPR) style. We ultimately seek to disambiguate between two alternative hypotheses: a) is the decline in distance judgment accuracy due to participants' decreased sense of presence in the NPR IVE, which interferes with their ability to act on what they see as if it were real, or b) is it better explained by the lack of sufficient low-level cues to 3D spatial location in the NPR IVE, that were formerly provided by the statistics of the photographic texture? We conducted a between-subjects experiment in which users were fully-tracked and immersed in an IVE that was either a photorealistically or a non-photorealistically rendered replica of our lab. We quantitatively assessed their depth-of-presence using physiological measures of heart-rate and galvanic-skin-response, along with characteristic gait metrics derived from full-body tracking data. Participants in each group were asked to perform a series of tasks that involved traversing the room along a marked path. They did the exercises first in the regular replica IVE and then in a stress-enhanced version, in which the floor surrounding the marked path was cut away to reveal a two-story drop. We measured the differences in each participant's physiological measures and tracked gait metrics between the stressful and non-stressful versions of each environment and then compared the results between the rendering conditions and found significant differences between the groups.

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33.326 **Effects of augmented reality cues on driver performance**

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Introduction: Intersections are among the most hazardous roadway locations, particularly for left turns. This study evaluated effects of augmented reality (AR) cues on decisions to turn left across gaps in oncoming traffic.

Method: Ten middle-aged drivers (Mean=40.6 years, SD=7.5; males=4) were tested on six simulated rural intersection scenarios. Drivers activated the high beam lever the moment they judged it safe to turn and released the lever the moment it was unsafe. A transparent 'no turn left' AR cue assisted the driver. It was positioned where oncoming traffic crossed the intersection, subtended 10°, signaled 4s time-to-contact (TTC) (cf., Nowakowski et al., 2008), and persisted until oncoming traffic passed. Uncued blocks (N=3) always preceded cued blocks (N=3). The three different cued blocks contained either: 1) 0% false alarms (FAs) and 0% misses, 2) 15% FAs, 0% misses, and 3) 15% misses (no cue despite <4s TTC), 0% FAs. A safety cushion was calculated as: (TTC when a driver judged it unsafe to go) – (actual turning time).

Results: There was a main effect of condition (3 cued, 3 uncued) on safety cushion (F(5,401)=3.14). The first of the three uncued conditions showed the smallest safety cushion (Mean=1.39 s, SE=0.20). The mean safety cushion for the later uncued conditions was 1.73 s (0.20) and similar to the mean for the cued conditions (Mean=1.74 s, SE=0.20). There were no differences between the cued conditions (p>.05, all cases).

Conclusions: AR cues may have influenced driver behavior. The safety cushion in uncued conditions increased after AR cue exposure. This more conservative behavior may reflect cue related learning or general learning; however, if this finding were due to general learning we would expect smaller cushions. The small proportion of FAs and misses did not appear to affect response to the AR cues, based on the finding of no differences between the cued conditions.

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33.327 **Looking where you are going does not help path perception**

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Sunday AM

It has been mathematically shown that when travelling on a circular path and fixating a target on the future path, flow lines for environmental points on the path would be vertical. Thus, by integrating all the vertical lines in the flow field, observers could recover the path trajectory directly from retinal flow without recovering heading (e.g., see Wann & Swapp, 2000). Here we test whether fixating a target on the future path helps path perception. Observers viewed displays (110°Hx94°V) simulating their traveling on a circular path over a textured ground (T=3 m/s, R=±3°/s or ±6°/s) for 1 s. Three display conditions were tested. In the path-fixation condition, the simulated gaze direction in the display pointed to a target along the path at 20° away from the starting position; in the non-path-fixation condition, the simulated gaze direction was on a target 10° inside or outside the path at the same distance; and in the heading-fixation condition, the simulated gaze pointed to the instantaneous heading (i.e., the tangent to the path). At the end of the trial, a probe appeared at 10 m. Observers used a mouse to place the probe on their perceived future path. For five observers (3 naïve), path errors (defined as the deviation angle between the perceived and the actual path at 10 m) were accurate only for the heading-fixation condition (mean error: 2.72° & 0.52° for R=3°/s & 6°/s, respectively). For the path- and non-path-fixation conditions, path errors displayed a positive slope (0.6 & 0.98, respectively), consistent with the fact that observers estimated the path curvature based on the total amount of rotation in the flow field. The findings suggest that fixating a target on the future path does not necessarily help the perception of the path trajectory. Path perception largely depends on solving the translation and rotation problem in retinal flow.

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Sunday AM

33.328 **Simulation of the retina in a sensory substitution device**

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Visual sensory substitution devices transmit the information from a video-camera via a substitute sense, usually the tactile or auditory sense (Bach-y-Rita, 1969). They have proved to give blind subjects perceptual abilities (see e.g. Auvray and Myin, 2009), and to induce activity in cerebral regions usually dedicated to vision (Poirier et al., 2005 ; Merabet et al., 2009). In this experiment, we manipulate the image of the video-camera to mimick the spatio-temporal response of the Magnocellular ON pathway (Hérault, 2009) and tested its effect on the mobility of blindfolded subjects. Blindfolded subjects equipped with a visuo-auditory substitution system named TheVIBE (Auvray et al., 2005) were told to complete a maze in the alley of a park. After four learning sessions lasting around 30 minutes, the image from the video-camera was reversed without the subject being aware of it. We measured a significant difference of performance showing that the device has an effect on the mobility of the subjects. Moreover, in the group including signal processing, we found a significant correlation between the effect of the image reversal and the improvement of the participants during the learning sessions, indicating an actual benefit of the device for mobility. We also report qualitative observations on the subjects' behavior. In particular, most of the participants made continuous low amplitude oscillatory movements resembling miniature eye movements. Auvray, M. et al. (2005) Journal of Integrative Neuroscience, Imperial College Press, 2005, 4, 505 Auvray, M. & Myin, E. (2009), Cognitive Science, 33(7). Bach-y-Rita, P. et al.. (1969) Nature, 1969, 221. Poirier, C. et al. (2005) Neurobiol Learn Mem 85 (1). Hérault, J. & Durette, B. (2007) IWANN 2007, Springer-Verlag Merabet, Lotfi B. et al. (2009). NeuroReport 20 (2)

33.329 **How Path Integration Signals Create the Spatial Representations upon which Visual Navigation Builds**

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Navigation in the world uses a combination of visual, path integration, and planning mechanisms. Although visual cues can modify and stabilize navigational estimates, path integration signals provide "ground truth" upon which vision builds, and enables navigation and dead reckoning in the dark. A complete understanding of visually-based navigation thus requires an understanding of how path integration creates the spatial representations upon which vision can build. Grid cells in the medial entorhinal cortex use vestibular path integration inputs to generate remarkable hexagonal activity patterns during spatial navigation (Hafting et al., 2005). Furthermore, there exists a gradient of grid cell spatial scales along the dorsomedial-ventrolateral axis of entorhinal cortex. It has been shown how a self-organizing map can convert the firing patterns across multiple scales of grid cells into hippocampal place cell firing fields that are capable of spatial representation on a much larger scale (Gorchetchnikov and Grossberg, 2007). Can grid cell firing fields themselves arise through a self-organizing map process, thereby providing a unity of mechanism underlying the emergence of entorhinal-hippocampal spatial representations? A self-organizing map model has been developed that shows how path integration signals may be converted through learning into the observed hexagonal grid cell activity patterns across multiple spatial scales. Such a model overcomes key problems of the useful oscillatory interference model of grid cell firing (Burgess et al., 2007). The proposed new model hereby clarifies how path integration signals generate hippocampal place cells through a hierarchy of self-organizing maps. Top-down attentional matching mechanisms are needed to stabilize learning in self-organizing maps (Grossberg, 1976). Such hippocampal-to-entorhinal feedback mechanisms illustrate how visual cues can build upon and modify entorhinal and hippocampal spatial representations during navigation in the light.

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33.330 **Hardware and software computing architecture for robotics applications of neuroscience-inspired vision and navigation algorithms**

Chin-Kai Chang[1](chinkaic@usc.edu), Christian Siagian[1], Laurent Itti[1]; [1]iLab, Computer Science Department, University of Southern California

Biologically-inspired vision algorithms have thus far not been widely applied to real-time robotics because of their intensive computation requirements. We present a biologically-inspired visual navigation and localization system which is implemented in real-time using a cloud computing framework. We create a visual computation architecture on a compact wheelchair-based mobile platform. Our work involves both a new design of cluster computer hardware and software for real-time vision. The vision hardware consists of two custom-built carrier boards that host eight computer modules (16 processor cores total) connected to a camera. For all the nodes to communicate with each other, we use ICE (Internet Communication Engine) protocol which allow us to share images and other intermediate information such as saliency maps (Itti & Koch 2001), and scene "gist" features (Siagian & Itti 2007). The gist features, which coarsely encode the layout of the scene, are used to quickly identify the general whereabouts of the robot in a map, while the more accurate but time consuming salient landmark recognition is used to pin-point its location to the coordinate level. Here we extend the system to also be able to navigate in its environment (indoors and outdoors) using these same features. That is, the robot has to identify the direction of the road, use it to compute movement commands, perform visual feedback control to ensure safe driving over time. We utilize four out of eight computers for localization (salient landmark recognition system) while the remainder are used to compute navigation strategy. As a result, the overall system performs all these computing tasks simultaneously in real-time at 10 frames per second. In short, with the new design and implementation of the highly-capable vision platform, we are able to apply computationally complex biologically-inspired vision algorithms on the mobile robot.

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33.331 **The Relationship Between Blink Rate and Navigation Task Performance**

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Emerging research has suggested a correspondence between eye-blink rate and task performance. Recently, Tsai, Viirre, Strychacz, Chase, & Jung (Aviation, Space, and Environmental Medicine, 2007) demonstrated an increase in blink rate as a function of split attention during a basic driving task. However, the relationship between blink rate and navigation performance in a more complex navigation task requires further investigation. The present study investigated the relationship between blink rate and navigation performance as a function of the complexity of an environment using a two-step navigation task in virtual reality. Participants were asked to navigate through two novel virtual environments to a central landmark, and then were asked to navigate back to the starting position. The two environments consisted of identical buildings, but differed in their arrangement within the environment, resulting in a high and low intelligibility environment. Additionally, the influence of textural information was manipulated between subjects by providing either unique or uniform textures for each building within the environments. An analysis of variance on the overall movement paths, duration of navigation, and blink rate for both the exploratory and wayfinding tasks revealed a significant main effect of configuration on the distance, duration, idiosyncracy of each path, and blink rate of each participant. Critically, this effect was observed during the wayfinding task, but not the exploration task, with a higher blink rate and longer movement paths being observed in the low intelligibility environment relative to the high intelligibility environment. Only limited evidence was found for the influence of textural information on these results. Taken as a whole, these results provide early evidence for the differential allocation of attention during navigation through complex environments, resulting in reduced navigation performance.

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Perceptual organization: Temporal processing

Orchid Ballroom, Boards 401–409

Sunday, May 9, 8:30 - 12:30 pm

33.401 Integration of visual information across time

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Introduction. We examine how observers combine spatial cues to estimate the center of a Gaussian distribution when the cues are presented one at a time in rapid succession. The rule of combination minimizing spatial variance in the estimate is to give equal weight to each cue independent of the order of presentation.

Methods. On each trial, we sampled nine values from a spatial univariate Gaussian (SD = 3.32 cm). The mean of the Gaussian varied from trial to trial. We drew small vertical ticks whose x-coordinate was the sample value and whose y-coordinate was the center of the display marked by a horizontal reference line. Each tick was visible for 150 msec followed by a 150 msec delay between successive ticks. Observers estimated the center of the Gaussian by clicking on the horizontal reference line. Observers completed 200 trials without feedback, followed by 300 trials with corrective feedback indicating the true center of the Gaussian.

Results. For each observer, we estimated the weights assigned to the first, second, etc. tick in the sequence separately for the first 200 trials (no feedback) and the last 200 trials (with feedback). Before feedback, observers assigned unequal weights as a function of temporal order ($F(8,32) = 4.21$, $p <0.002$). However, after feedback, the weights appeared uniform in time ($F(8,32) = 0.81$, $p > .05$). Crucially, there was a significant interaction between sequence position and the presence of feedback, $F(8,68) = 3.14$, $p <0.005$, driven primarily by increased weight given to the first three sequence elements prior to feedback, $t(4)=3.166$, $p = 0.03$.

Conclusion. Observers initially assigned more weight to early points than is consistent with minimizing spatial variance. With feedback they moved toward an equal weight minimum variance rule of combination. The temporal integration mechanism used by the visual system appears malleable in the face of corrective feedback.

33.402 Fast grouping processes allow for response priming effects in a primed flanker paradigm

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Grouping mechanisms are exceedingly important to organize our environment into coherent units. However, perceptual grouping is no unitary process but a mixture of several coexisting mechanisms (e.g. groupings by color, size, connectedness…) which seem to vary fundamentally in their time course and attentional demands. We performed several experiments to compare the influences of different grouping mechanisms on 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 stimulus-onset asynchrony (SOA) of either 12, 24, 36, 60, 84 or 108 ms and flanked the primes. In each experiment, two contrasting grouping principles organized the stimuli in vertical or horizontal direction. Primes and targets on each side could be either consistent or inconsistent in their orientation. Subjects should always respond as fast as possible towards the vertically oriented target. Response times showed strong priming effects depending on SOA and task-relevant grouping principles. This also held true for stimuli which could be organized according to two groupings at once so that subject's responses only depended on the particular instruction which to attend. Accordingly, principles of perceptual grouping are in fact considerably different regarding their time course and influences on the visuomotor system. Results are discussed and embedded in current theoretical frameworks.

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33.403 Backward-masking of figure-ground signal by feed forward inhibition

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In backward masking, a target stimulus is rendered less perceptible or even invisible through the presentation of a second stimulus, the mask. Feedforward inhibitory models explain backward masking by asserting that the second stimulus exerts an inhibitory influence on the responses of a neuron evoked by the target. Another set of theories argue that the masking interferes with recurrent or reentrant processing. Earlier neurpohysiological studies have demonstrated that the feedforward processing of the target remains largely intact. Strong evidence favoring the role of recurrent processing is backward masking of figure-ground textures. Figure-ground activity is believed to be contingent on feedback, and represents a neural correlate of visual perception. Rendering the figure invisible by backward masking abolishes the figure-ground modulated responses while leaving the detection of features intact. Thus, the results of figure-ground masking favor the hypothesis that backward masking blocks conscious processing by disrupting reentrant signals. Recently we described a computational spiking model that performs figure-ground segmentation of in a purely feed-forward manner. In this model global feedforward inhibition suppresses background responses but not the figure responses and can account for the segregation of textured figures. Here we used this model to test whether backward masking interrupts the feedforward segmentation of figure from ground. Our results show that feature extraction is intact while figure-ground segregation is interrupted in the pattern mask but not in the blank mask condition. These observations are very similar to the neurophysiological findings in the primate visual cortex where figure-ground activity was specifically disrupted by a pattern mask but not by a blank mask. We further examined the behavior of the model by forward and backward masking using a surround mask. In conclusion our results show that feedforward inhibition can account for backward masking effects of figure-ground stimuli.

33.404 Dynamic coupling of bistable stimuli reveals long-range connectivity

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Are the dynamics of bistable stimuli distributed in the visual field independent? We address this issue by characterising the endogenous bistable dynamics of a motion stimulus in presence of a similar, exogenously driven, contextual stimulus whose perception periodically alternates between a motion-bound and a motion-unbound state. In four experiments, observers reported their perceptual alternations during 3-4 min runs for different relative positions -within or across hemifields-, direction of motion and mirror symmetry between the two displays. Results showed that the dynamics of endogenous perceptual transitions of an ambiguous stimulus are coupled depending on the inductive context's characteristics: coupling was stronger for symmetrical stimuli presented in both hemifields and

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decreased for other spatial configurations. Coupling was weakest when stimuli with opposite motion direction were presented within the same - left or right- hemifield. Overall, mirror symmetry and common fate reliably influence the dynamic coupling of bistable stimuli. The distribution of the relative coupling strengths across experimental conditions indicates that it does not result from a decision bias or from 'high-level' Bayesian inferences. Our findings rather suggest that bistable neural attractors underlying the processing of each stimulus are coupled. The effect of common fate could reflect activity of neurons with large receptive fields encompassing the two stimuli, e.g. in area MT/MST. On the other hand, the strong effect of mirror symmetry could reflect the contribution of long-range connections through the corpus callosum. We tested this hypothesis by changing the relative locations of the inductive and target stimuli in each hemifield, thus altering mirror symmetry while keeping stimulus separation identical. Results showed decreased coupling whenever vertical symmetry was broken. Overall, we suggest that coupled dynamics of bistable stimuli reflect long-range connectivity, thus allowing a behavioural mapping of its functional properties.

33.405 **Dynamics of ménage à trois in moving plaid ambiguous perception**

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The perception of ambiguous moving rectangular plaids with transparent intersections is tristable rather than bistable. Not only does it alternate between coherent and transparent motion, but also for transparent motion which grating is perceived in front is ambiguous and alternates (Hupé & Juillard, SFN 2009). The dynamics of perceptual tristability can inform us about how the visual system deals conjointly with two computational challenges among the most important in perceptual organization: motion integration vs. segmentation and depth ordering. Twenty-six subjects reported continuously the three possible percepts of red/green plaids displayed for 1 minute (for transparent motion they had to indicate whether the red or the green grating was in front). The sequence between the three possible transitions was neither random nor hierarchical (as observed in multistable binocular rivalry by Suzuki & Grabowecky, 2002). Rather, switches between two transparency states were typically interleaved by a coherent percept. Moreover, the duration of that coherent percept determined whether switching to the opposite depth ordering should occur (for short coherent percept duration) or not. The preferential status of the coherent interpretation in this threesome may explain why the first percept is systematically coherent and lasts longer than subsequent coherent percepts, even for parameters that strongly favor the transparent interpretation (Hupé & Rubin, 2003. Such a behavior is not typical in bistable perception, but it was also observed for auditory streaming: Pressnitzer & Hupé, 2006). I tested this hypothesis by making the plaid perception bistable, introducing either occlusion or stereo cues to remove the ambiguity of depth ordering. Both manipulations resulted in the first percept (when coherent) having now the same duration as subsequent coherent percepts. Interestingly, the preference for coherency (first percept bias) was affected by stereo but not occlusion cues, meaning that the first percept bias for coherency and its longer duration are two independent phenomena.

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33.406 **Temporal Dynamics in Convexity Context Effects**

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Convex regions are more likely to appear as objects (figures) than abutting concave regions, but context modulates this likelihood: In 100-ms displays, convex regions are increasingly likely to be seen as figures as the number of alternating convex and concave regions increases from 2 to 8 (57% - 89%; Peterson & Salvagio, 2008). These convexity-context effects occur only when the concave regions are uniform in color. We hypothesized that convexity-context effects arise when the interpretation of a single large surface pre-empts that of multiple same-color concave figures, which then allows convex figures to dominate. We investigated whether it takes time for surface pre-emption to occur by presenting a mask at different inter-stimulus-intervals (ISIs) after the figure-ground display, following a tradition in which masks are used to test the dynamics of visual processing. When the mask immediately followed the 100-ms display (0-ms ISI), simple effects of convexity were observed in that convex regions were seen as figure significantly more often than chance (56%), p . 20. When the onset of the mask was delayed by 100 ms, convexity-context effects were evident, $p < .01$, and the pattern was significantly different from that obtained in the 0-ms ISI condition, p .70. Our results indicate that more time is required for convexity-context effects than for simple effects of convexity, perhaps because it takes time for surface interpolation and pre-emption to occur. We interpret these results within a recurrent model of figure-ground perception in which figure assignment emerges from interactions between as well as within levels of the hierarchical visual system.

33.407 **Spatiotemporal Boundary Formation: Similar Performance for Modal and Amodal Completion**

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There is a controversy about whether modal and amodal completion are driven by the same or by different mechanisms. In this sense, there are experimental and theoretical evidence in the literature supporting both hypotheses. In this study, we present the results of three experiments showing that performance for modal and amodal completion in the case of Spatiotemporal Boundary Formation (SBF) are similar. We use the type of stimuli used Shipley and Kellman (1993) to explore SBF and introduced disparity to produce modal and amodal percepts. In the first experiment we performed a Vernier acuity task between two motion-defined bars and tested the threshold for a range of disparities (+3, +1, 0, -1, -3), speeds (1, 2, 4 deg/s), and dot densities (4 and 8 dots/deg2). Results show that Vernier threshold does not depend on the amount of disparity for all experimental conditions. Moreover, there are no significant differences between thresholds obtained with positive and negative disparities, which would suggest a similarity between modality and amodallity. We wondered whether this result would keep the same for other tasks used in previous experiments such as form discrimination. In the second experiment, we used the same type of stimulus but asked the observers to discriminate between thinned and fattened bars. Results show no differences between modal and amodal perception, consistently with the first experiment. In the third experiment we measured Vernier thresholds for three temporal windows (50, 100, 350 ms), since it was found, in previous studies, some differences between modal and amodal perception for short stimulus presentation. Results show that for 100 ms four of six subjects present slight differences between thresholds obtained with positive and negative disparities. These results show that mechanisms underlying modal and amodal completion have the same efficiency, which could suggests that they are actually the same.

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33.408 **Temporal dynamics of face amodal completion in human visual cortex**

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A remarkable ability of our visual system is to perceive occluded stimuli as whole and complete immediately and effortlessly, which is known as amodal completion. In this study, we combined psychophysics and functional magnetic resonance imaging (fMRI) to investigate how amodal completion is implemented in the visual hierarchy. Identical face fragments from 5 deg face side views (either left tilted or right tilted) were presented stereoscopically either behind or in front of an occluder. When the fragments were behind the occluder, they were amodally completed and perceived to be a coherent face. When the same fragments were in front of the occluder, they were perceived as disjoint face patches. These two kinds of stimuli were presented with various durations (50-350ms) and followed by a mask. Subjects were asked to judge the orientation of face views. The time course of face amodal completion was assessed using a performance-based measure (Murray et al., 2001). We found that the completion took place between 100 and 300 ms. Meanwhile, subjects were scanned to measure their cortical responses to the stimuli throughout the visual hierarchy. Early visual areas (V1 and V2) showed a higher response to the perceived fragmented faces than to the perceived completed faces when the stimuli were presented for 50 and 150 ms. However, higher visual areas (OFA and FFA) showed the opposite pattern when the stimuli were presented for 250 and 350 ms. In a second experiment, subjects were asked to do an RSVP task at fixation point and ignore the face stimuli. We found that this attentional manipulation largely abolished all the differential responses. These findings suggest that face amodal completion results from early suppression in early visual areas and late enhancement in higher visual areas and attention plays a critical role in these neural events.

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33.409 Figure-ground signals in early and object specific visual areas: A combined fMRI, EEG and rTMS study

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Two processes can be discriminated when distinguishing a figure from its background: boundary detection and surface segregation. The neural origin and temporal dynamics of these two processes are still much disputed. In this study we used motion and texture defined stimuli that differentiate between edge detection and surface segregation. In order to investigate the function of networks involved in figure-ground segregation, we combined online rTMS and EEG and disrupted processing in nodes of distinct visual networks (dorsal vs. ventral). For motion defined stimuli rTMS/EEG results indicate that rTMS alters figure-ground related processes differentially depending on whether the dorsal (V5/MT) or ventral (Lateral Occipital [LO]) network was stimulated. The data suggest that disrupting V5/MT impairs surface segregation but not edge detection. This behavioral effect was reflected in interrupted feedback signals to occipital areas as measured by EEG. However, disrupting LO has the opposite effect, it enhances surface segregation and boosts feedback signals to occipital areas. To interpret the rTMS/EEG results, BOLD-MRI was measured in both areas. fMRI data showed that V5/MT differentiates between edge detection and surface segregation for motion defined stimuli, while LO does not. For texture defined stimuli no differentiation was found between edge detection and surface segregation in both areas. In general, the rTMS/EEG and fMRI data suggest a battle of resources between the dorsal and ventral stream in the process of figure-ground segregation. When the stream that is less involved in this process becomes disrupted, the stream that is more involved can become more dominant, resulting in better performance and enhanced feedback signaling to occipital areas.

Perceptual organization: Objects

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Sunday, May 9, 8:30 - 12:30 pm

33.410 Binary Division Constrains Human but not Baboon Categorical Judgements within Perceptual (colour) Continua

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In Experiment 1, two human populations (Westerners and Himba) and old-world monkeys (baboons: Papio papio) were given matching-to-sample colour tasks. We report a similar strong tendency to divide the range of coloured stimuli into two equal groups in Westerners and in the remote population (Himba), but not in baboons. When matching the range of colours to the two samples, both human groups produced a boundary at the midpoint of the range and it was at this point where there was most uncertainty of the best match. The boundary depended on the range of stimuli and hence overrode established colour categories. However, range differences did not affect the names given to the colours by either Western or Himba observers. In Experiment 2, we showed that a distinctive stimulus (focal colour) in the range affected the equal division though observers again made a boundary. Experiment 3 employed an implicit task (visual search) to assess colour categorization (Categorical Perception), and it was only in this task that categorization was immune to range effects and observed only at the established colour boundary. Nevertheless, prior exposure to the range of colours did affect naming producing binary division for a restricted range of colours. Thus, irrespective of whether colour categories are taken to be universal (Berlin & Kay, 1969) or language induced (Davidoff, Davies & Roberson, 1999), they are overridden in colour decision tasks by this stronger human tendency to divide continua into two. It is argued that binary division is the basic human mechanism whereby labels are used to establish colour categories.

33.411 The effect of temporal frequency on the local and global structure of Glass patterns

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Glass patterns are moirés created from a sparse random-dot field paired with it spatially shifted copy. Because discrimination of these patterns cannot be based on local features, they have been used extensively to study global integration processes. Using a multi-frequency tagging technique to record visual evoked potentials (VEPs), we can simultaneously measure neural sensitivity to local and global structure to Glass patterns. We have previously found that sensitivity to local and global structures of Glass patterns have different specificities: global responses were largely independent of luminance contrast while local responses were not (Palomares, et al, 2009, Journal of Cognitive Neuroscience), global responses were unaffected by directed attention while local responses were not and scalp topographies of global responses were localized more laterally than local responses (Palomares, et al, VSS 2009). Here, we evaluated the specificity of local and global responses to the local temporal frequency of Glass patterns. If sensitivity to global structure is independent from local structure, one strong expectation is that global responses to Glass patterns would remain unaffected by the local update of the dots. Random dot patterns were spatially offset to create concentric Glass patterns and alternated with randomized versions every 600 ms. Thus the global structure changed at 0.83 Hz. Different exemplars of concentric Glass patterns or randomly-oriented dipoles were sequentially presented at faster rates (every 66, 50 or 33 ms); the local structure changed at 15, 20 or 30 Hz. Our results show that sensitivity to local responses were highest at lower frequencies, while global responses were best at higher frequencies. VEP source-imaging on fMRI-based regions of interest suggest that this pattern is strongest in V4. Our data further demonstrate that sensitivity to local and global structure in dynamic Glass patterns is mediated by different, complementary mechanisms.

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33.412 Interpolation of Expanding/Contracting Objects behind an Occluding Surface

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Visual systems of humans and animals seem to extract critical information for object perception from the changing visual stimulation produced by object and observer motion. Although objects in ordinary scenes are often partially occluded, observers routinely perceive the shape of objects despite the occlusion and motion. This ability depends on interpolation processes that connect fragments across gaps in space and time to represent dynamically-occluded objects. Palmer, Kellman, and Shipley (2006, JEP:G) proposed that spatiotemporal interpolation depends on a Dynamic Visual Icon (DVI) which represents and positionally updates previously visible fragments. Little research, however, has explored the range of motions that support interpolation or the ecological validity of transformations that may be important to object interpolation in ordinary environments.

In the present study, the effect of velocity gradients on interpolation of objects expanding or contracting behind occluding surface was examined. Six participants observed the shapes of interpolated objects through multiple apertures and made two-alternative forced choice of objects. Three conditions of velocity gradients were compared using correct response rate as a measure of object interpolation: (1) acceleration condition where local speeds of visual edges increased linearly towards periphery, (2) negative-acceleration condition where speeds of edges decreased linearly towards periphery, and (3) constant-speed condition where local speeds were held constant. The results showed that effects of velocity gradients were significant, and that observers perceived interpolated objects with higher probability in acceleration condition than in negative-acceleration or in constant-speed condition. These results suggest that direction and velocity gradients of moving edges which may represent approaching and receding objects have critical effects on visual interpolation of moving objects.

33.413 Object-based attention benefits demonstrate surface perception in two-dimensional figure-ground displays

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Objects tend to be convex rather than concave, but convexity is not a strong figural cue in two-dimensional displays unless (1) multiple convex regions alternate with multiple concave regions, and (2) the concave regions are the same color (Peterson & Salvagio, 2008). To explain these effects, we hypothesized that the interpretation of a single large surface pre-empts that of multiple same-color concave shapes. Consequently, the competition from concave shapes at individual borders is reduced, and convex shapes dominate. On this surface pre-emption hypothesis, separated same-color concave regions in multi-region figure-ground displays would be perceived as portions of a single surface whereas separated same-color convex regions in the same displays would not. To test this hypothesis, we adapted a cued target discrimination paradigm Albrecht, et al. (2008) had used with three-dimensional displays for use with our 2-D figure-ground displays. We examined whether object-based attention benefits—shorter reaction times to a target appearing within the same object as a pre-cue rather than in a different object -- are obtained for two same-color concave regions separated by a convex region but not for two same-color convex regions separated by a concave region. Consistent with the surface pre-emption hypothesis, object-based attention benefits were obtained for targets shown on same-color concave regions flanking a convex region but not for targets shown on same-color convex regions flanking a concave region ($p < .05$). This finding was apparent in both accuracy and inverse efficiency measures, but not in reaction times. Thus, results showed that separated same-color concave regions were perceived as portions of a single object (surface) completing behind the convex regions, which were perceived as different objects (figures). In addition, this experiment reveals that a particular pattern of object-based attention benefits in a cued target discrimination task can provide an indirect measure of figure-ground perception.

33.414 **Shape dimensions, perceptual organization and intermodal selective attention: anterior extrastriate fMRI**

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Shape-selective regions have been identified in multiple human visual system regions, but it remains unclear what aspects of shape information drive these diverse regions. “Shape” can mean scale-invariant image features, but can also denote unitization of a spatial region. This study used simple rectangles to identify cortical regions that responded to integrated spatial dimensions, figural goodness, or both, and the extent to which these responses depended on selective attention. 15 subjects participated in 4.5 hours of fMRI each while performing 1-back matching tasks. Within a given trial block, rectangles varied by aspect ratio, surface area, or major axis length. Trial blocks also differed according to the portrayal of the rectangles: either a closed line drawing of the rectangle, fragmented vertex lines corresponding to the rectangle’s corners, or rotated vertices that reduced the rectangle’s figural goodness. The visual matching task formed part of an intermodal attention experiment with four main conditions: visual task only, visual task with ignored auditory stimuli, auditory task only, and auditory task with ignored visual stimuli. We contrasted the two bimodal conditions (visual task with ignored sounds, and vice-versa), which contained identical stimuli, to examine the effects of selective attention on visual responses. Imaging results showed that anterior ventral visual cortex was divided into lateral and medial bands that responded selectively to variations in aspect ratio and single-dimension changes, respectively. The anterior inferior temporal sulcus, extending to perirhinal cortex, was selective for aspect ratio vs. area changes; anterior parahippocampal cortex was activated more by major axis changes than by either aspect ratio or area changes. The intraparietal sulcus showed attention-dependent activation following a lateral (well-formed figures) to medial (poorly-formed) gradient. The fact that rectangle line drawings produced extensive and robust extrastriate activation emphasizes the explanatory power of perceptual integration for understanding visual cortex functional organization.

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33.415 **Contextual Modulation of Global Form Perception**

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We demonstrate a novel contextual modulation of global form perception with Glass patterns in a center-surround configuration. Glass patterns contain randomly distributed dot pairs, or dipoles, whose orientations are determined by a geometric transform. By integrating across over dipoles, an observer can have a percept of a specific global structure in the image. In our experiment, the test targets were Glass patterns presented in a circular region (2.5 degree radius) centered at the fixation. The surround was an annulus (2.5 degree inner radius and 8 degree outer radius) presented adjacent to the target. We measured the coherence threshold, the minimum proportion of the signal dots in the target for an observer to detect the global form, at 75% correct level with a temporal 2AFC paradigm. There were four types of global forms: concentric, radial, spiral and translational. The coherence thresholds of the central target Glass patterns were either measured alone or measured with the presence of various types of Glass pattern surrounds. Compared with the coherence measured with the target alone, the concentric and the spiral surrounds increased the coherence threshold for the concentric target by 60% while the radial surround had little effect. The coherence threshold for the radial pattern was elevated 30% by the spiral surround. The spiral and translational Glass patterns were not affected by any surrounds. The effect sustained even when a blank ring was inserted between the center and surround region. Our result shows that the global form perception can be modulated by the contextual information. The modulation depends on the spatial structure of both the central target and the surround context.

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33.416 **Ubiquitous log odds: Distortion of frequency estimates in visual numerosity tasks**

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Background: In decision making, people distort probability information (Kahneman & Tversky, 1979, Econometrica). We show that similar distortions are found in many research areas including visual frequency estimation, memory, and motor decisions. Distortions in all tasks can be accurately modeled as lo(d(p)) = a*lo(p) + b where lo(p) denotes the “logit” or log odds, log(p/(1-p)). The slope coefficient a is roughly .6-.7 in decision making but typically greater than 1 in equivalent motor tasks (Wu Delgado, Maloney, 2008, PNAS). What determines the distortion coefficients a, b in all these tasks? Are they task or observer specific? We tested whether observers would vary a, b across conditions in a visual frequency estimation task where we manipulated experience and sample numerosity. Method: Eleven observers saw black and white dots randomly scattered on a display screen for 1.5 seconds and estimated the relative frequency of black or white dots. No feedback was given. Trials were organized into 100 trial blocks. In each block the relative frequencies 0.01, 0.02, ..., 0.99 except 0.50 occurred once in randomized order. Subjects completed two sessions of four blocks. The number of dots in a display could be 200, 300, …, 600. Results: We fitted estimates of frequency distortion in each block. Nine out of 11 observers had slope smaller than 1 with mean slope 0.79. Slope was shallower for later blocks than for earlier blocks by about 16% ($F(7,70) = 5.592$; $p < .0001$) and shallower for larger numerosity than for smaller numerosity. by about 18% ($F(4,40) = 17.714$; $p < .0001$). Conclusions: Distortion of probability/frequency is ubiquitous in cognitive and visual tasks but degree of distortion varies with task. We show that distortions vary systematically even within a single type of task and discuss normative models for selection of distortion coefficients a,b.

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33.417 **Inferential challenges for General Recognition Theory: Mean-shift Integrality and Perceptual Configurality**

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General recognition theory (GRT) provides clear definitions and distinctions for the way in which perceptual and decision processes can interact across dimensions. As perceptual configurality is often defined in terms of feature or processing interactions (Wenger & Townsend, 2001), GRT provides a conceptual framework for assessing perceptual configurality. However, there are a variety of different quantitative and statistical methodologies available for relating data to theory. One of the challenges for

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these methods is to address issues of model identifiability that can arise when there is a one-to-many mapping from empirical data to the GRT framework. Mean shift integrality is such a situation, under which inferential errors can occur because there are multiple solutions in GRT. A mean shift integrality arises when changing one dimension of a multidimensional stimulus shifts the perceptual representation of all other dimensions. We have developed two techniques that can facilitate identification of a mean shift. The first is a collection of probit models that can be estimated simultaneously across two dimensions (DeCarlo, 2003), allowing bivariate correlations with perceptual distributions to be directly estimated. When a mean shift in distributions is accompanied by a continuous decision bound, the probit models identify bivariate correlations of the same sign and similar magnitude across all distributions. They also identify any shift in decision bound relative to the distributions. The second approach is an application of polychoric and tetrachoric correlations both within and across all distributions. Tetrachoric correlations applied to data sampled from mean-shift distributions accompanied by a continuous decision bound shift revealed significant non-zero correlations in the response space. These estimates are sensitive to the magnitude of the mean shift. Results from the two approaches are contrasted with more traditional multidimensional signal detection theory approaches (Kadlec, 1995; 1999).

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33.418 **Hemifield modulation of approximate number judgments**

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The visual system offers several types of summary information about visual features, including approximate number (Miller & Baker, 1968). Approximate number perception can be affected by adaptation in a hemifield specific manner (Burr & Ross, 2008; but see also Durgin, 2008). After adapting to a large and a small number of dots in different hemifields, a later presentation of identical sets of dots appears to have the opposite relationship (smaller and larger, respectively). This result raises the possibility that numerosity information is extracted independently over each hemifield. We directly tested this possibility by asking participants to judge the larger of two collections of dots, one presented across the hemifield boundary (between-hemifield presentation) and the other presented within one of the hemifield (within-hemifield presentation). The between- or within- hemifield manipulation was made by keeping the dot collections in the same locations, but then changing fixation location. Participants systematically judged the within-hemifield collections as having more dots. However, this effect disappeared when (1) the fixation location was manipulated so that neither collection fell on the hemifield boundary, and (2) the two collections were presented sequentially. In other words, any hemifield modulation in numerosity judgments occurred only when a subset of dots crossed the hemifield boundary. The results together suggest that when creating an approximate number representation, dots falling in the same hemifield are to mandatorily pooled.

Motion: Biological motion

Orchid Ballroom, Boards 419–435

Sunday, May 9, 8:30 - 12:30 pm

33.419 **The Effects of TMS over STS and Premotor Cortex on the Perception of Biological Motion**

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Multiple brain areas have been identified as important for biological motion processing in neuroimaging and neuropsychological studies. Here, we investigated the role of two areas implicated in biological motion, the posterior superior temporal sulcus (STS) and the premotor cortex, using offline transcranial magnetic stimulation (TMS). Stimuli were noise masked point light displays (PLDs) of human figures performing various actions, and scrambled versions of the same stimuli. Subjects had to determine whether a moving person was present in each trial. Noise levels were determined individually based on each subject's 75% accuracy threshold estimated adaptively prior to the session. After three baseline runs of 40 trials each, theta burst TMS was delivered over left premotor cortex (near the inferior frontal sulcus, IFS), left STS, or vertex in different sessions. The coordinates of stimulation were based on our previous lesion-mapping study (Saygin, 2007, Brain). Subjects then completed three post-TMS runs. A non-biological motion task (detecting PLDs of translating polygons) served as a further control. Accuracy decreased significantly after TMS of the IFS, while reaction times shortened significantly after TMS of the STS. Using signal detection analysis, we observed that d' and criterion values were significantly decreased after TMS of the IFS, (but not STS), which was due to subjects making significantly more false alarms post-TMS. None of these TMS effects were found for the non-biological control task, indicating some specificity to biological motion. Our findings constitute important steps towards understanding the neural systems subserving biological motion perception, but future work is needed to clarify the precise functional roles of these two areas in biological motion perception. We hypothesize that during biological motion perception, premotor cortex provides a modulatory influence to help refine the computations of posterior areas. Alternatively, premotor cortex might be important for decision making regarding biological motion.

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33.420 **Contribution of body shape and motion cues to biological motion selectivity in hMT+ and EBA depends on cue reliability**

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The perception of biological motion involves the integration of motion cues with form cues such as body shape. Recently it was shown that voxel-wise selectivity for biological motion within motion area hMT+ and extrastriate body area (EBA) correlated with selectivity for static bodies but not with motion (Peelen, Wiggett, & Downing, 2006). This suggested that the response to biological motion in these regions was driven entirely by the response to body selectivity and not by motion. Here we examined if the contribution of motion and body shape selectivity to biological motion selectivity in hMT+, EBA, as well as the fusiform body area (FBA) is fixed or if it relies in part on the reliability of form and motion cues. We hypothesized that while form cues might be most reliable with foveal presentation of stimuli, reliability should decrease if stimuli are presented in more peripheral locations. In contrast, we hypothesized that eccentricity would have little effect on motion cue reliability, leading to an increased contribution of motion selectivity to biological motion selectivity at more peripheral locations. Using fMRI, we identified hMT+, EBA, and FBA using standard localizers. Participants then performed a one-back task on point-light biological motion or tool motion stimuli presented centrally or more than 5o right of left of fixation. Using correlation-based multivoxel pattern analysis (MVPA), we replicated the finding that biological motion selectivity was associated with body selectivity but not motion selectivity in hMT+, EBA, and FBA - but only with foveal presentation. Presenting stimuli at more peripheral locations led to a significant correlation between motion selectivity and biological motion selectivity in hMT+ and EBA. These findings suggest that cue reliability is taken into account as form and motion cues are integrated during the neural processing of biological motion.

33.421 **Multi-voxel pattern analysis (MVPA) of the STS during biological motion perception**

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Neuroimaging studies have identified the human superior temporal sulcus (STSp) to have brain responses correlated to the perception of biological motion (e.g. Grossman et al., 2000; Allison, Puce & McCarthy, 2000). The human STS is believed to be the homologue to monkey superior temporal polysensory area (STPa), in which single-unit physiology studies have shown neurons responsive to biological motion (e.g. Perrett et al., 1996). Many neurons in monkey STPa are reported as sharply tuned to particular actions, and are proposed to form the basis of action recognition. The aim of this study is to determine whether the human STS, like the monkey STPa, has unique neural populations supporting the recognition of different biological actions. If such neuronal populations exist, they are likely organized at a sub-voxel spatial scale. To overcome these spatial resolution limitations of functional magnetic resonance imaging, we have measured the informa-

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tion content in the fMRI BOLD responses using support vector machines in conjunction with multi-voxel pattern analysis. We specifically measured whether the STS response discriminates between different biological action as well as between those actions and motion-matched non-biological control stimuli ('scrambled' motion). Human subjects viewed blocks of three different conditions (jumping jack, profile view of walker and hand waving in the air), and a scrambled animation condition. We measured classification performance in the STSp and in the motion sensitive hMT+, both independently localized in separate scans. We found above chance classification performance in these regions, which is evidence of sufficient information in the BOLD pattern to discriminate different unique actions. This study provides insight into neural activity at the sub-voxel level in human brain areas involved in biological motion perception, and our findings suggest that action recognition is supported by highly-tuned neuronal ensembles in visual cortex.

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33.422 Attention-based motion analysis of biological motion perception

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Human observers can recognize actions in point-light biological sequences with relative ease. This skill is believed to be the consequence of motion-based visual analyses, although the exact nature of these computations remains unclear. Typically, point-light animation sequences are depicted as luminance-defined tokens that are easily detected as biological by our first-order motion system. Contrast-defined (second-order) point-light sequences are also readily recognized as biological (Ahlström, Blake, Ahlström, 1997). More recently, some findings have implicated attention-based (third-order) motion as the critical motion analysis in biological motion perception (Thornton, et al., 2000; Garcia & Grossman, 2008). To determine whether third-order motion analyses are sufficient for biological motion perception, we have constructed biological motion displays that are defined by alternating features (e.g. Blaser et al., 2000), and are thus encoded by attention-based motion systems. Target tokens within a larger array of gabors depict human actions by coherently varying on key dimensions (contrast, spatial frequency, gabor orientation, phase or drifting speed). We measured the magnitude of the feature differences (e.g. contrast increments) for threshold discrimination and detection performance in second-order displays using an adaptive staircase. The alternating feature displays were created by varying each gabor dimension, frame-by-frame, of target tokens relative to the background. In these alternating feature displays, the global motion signal is constructed by tracking these salient differences across feature space. We found that for second-order motion, subjects require more feature differences (e.g. higher contrast, larger orientation tilt) for biological motion discrimination compared to detection, as expected. However, we also found that observers can readily detect and discriminate the third-order alternating feature displays. These findings are evidence that attention-based third-order motion analyses may promote biological motion perception through feature tracking.

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33.423 Perceptual biases in biological motion perception and other depth-ambiguous stimuli

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Biological motion stick-figures rendered orthographically and without self-occlusions do not contain any information about the order of their elements in depth and therefore are consistent with at least two different in-depth interpretations. Interestingly, however, the visual system often prefers one over the other interpretation. In this study, we are investigating two different sources for such biases: the looking-from-above bias and the facing-the-viewer bias (Vanrie et al. 2004). We measure perceived depth as a function of the azimuthal orientation of the walker, the camera elevation, and the walker's gender, which have previously been reported to also affect the facing bias (Brooks et al, 2008). We also compare dynamic walkers with static stick-figure displays. Observers are required to determine whether 0.5 s presentations of stick-figures are rotating clockwise or counter-clockwise – basically telling us in that way which of the two possible in-depth interpretations they are perceiving. In contrast to previous work, this measure is entirely bias-free in itself. Data collected with this method show that the facing-the-viewer bias is even stronger than previously reported and that it entirely dominates the viewing-from-above bias. Effects of walker gender could not be confirmed. Static figures which imply motion result in facing biases which are almost as strong as obtained for dynamic walker. The viewing-from-above bias becomes prominent for the profile views of walkers, for which the facing-the-viewer bias does not apply, and for other depth ambiguous stimuli (such as the Necker cube). In all these cases, we find a very strong bias to interpret the 2D image in terms of a 3D scene as seen from above rather than from below. We discuss our results in the context of other work on depth ambiguous figures and look at differences between the initial percept as measured in our experiments and bistability observed during longer stimulus presentations.

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33.424 Local motion versus global shape in biological motion: A reflexive orientation task

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Our visual system can extract directional information even from spatially scrambled point-light displays (Troje & Westhoff, 2006). In three experiments, we measured saccade latencies to investigate how local features in biological motion affect attentional processes. Participants made voluntary saccades to targets appearing on the left or the right of a central fixation point, which were congruent, neutral or incongruent with respect to the facing direction of a centrally presented point-light display. In Experiment 1, we presented two kinds of human point-light walker stimuli (coherent and spatially scrambled) with three different viewpoints (left-facing, frontal view, right-facing) at two different stimulus durations (200 and 500 ms) to sixteen observers. The saccade latency of the incongruent condition was significantly longer compared to that of the congruent condition for the 200-ms coherent point-light walker stimuli, but not for the spatially scrambled stimuli. In Experiment 2, a new group of observers (N = 12) were presented with two point-light walker displays. The only difference with respect to Exp. 1 was, that in the scrambled version of the stimulus, the location of the dots representing the feet, was kept constant. Different from the results of Experiment 1, the saccade latency in the incongruent condition was significantly longer than that in the congruent condition irrespective of the stimulus types. In Experiment 3, we put into conflict the facing direction indicated by the local motion of the feet and the facing direction as indicated by the global structure of the walker by presenting newly recruited observers (N = 12) with backwards walking point-light walkers. In agreement with the results of Experiment 2, the modulation of the saccade latency was dependent on the direction of feet motion, irrespective of the postural structure of the walker. These results suggest that the local motion of the feet determines reflexive orientation responses.

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33.425 Searching for a "super foot" with evolutionary-guided adaptive psychophysics

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The walking direction of a biological entity is conveyed by both global structure-from-motion information and local motion signals. Global and local cues also carry distinct inversion effects. In particular, the local motion-based inversion effect is carried by the feet of the walker. Here, we searched for a "super foot", defined as the motion of a single dot that conveys maximal directional information and carries a large inversion effect, by using a psychophysical procedure driven by a multi-objective evolutionary algorithm (MOEA). We report on two rounds of searches involving the evolution of 25-27 generations each (1000 trials/generation) conducted via a web-based interface. The search involved an eight-dimensional space spanned by amplitudes and phases of a 2nd-order fourier representation of the dot's motion in the image plane. On each trial, observers were presented with multiple copies of a "foot" chosen from a population of feet stimuli for the current generation and were required to indicate whether the perceived stimulus was right- or left- facing. The stimuli were shown at upright and inverted orientations. Upon completion of a generation, each stimulus was evaluated for its "fitness" based upon its ability to convey direction and carry an inversion effect from observer accuracy rates. The fittest stimuli were then selected to form a subsequent generation for

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testing via methods of crossover and mutation. We show that the MOEA was effective at driving increases in accuracy rates for the upright stimuli and increases in the inversion effect, quantified as the difference between upright and inverted stimuli, across generations. We show further that the two rounds of searches, beginning at different points in space, converge towards the same region. We characterize the "super foot" in relation to current theories about the importance of gravity-constrained dynamics for biological motion perception.

33.426 Distributions of fixations on biological motion displays depend on the task: Direction discrimination vs. gender classification

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Even when a display of a person walking is presented only as dots following the motion of the major joints, human observers can readily determine both the facing direction of locomotion and higher-level properties, including the gender of the individual. We investigated the spatial concentration of direction and gender cues, by tracking the eye movements of 16 participants while they judged either property of a point-light display. The walkers had different levels of ambiguity of both their direction and their gender, which affected the difficulty of the tasks. Fixation locations were recorded throughout the 2 s presentation times. We analyzed the fixation data in two ways: first by creating fixation maps for the different conditions, and second by finding the average number of fixations that fell into three ROIs, representing the shoulders, pelvis and feet. In accordance with past literature emphasizing the role of lateral shoulder sway in gender identification, participants on average fixated more on the shoulders in the gender task than in the direction task. Analysis of individual differences showed that more fixations in the shoulder region predicted slightly better performance in the gender task. On the other hand, the number of fixations on the pelvis, an area also known to contain gender information, was not significantly different between tasks. In accordance with studies showing that the motion of the feet contains cues to direction, participants fixated significantly more often on the feet in the direction task. The feet were rarely fixated in the gender task. In general, task difficulty did not have an effect on fixation patterns, except in the case of walkers viewed from the side, which produced on average slightly fewer feet fixations in the direction task.

33.427 The Perceived Sex of Biological Motion Displays is Influenced by Adaptation to Biological Motion but Not Adaptation to Static Faces

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Previous research has shown that adapting to biological motion creates an aftereffect in the perceived sex of subsequently viewed biological motion displays. Also, adapting to a face creates an aftereffect in the perceived sex of subsequently viewed faces. We sought to determine whether a sex aftereffect in biological motion can be created from adapting to a face. Participants first classified the sex of thirteen biological motion displays and thirteen faces that varied in appearance from male to female. A subset of these stimuli was used in an adaptation experiment. Participants adapted to either biological motion or static faces that were male, neutral, or female. After 10 seconds of adaptation, participants viewed a biological motion test display that in an unadapted state ranged from male to female. The data showed that adapting to biological motion biased the perception of the test stimulus towards the opposite sex. However, there was no effect of adapting to static faces. The results suggest that adapting to faces does not create sex aftereffects in biological motion perception. This suggests that there are independent neural sites for sex adaptation for faces and for biological motion.

33.428 Effects of social context on walking and the perceptions of walkers

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Research using point-light walker stimuli shows that biological motion alone can signal various types of information, such as age, sex, and identity. However, all these experiments involve creating videos of walkers in a context in which actors are aware that they are being filmed and observed. Given the effects of social context on other behaviours, we decided to investigate whether walking while being aware versus unaware of being observed would affect perceptions of those actors. Walkers were filmed in two conditions, first through the use of a hidden camera, and second with a visible camera operated by the experimenter. Point-light stimuli were then created from the videos. These stimuli were then viewed by a second set of participants, who rated them for various traits including health and personality. Results demonstrated that perceptions of people differed depending on the context in which they were filmed. For instance, actors were rated as more extraverted and more feminine when they were unaware of being filmed and walked while alone. In addition, we were able to investigate how accurate raters' perceptions of these actors were. These findings have implications for both past and future studies of perception from biological motion, highlighting the need to consider social context when exploring the nature of information signalling.

33.429 Visual Sensitivity to Point-Light Actors Varies With the Action Observed

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Background & Research Question: Traditional models of the visual system describe it as a general-purpose processor that analyzes all classes of stimuli with the same menu of visual processes (e.g. Marr, 1982). In contrast, there are classes of theories that place emphasis on the uniqueness of human motion perception (Blake & Shiffrar, 2007 for a review). Of theories that emphasize the uniqueness of human motion perception, many implicitly assume that visual sensitivity to human movement is action independent, as long as the observer can or has performed the observed action. Is visual sensitivity to human movement action independent? We examined whether the ability to detect a masked point-light person varies as a function of the action observed. Methods: Exp. 1 examined whether the detection of a moving point-light person varies depending on the action observed (lifting, running, throwing or walking). Exp.'s 2 and 3 examined whether person-detection varies as a function of observers' expectancies about upcoming actions. Exp. 2 examined whether knowledge of the upcoming action would influence the ability to detect a point-light person across observed actions. Exp. 3 examined whether or not being misinformed about the upcoming action would influence the ability to detect a point-light person across observed actions. Results & Discussion: Similar patterns emerged from all three experiments: visual sensitivity was action dependent, being greatest for walkers and worst for lifters. Interestingly, differences in person detection cannot be attributed to expectancies. Previous researchers may have overestimated visual sensitivity to human movement by relying heavily on the perception of point-light walkers. Furthermore, easily performable human actions do not represent a single perceptual category, as the ability to detect a person varies with the action observed. Later experiments will look at the role of dynamic symmetry (or lack thereof) as well as motor or visual familiarity.

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33.430 Multimodal integration of the auditory and visual signals in dyadic point-light interactions

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Multimodal aspects of non-verbal communication have thus far been examined using displays of a solitary character (e.g. the face-voice and/or body-sound of one actor). We extend investigation to more socially complex dyadic displays using point-light displays combined with speech sounds that preserve only prosody information. Two actors were recorded approaching each other with three different intentions: negative, positive and neutral. The actors' movement was recorded using a Vicon motion capture system. The speech was simultaneously recorded and subsequently processed with low-pass filtering to obtain an audio signal that contained prosody information but not intelligible speech. In Experiment 1, displays were presented bimodally (audiovisual) and unimodally (audio-only and visual-only) to examine whether bimodal audiovisual conditions would facilitate perception of the original social intention, compared to the unimodal conditions. In Experiment 2, congruent (visual and audio signal from same actor and intent) and incongruent displays (visual and audio signal from different actor and intent) were used to explore changes in social perception when the sensory signals gave discordant information. Results supported previous findings obtained with solitary characters: the visual signal dominates over the auditory signal (however, auditory information can influence the visual signal when the intentions from both modalities are discordant). Results also showed that this dominance of visual over auditory is significant only when the interaction between characters is perceived as socially meaningful i.e. when positive or negative intentions are present.

33.431 **Recognition of self-produced and friends' facial motion**

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Previous studies of walking gait have reported counter-intuitive self-recognition effects whereby actors are able to better identify allocentric displays of their own walking gait, than those of friends. Insofar as actors typically have little visual experience of their own gaits from third-person perspectives, such effects may indicate a contribution to perception from the motor system. Here we sought to determine whether participants showed a similar self-recognition effect when asked to identify facial motion derived from themselves, friends or strangers. Motion was isolated from form cues using a markerless image processing technique, and used to animate an average head avatar. A single avatar stimulus was presented on each trial and participants were required to respond self, friend or other. Participants first completed a block of upright trials and then completed a second block with stimulus orientation inverted. Some evidence of superior self-recognition was found, in that stimuli were correctly identified more often when viewed by the actor from which they were derived, than when viewed by friends or strangers. However, the self-recognition effect observed was primarily attributable to performance in the inverted condition. Whereas orientation inversion drastically impaired friends' ability to recognise an actor, inversion had no effect on the ability of actors to recognise themselves. These findings suggest that recognition of self-produced and friends' motion may be mediated by different cues. Since recognition of friends' motion is sensitive to orientation, friend recognition may require the perception of configural, correlated motion cues derived from across the whole face. In contrast, self-recognition may rely on local motion cues extracted from particular features, and thus be insensitive to inversion. An observer's motor system may also serve to enhance recognition through the representation of the rhythmic or temporal characteristics of local motion cues.

33.432 **Dissociation between biological motion and shape integration**

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While studies have pointed to a relationship between form processing and biological motion perception, the extent to which the latter depends on ventral stream integration is unknown. Here, we took advantage of patient LG's neuropsychological profile to address this question. LG has developmental visual agnosia, with severe difficulty in object recognition, but apparently normal motion perception. LG reports recognizing people from the way they move, suggesting he may use biological motion to support perception. In a recent neuroimaging and behavioural study we presented LG's abnormal visual cortical organization (Gilaie-Dotan et al, 2009, Cerebral Cortex). LG exhibited deficits in form processing, normal motion processing, and significant abnormalities in his visual hierarchy. In particular, LG's lateral occipital (LO) region did not show typical object selectivity, while motion sensitive MT+ showed typical activation patterns. Here, LG and age-matched controls performed motion-direction judgments on point light displays depicting either biological or non-biological motion. Using point lights allowed us to investigate structure from motion perception without relying on shape connectivity that assists integration processes. The biological motion stimuli depicted a person walking to the right or to the left (but without translation, as if on a treadmill), whereas non-biological motion consisted of a rectangle moving to either direction. The stimuli were embedded in noise dots in order to obtain sensitivity thresholds, which were calculated adaptively. The noise dots were created by spatially scrambling the target motion. While LG showed a significant deficit in the non-biological motion task, his biological motion performance was clearly within the normal range. His intact biological motion perception was further confirmed in a second experiment using different stimuli and task (Saygin, 2007, Brain). These results suggest that successful biological motion perception can be achieved without strict reliance on the integrity of hierarchical ventral stream integration.

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33.433 **Asymmetry in visual search for local biological motion signals**

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The visual search paradigm has been widely used to study the mechanisms underlying visual attention, and search asymmetry provides a source of insight into preattentive visual features. In the current study, we showed that observers were more efficient in searching for a spatially scrambled (or feet only) upright biological motion target among spatially scrambled (or feet only) inverted distractors than vice versa, suggesting that local biological motion signals can act as a basic preattentive feature for the human visual system. Interestingly, such search asymmetry disappeared when the global configuration in biological motion was kept intact, indicating that the attentional effects arising from biological features (e.g., local motion signals) and global novelty (e.g., inverted human figure) could interact and modulate visual search. Our findings provide strong evidence for local biological motion processing independent of global configuration, and shed new light on the mechanism of visual search asymmetry.

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33.434 **Search asymmetry in perceiving walkers: an approaching walker is easier to be found than a deviating walker**

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In a social situation, an observer needs to perceive directions of other walkers. It is a dynamic social interaction in our everyday life. We aimed to investigate human perception of walkers, particularly the perceptual function to identify an approaching or a deviating walker among distracters. In Experiment 1, we presented 2, 4, or 6 human walkers (front view, smooth shaded 3-dimensional computer graphics), one of which was approaching to an observer, and the other walkers deviated 6, 12, 24, or 48 deg from the observer. Eight observers were asked to identify the approaching walker as accurate and quick as possible. Reaction time increased as larger number of walkers and as larger deviation of distracters. In Experiment 2, we used inverted walkers and found that the search efficiency was worse than that of upright walkers. In Experiment 3, we presented 3, 4, or 6 walkers, one of which was approaching to or deviating from the observer, and the other walkers deviated from or approaching to the observer, respectively to investigate search asymmetry (deviation angle was 6 or 12 deg). Identification of an approaching walker among deviating walkers was quicker than the opposite identification, particularly with the small deviation. In Experiment 4, we presented 6 walkers with 6, 30, or 60 deg deviations, and the other methods were identical to Experiment 3. We found that the search asymmetry reversed with 30 and 60 deg deviations. At large deviations, identification of a deviating walker was quicker than an approaching walker. These results suggest that perception of approaching/deviating walkers with small deviations is different from that with large deviations. The former would be related to social perception in which an approaching walker is more important for observers. The latter would be related ordinal object perception in which deviation properties are more important.

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33.435 **Can you see me in the snow? Action simulation aids the detection of visually degraded human motions**

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When viewing the actions of others, we often see them imperfectly, briefly disappearing from view or otherwise obscured. Previous research shows that individuals generate real-time action simulations aiding prediction of an action's future course, such as during brief occlusion from view (Graf et al, 2007).

The current study investigates whether the action simulation directly aids the perception of visually degraded actions. Dynamic human actions such as a basketball shot were presented using point-light (PL) actors embedded in a dynamic visual black-and-white noise background resembling "TV snow". The PL actor was clearly visible at first (1-1.5 s), then briefly disappeared (400 ms 'occlusion') – during which the participant generates a real-time action simulation – and then reappeared (360 ms test motion). Prior to occlusion, the PL actor joints were easily visible squares of white pixels, but in the test motion, the PL joints were comprised of dynamic random white and black pixels. By changing the percentage of white versus black pixels in joints, and thus varying contrast against the noise background, the test motion was visually degraded. The test contrast was adjusted using an adaptive staircase method to measure contrast-thresholds for the detection of test motion appearance. In the crucial manipulation, the test motion was either a natural progression of the motion as it would have continued during occlusion, and thus temporally matching the simulation, or temporally shifted earlier or later (±300 ms). Contrast-thresholds for detection were lower for natural compared to shifted test motions, suggesting that when the visually degraded test motion temporally matches the simulation it is more easily detectable. Overall, these results suggest that real-time simulation of human actions during occlusion aids the detection of visually degraded actions, indicating a strong perceptual role for action simulation in human motion processing.

Attention: Numbers and things

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33.436 Rapidly learned expectations alter perception of motion

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Expectations broadly influence our experience of the world. However, the process by which they are acquired and then shape our sensory experiences is not well understood. Here, we set out to understand whether expectations of simple stimulus features can be developed implicitly through fast statistical learning, and if so, how they are combined with visual signals to modulate perception. On each trial human participants were presented with either a low contrast random dot kinematogram moving coherently in a single direction, or a blank screen. They were tested on their ability to report the direction (estimation) and the presence (detection) of the motion stimuli. Participants were exposed to a bimodal distribution of motion directions where two directions, 64° apart from each other, were presented in a larger number of trials than other directions. After a few minutes of task performance, participants perceived stimuli to be moving in directions that were more similar to the most frequently presented directions than they actually were. Further, on trials where no stimulus was presented, but where participants reported seeing a stimulus, they were strongly biased to report motion in these two directions. No such effect was observed on trials where they did not report seeing a stimulus. Modelling of participants' behaviour showed that their estimation biases could not be well explained by a simple response bias nor more complex response strategies. On the other hand, the results were well accounted for by a model which assumed that participants solved the task using a Bayesian strategy, combining a learned prior of the stimulus statistics (the expectation) with their sensory evidence (the actual stimulus) in a probabilistically optimal way. Our results demonstrate that stimulus expectations are rapidly learned and can powerfully influence perception of simple visual features, both in the form of perceptual biases and hallucinations.

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33.437 Seeing without Knowing: Three examples of the impact of unconscious perceptual processes

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While it is quite evident that we are not aware of all cortical activity, evidence is still sparse concerning what unconscious information is usable for task performance. The famous case of Blindsight underscores the importance of this issue - in brains with specific damage. We present three cases of the use of information of which (healthy) participants are not consciously aware.

1. Following brief presentation of four pacman-like forms, which describe a rectangle, a triangle (by three pacmen), or no form at all (e.g. with jumbled or outward-facing pacmen), subjects often report that they have not detected the illusory contour form, (when one was present), but they are nevertheless well above chance at guessing its shape.

2. Searching for a pair of identical patterns in an array of otherwise heterogeneous patterns, (with target present in 50% of trials), eye movement patterns reflect early concentration on the target (when present), well before participants are aware of its presence.

3. In a novel search task, performance is enhanced by use of utrocular (eye-of-origin) information, which participants are wholly unaware of.

These examples demonstrate not only that information of which we are unaware is usable for task performance, it also points to the high-level nature of such unconscious information. As in Reverse Hierarchy Theory, these phenomena point to a site-independent neural correlate of conscious perception.

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33.438 Tracking of food quantities by coyotes (Canis Latrans)

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What types of visual quantitative competencies do nonhuman animals possess, in the absence of linguistic labels for quantity? A wealth of previous studies have identified approximate systems of number representation in various species, suggesting that we may share with other species a rough nonverbal numerical competence. Previous studies have demonstrated that the numerical discrimination abilities across these various species—including the nonverbal representations of humans—are mediated by the ratio between numerical options; such approximate systems of quantification have been dubbed 'analog magnitude' representations of number (see Brannon and Roitman, 2003, for one review). The current experiment is the first to specifically test coyotes' quantitative discrimination abilities. In particular, we tested semi free-ranging coyotes' ability to discriminate between large and small quantities of food items and investigated whether this ability conforms to predictions of Weber's Law. We demonstrate herein that coyotes can reliably discriminate between large versus small quantities of food. As predicted by Weber's Law, coyotes' numerical discrimination abilities are mediated by the numerical ratio between the large and small quantities of food. This trend is indicative of an analog magnitude system of number representation. Furthermore, in this task, coyotes were not discriminating large versus small quantities based on olfactory cues alone; instead, they were visually tracking quantity. Our results also indicate that coyotes do not show evidence of learning effects within this task; in other words, they do not perform better on trials completed first, compared to trials completed last. In the future, we plan to conduct this same study with domestic dogs, in order to compare visual quantitative sensitivity between these two closely related species.

33.439 The Impact of Distracting Web Advertisements on Brand Awareness and Reading Comprehension

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It has been known for many years that moving objects and salient colors capture attention. Many websites have colorful, animated advertisements that are intended to attract users' interest. Previous work has evaluated the impact of distracting ads on brand awareness, but there is little research about the impact of distracting ads on reading comprehension, even though distracting ads are commonly placed near passages of text on websites. We investigated the impact of various forms of advertisements on both brand awareness and reading comprehension. In the first phase of the experiment, participants attempted to verbally name 24 (of 100 possible) brand logos and voice onset response time was measured. Logos were modified to contain no text or other identifying characteristics (e.g., the Red Bull logo

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was not used because it contains two red bulls). In the second phase of the experiment, participants read 24 modified encyclopedia passages while one of four ad types was displayed next to the text. The four possible ad types were: no ad, static ad, color salient ad, or animated ad. Following each passage, participants answered four multiple choice questions and their response time and accuracy were recorded. In the final phase of the experiment, participants named the 24 brand logos again and priming was calculated. Results indicate that animated ads received the most name priming followed by color salient ads. Static ads received no more priming than the no ad baseline condition. Despite the fact that animated ads were more attended to (as indexed by name priming), reading comprehension while viewing animated ads was slightly better than the other three ad conditions. Informal reports from participants indicated that animated ads were the most distracting, yet they produced the highest brand recognition and did not impact reading comprehension.

33.440 **Clarifying the role of gaze cueing using biologically natural and unnatural gazes**

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Previous studies have reported reflexive attention shifts using a symbolic cue of a schematic face with eyes moving to the left or right. It is thought that these gaze cues elicit reflexive orienting because the eyes play an important role in social cognition. However, there remains conflicting evidence regarding the type of orienting produced by gaze cues. Here, we sought to clarify the role of gaze cues in attentional orienting by testing the extent to which the gaze cue effect depends on biologically natural gazes. Subjects were presented with a line-drawing of a natural or unnatural face looking left, right, or straight ahead. In the 2-eye condition both eyes looked in the same direction. In the 1-eye condition only one eye looked left or right and the other eye looked straight ahead. In the Cyclops condition the face had only one looking eye. Then a target (an F or T) appeared on either side of the face. The cue-target onset asynchrony (CTOA) was randomized (105ms, 300ms, 600ms, or 1005ms). All cues were uninformative and subjects were told the direction of gaze did not predict target location. Subjects made speeded button press responses to identify the letter. Results show that reaction times (RTs) in the 2-eye condition were faster for valid cues at the 300ms and 600ms CTOAs, indicating that biologically natural gaze cues can elicit reflexive attentional orienting. RTs in the 1-eye condition and the Cyclops condition were only faster for valid cues at the 1005ms CTOA, suggesting that biologically unnatural gaze cues involve goal-driven attentional orienting. Overall RTs were slowest in the Cyclops condition and fastest in the 2-eye condition. Our findings further clarify the role gaze cues play in attention and suggest a specialized brain mechanism for attentional orienting in response to biologically natural gaze shifts.

33.441 **Attraction without distraction: Effects of augmented reality cues on driver hazard perception**

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Introduction: Collision warning systems use alerting cues to enhance awareness and response to hazards (Ho & Spence, 2005; Scott & Gray, 2008). These cues are meant to attract attention, yet may be distracting due to masking. This study evaluated effects of: 1) static visual cues (solid shape) and 2) graded dynamic visual cues that converged around approaching targets. We hypothesized that cues would reduce RT required to recognize potential hazards (e.g., pedestrians).

Methods: Six young drivers (Mean=25 years, SD=5; males=3, females=3) drove five simulated straight rural roadways under three conditions (static cued; dynamic cued; uncued). We examined RT from when a potentially hazardous target event (90 trials) first appeared to when the driver detected it. Subjects were also tested on detection of non-target (peripheral) objects (60 trials) that appeared on the roadside opposite the targets (forced choice questions).

Results: There was a main effect of condition on the RT (seconds) to perceive potential hazards ($F(2,22)=6.02$) and no effect on periphery accuracy ($F(2,22)=0.23$). The RT for the uncued condition (Mean=3.18, SE=0.41) was faster than the static condition (Mean=4.79, SE=0.52, $p = 0.002$), but was not different from the dynamic condition (Mean=3.44, SE=0.52, $p = 0.59$). The RT was lower for the dynamic condition versus the static condition ($p = 0.03$).

Conclusions: Results did not show direct RT benefits for the tested AR cues. In fact, static AR cues increased RT for detecting hazards. This was likely due to local (lateral) masking or obstruction. AR cues did not impair perception of non-target objects in the periphery. The study was limited due to task simplicity and excessive cue salience. A follow up study is addressing these limitations using a more difficult (dual) task and more ecologically congruent AR cues.

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33.442 **Attentional shifts due to irrelevant numerical cues: Behavioral investigation of a lateralized target discrimination paradigm**

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Behavioural evidence indicates the existence of a link between numerical representations and visuo-spatial processes. A striking demonstration of this link was provided by Fischer and colleagues (2003), who reported that participants detect a target more rapidly in the left hemifield, if it is preceded by a small number (e.g. 2 or 3) and more rapidly in the right hemifield if preceded by a large number (e.g. 8 or 9). This is strong evidence that numbers orient visuo-spatial attention to different visual hemifields (e.g., left and right) depending on their magnitude (e.g., small and large, respectively). Here, we sought to replicate number-related attentional shifts using a discrimination task. The participants (n=16) were presented 1 digit (1,2 vs. 8,9) at the centre of the screen for 400ms. After 500ms, 1000ms or 2000ms, a target was briefly flashed in either the right or left hemifield and participants had to report its colour (red or green). They were told that the central digit was irrelevant to the task. We hypothesized that the attentional shift induced by the centrally presented numbers should induce congruency effects for the target discrimination task, so that small (or large) numbers would facilitate the processing of left (or right) targets. Our results confirmed this prediction, but only for the shortest digit-target interval (500ms). This is supported by a significant interaction between number magnitude (small/large) and target hemifield (left/right). The link between numerical and spatial representations further predicts a positive relation between number magnitude and the difference in RT between left and right targets. Regression slopes were computed individually and a positive slope was obtained for short number-target interval. These findings indicate that the attentional shifts induced by irrelevant numerical material are independent of the exact nature of target processing (discrimination vs. detection).

33.443 **Looking ahead: Attending to anticipatory locations increases perception of control**

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According to the theory of apparent mental causation (Wegner & Wheatley, 1999), people are more likely to perceive themselves as in control of a particular action when thoughts about this action occur before the action itself. This priority hypothesis suggests a potential relationship between visual attention and the perception of control. In two experiments, we tested the hypothesis that observers would feel more control over an object if we directed them to pay attention to a location where the object was headed. Participants attempted to keep a moving object inside a narrow vertical path as it moved upwards for five seconds. The object took random steps to the left and right that participants could counter with key presses. We varied the participants' objective level of control over the object across trials and asked participants to rate their subjective feeling of control over the object at the end of each trial. We directed participants' visual attention to particular locations along the object's path by having them discriminate the color of a flash that was briefly presented during the task. In Experiment 1, participants reported greater subjective feelings of control when the flash appeared where the object was headed than when it appeared where the object had already been. The results of Experiment 2 showed that participants reported the highest levels of control when a brief autopilot function steered the object directly over the flash location. Taken together, these results suggest that we perceive more control over objects when they move to where we are attending: If an object goes where we are looking, we feel like we made it go there. Although some researchers have primarily employed the theory of apparent mental causation to study high-level metacognitive issues, these experiments demonstrate the theory's relevance to vision science.

33.444 Thinking of God Moves Attention

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How strongly do we associate "God" and "Devil" with our physical world? Humans have long used spatial metaphors for abstract concepts of the divine, ranging from Mt. Olympus and the underground Hades in ancient Greece to the current conceptions of Heaven and Hell. Such metaphors are useful as they provide a common metric, physical space, to which abstract information can be bounded and communicated to other people. Indeed, such spatial metaphors are so pervasive in divine concepts that many religious and cultural traditions have representations in either or both vertical and horizontal space. Given the reliance on spatial metaphors in concepts of the divine, it is possible that merely thinking of concepts of God or Devil might invoke brain activity associated with the processing of spatial information and orient people's attention to associated locations. To examine if exposure to divine concepts shifts visual attention, participants completed a target detection task in which they were first presented with God and Devil-related words. We found faster RTs when targets appeared at locations compatible with the concepts of God (up/right locations) or Devil (down/left locations), and also found that these results do not vary by participants' religiosity. These results demonstrate that even a highly abstract concept such as God can lead individuals to orient their attention to spatially compatible locations. These findings provide further evidence that the traditional view of exogenous and endogenous attentional processes may not be adequate, as divine concepts generated involuntary shifts of attention without any corresponding peripheral events. Moreover, these results add further support to the notion that abstract concepts like the divine rely on metaphors that contain strong spatial components.

Search: Learning, memory and context

Orchid Ballroom, Boards 445–457

Sunday, May 9, 8:30 - 12:30 pm

33.445 Training, Transfer, and Strategy in Structured and Unstructured Camouflage Search Environments

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The visual scenes we search every day are far more complex than typical search paradigms. Recent research has addressed this by examining the role target-background similarity plays in search. Previous studies of target-background similarity (camouflage) have utilized a paradigm that includes a complex background created from tiled square segments of the target object (Boot, Neider, & Kramer, 2009). These studies have found large improvements with training and transfer to novel camouflage stimuli. Interestingly, participants were biased to look at salient non-target objects rather than the target-similar background. Is this a true object bias? An alternative explanation is that the regular, crystalline structure of the background encouraged participants to fixate breaks in this pattern (i.e., salient objects). It is possible the high degree of transfer observed was a result of this strategy. We developed a modified paradigm to address these issues. Backgrounds were created through the random placement of geometric cutouts of the target object to remove target location cues provided by breaks in a patterned background. Error rates and reaction times were increased compared to search performance with structured backgrounds, suggesting structure was important in previous studies. Fixations on the randomized backgrounds were significantly greater, suggesting that previous evidence of an object bias in camouflage search may have been attributable to search strategies developed specifically for structured backgrounds. An additional training study examined search improvement and transfer in this more difficult task. Participants were trained to find camouflaged targets embedded within structured or unstructured randomized backgrounds. After four sessions of training, all participants searched for novel targets embedded within unstructured backgrounds. Preliminary results suggest that transfer of training to novel stimuli is much more limited when participants have to search unstructured camouflage environments. These results have theoretical implications for object-based conceptions of attention and may have important applied implications as well.

33.446 The influence of expertise on comparative visual search performance

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From studies using the comparative visual search paradigm it is known that there is a trade-off between inter-hemifield gaze shifts and visual short-term memory (VSTM) when searching for differences between two simultaneous presented displays. These gaze shifts were calculated from eye and head movements between two images. Hardiess, Gillner and Mallot (2008) formed their visual search task by two shelves filled with objects that differed in shape and color. They were presented with a distance between 30° and 120°. The results showed the trade-off based on a smaller number of shifts in greater distance conditions, suggesting higher working memory load. We extended their findings toward more complex materials, namely stills of pendulum clocks. The participants were asked to find differences between two images. The presentation distance varied between 30° and 120°. Furthermore, the factor expertise was varied to examine possible effects of prior knowledge on search effectiveness. As dependent variable we measured inter-hemifield gaze shifts. The experiment comprised two blocks: After the first block, half of the participants were given relevant information about the mechanical principles of a pendulum clock. The other half received irrelevant information. We hypothesized that expert knowledge increases search effectiveness, as participants are able to encode larger information chunks. We were able to replicate former findings with more complex material. An increased distance leads to a reduced number of gaze shifts suggesting both more effort for gaze shifts and more use of VSTM in large distance conditions. Additionally, there was no influence of expertise on search behavior. In both relevant and irrelevant information conditions participants showed higher performance in the second block, suggesting a general change of strategy that is independent of prior knowledge concerning the function of a pendulum clock. Consequently, we infer a powerful robustness of the trade-off effect in comparative visual search tasks.

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33.447 History repeats itself: A role for observer-dependent scene context in visual search

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Eye guidance during visual search and naturalistic scene exploration is based on combining information from image-based cues and top-down knowledge (e.g. target features, Zelinsky, 2008; scene context region, Torralba et al, 2006). It is not known whether previous searches of a scene contribute to search guidance. How much information is gained by knowing an observer's history of searching familiar scenes? To probe this question, we recorded eye movements while observers searched for a camouflaged book in indoor scenes (100% target prevalence). In the repeated condition, scenes were searched 8 times by the same observer, while in the novel condition each scene was searched once. This large dataset of search fixations was used to evaluate the similarity between scene locations fixated during an observer's repeated search relative to novel searches of the same scene.

An ROC analysis was used to evaluate how accurately fixated locations were predicted by distributions representing several types of top-down knowledge: (1) Categorical scene context: fixations drawn from different observer's search of a novel scene, (2) Learned scene context: fixations drawn from different observer's repeated searches of the scene; and (3) Observer-dependent scene context: fixations from one observer's repeated searches of the scene. The results reported below used the first three search fixations of each trial, but similar results were obtained using the first fixation exclusively. Categorical scene context predicted fixated locations of different, novel searchers with a high degree of accuracy (84%). Learned scene context, based on different searcher's repeated fixations, was similarly accurate (85%). Observer-dependent scene context, interestingly, provided a significant improvement in prediction accuracy relative to baseline controls and other forms of context (90%). In summary, having an observer's history of search fixations in a specific scene provides, on average, more accurate and less variable predictions of where that observer is likely to look.

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33.448 **Observers are inconsistent and inaccurate in judging their own visual detection ability at different retinal locations**

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Background: Recent computational models of human visual search presuppose that the visual system has access to accurate estimates of visual detection ability for stimuli at different retinal locations (E.g. Najemnik & Geisler, Nature, 2005). To test this assumption, we designed a decision task that revealed subjects' estimates of their performance for different contrast levels at different retinal eccentricities. Methods: In a calibration session, we mapped the subject's probability of correct response as a Weibull function of retinal eccentricity for targets at each of three contrast levels (low, medium, high). The subjects also learned to associate a color symbol with each contrast level. In the subsequent decision part, we asked subjects to choose between two possible combinations of contrast and eccentricity. E.g. low contrast at 2 degrees or high at 10 degrees. They knew they would actually attempt some of their preferred choices at the end of the experiment and earn monetary rewards for correct responses. We used a staircase procedure to measure the point of subjective indifference between targets that differed in contrast, one fixed in eccentricity and the other varied in eccentricity. For each subject we used 12 such staircases (3 contrasts x 4 probabilities) and estimated the eccentricity that the subject considered to be equally detectible for the variable contrast. Eight naïve subjects participated. Results: Despite their calibration experience, all eight observers matched probabilities incorrectly, with 0.14 mean error over all observers, conditions (theoretical upper limit 0.35). The matching failures showed a common pattern of underestimating the difference between high and low contrasts. Conclusion: Observers exhibited little knowledge of their visual detection ability as a function of contrast and retinal eccentricity. We find no evidence that the visual system has access to accurate estimates of detection ability for different types of targets at different eccentricities.

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33.449 **Altering the rate of visual search through experience: The case of action video game players**

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Many aspects of endogenous visual attention are enhanced following habitual action video game play. For example, those who play fast-paced action video games (such as Halo or Call of Duty) have demonstrated superior performance on tasks requiring sustained attention to several objects, as well as enhanced selective attention in time and in space (Hubert-Wallander, Green, and Bavelier, under review). However, using one of the diagnostic tasks of the efficiency of visual attention, a visual search task, Castel and collaborators (2005) reported no difference in visual search rate, proposing that action gaming may change response time execution rather than visual selective attention itself. Here we used two hard visual search tasks, one measuring reaction time and the other accuracy, to test whether visual search rate may be changed by action video game play. In each case, we found faster search rates in the gamer group as compared to the non-gamer controls. We then contrasted these findings with a study of exogenously-driven attentional processes. No differences were noted across groups, suggesting that the neural mechanisms subserving the willful and flexible allocation of attentional resources may be more susceptible to training than the processes by which attention is exogenously summoned.

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33.450 **Effects of high-level ensemble representations on visual search**

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The visual system's ability to extract ensemble representations from cluttered scenes has been demonstrated for low-level features as well as high-level object properties such as facial expression (Ariely, 2001; Chong & Treisman, 2003; Haberman & Whitney, 2007; Parkes et al., 2001). Our previous work suggests that ensemble information influences visual search efficiency: participants were faster to detect a target face when its expression deviated substantially from the mean of the set, but only within sets containing low rather than high variance in expression (Puri et al., 2009). Thus, the relatively precise summary representations known to arise under low-variance conditions (Dziuk et al., 2009) may provide a basis for deviance detection. Here we tested whether an individual's ability to extract summary information from low- compared to high-variance sets predicts the degree of benefit when searching for deviant targets under the two variance conditions. Participants estimated the mean expression of face sets with either low or high variance. In a separate task, the same participants searched for a particular identity within low- and high-variance sets; the expression of the target face could be either near or far from the mean expression of the set. Across participants, the difference in mean estimation performance for low- versus high-variance sets was correlated with the relative benefit for detection of deviant targets within low- versus high-variance sets. In addition, within individuals, search times were more positively correlated across two separate presentations of the same display when the variance of the set was low. These results suggest that readily extracted ensemble representations enhance deviance detection. Furthermore, the availability of ensemble information may contribute to consistencies in search behavior within an individual.

33.451 **Reducing Satisfaction of Search Errors in Visual Search**

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Several occupations rely upon the ability to accurately and efficiently perform visual search. For example, radiologists must successfully identify abnormalities, and airport luggage screeners must recognize threatening items. By investigating various aspects of such searches, psychological research can reveal ways to improve search performance. We (Fleck, Samei, & Mitroff, in press) have recently focused on one specific influence that had previously been explored almost exclusively within the study of radiology: Satisfaction of Search (SOS), wherein the successful detection of one target can reduce detection of a second target in the same search array. To eliminate SOS errors, we must delineate the sources of the errors. Combined with our prior work, here we examine the specific roles of target heterogeneity and the decision-making component of target-distractor discrimination (i.e., how easy it is to determine whether a stimulus is a target or a distractor). In the current experiments, subjects searched arrays of line-drawn objects for targets of two different categories (tools and bottles) amongst several categories of distractor objects. On any given trial, there could be no targets, one target (either a tool or bottle), or two targets (both a tool and a bottle). The relative occurrence of these trial types varied across experiments. Compared to previous experiments that employed homogeneous targets and that required effortful evaluation to discriminate targets from distractors, the SOS effect was reduced here. That is, search accuracy for easily discriminable, heterogeneous objects was no worse for dual-target trials than for single-target trials. These results suggest that target heterogeneity and target-distractor discriminability may both play key roles in multiple target search accuracy.

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33.452 **Memory and attentional guidance in contextual cueing**

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What is the mechanism that underlies contextual cueing? The 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 functions) in contextual cueing, a criterion used for establishing the presence of attentional guidance in standard search. However, we argue that the candidate source of guidance in contextual cueing – memory for the repeated displays – is fundamentally different than that of standard search tasks. It is this difference, rather than a lack of attentional guidance, that explains the failure to observe decreased search slopes in contextual cueing. While the quality of guidance derived from feature dimensions of the display in standard search is constant across set sizes, as set size increases in a contextual cueing task, so does the burden on the memory system. I.e., the smaller set size displays are easier to remember and thus offer better quality guidance than the larger set sizes. To directly investigate the availability/strength of memory traces for the repeated displays we utilized a measure of interference in a standard contextual cueing task. After learning had occurred and the contextual cueing effect was present, the location of the target in each repeated display was changed. This manipulation resulted in increased mean response times (interference) in the repeated condition after the change. The magnitude of interference varied inversely with set size indicating that the availability of context memory is contingent upon the amount of information contained within the display. These findings indicate that a lack of decreased search slopes alone is insufficient to discount attentional guidance as the mechanism underlying contextual cueing.

33.453 **It's a MAD visual world: How do we search it?**

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Visual search in the real world is complex and can involve high numbers of static and moving elements, some of which also change in luminance or disappear over time. To date, most visual search tasks have not examined the impact of these simultaneous, dynamic effects on search performance. We investigated how participants search a complex environment in the laboratory by designing a Multi-element Asynchronous Dynamic (MAD) visual search task which has (a) a high set size, (b) moving and static stimuli, (c) stimuli that change their luminance over time (by gradually blinking on and off) and (d) target uncertainty (e.g., the target was one of five possible letters, could be in any of moving or blinking groups and was absent on a subset of trials). Experiments 1 and 2 found that under these complex, MAD conditions search for moving items was less efficient than search for static items; however there was no effect of luminance change. Participants also missed a high percentage of the targets. In Experiment 3, participants knew in advance whether the target would be moving and/or blinking. Even with this advanced knowledge, search for moving targets was less efficient than search for static targets and there was no effect of luminance change. Finally, Experiment 4 replicated MAD search using smaller set sizes. Now search through moving and static items was equivalent, there was no effect of luminance change and error rates were reduced. Overall, the data show that increasing the complexity of the display drastically changes the way people perform a search task.

33.454 **An abstract equivalent of visual search: Gain maximization fails in the absence of visual judgments**

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Consider two sequential tasks, one visual, one abstract. In the visual search task, observers examine object after object to find a target. The target is present on only a proportion of the trials, observers search as long as they like and declare finally whether the target is present or absent. They are rewarded for correct responses. In the abstract task, observers click on a series of boxes on a computer display, one of which may contain a prize. There is a cost to opening each box and they continue opening boxes until they find the reward or decide not to look further. These tasks are similar in structure. However, in the visual task, observers were nearly optimal gain maximizers with average winnings above 95% of optimal, while in the abstract task, they were far below optimal, with average winnings about 65% of optimal. In the box task, the longer it had been since the last time observers found a prize, the fewer boxes they would open. This behavior suggests that they may have treated the independent trials as non-independent in the box task, but not in the visual search task. Moreover, while visual search observers compensated effectively for changes in target prevalence and remained nearly optimal, in the abstract task, prevalence changes lead to even greater deviations from optimality. Our results clearly show fundamental differences between how visual and abstract information is exploited. One possibility is that visual decisions were optimal because observers made multiple rapid decisions about items in the display, while the longer box decision times allowed opportunities for biases to creep in. Alternatively, we may be evolutionary equipped for visual search but not for abstract reasoning. Estimating probabilities in the search task may be easier than processing the explicitly stated probabilities in the box task.

33.455 **Searching for two objects: Does knowing their relational alignment produce greater search guidance?**

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We often search for co-occurring objects in a specified relationship, such as when we are told that X is above Y when shopping at a grocery store. In this situation, do we search for: just X, Y then X, X and Y simultaneously, X and Y and a vertical orientation, or specifically X above Y? The goal of this study was to determine how relational information is combined with pictorial information to generate a more effective target template. Search displays consisted of six pairs of real-world objects (three oriented horizontally and three vertically); the subject's task was to find a specific object pair. Target cues consisted of one or both objects from the target pair, presented either as they would appear in the search display, flipped across the pair's horizontal or vertical axis, or in a different orientation. These pictorial cues were accompanied by varying degrees of relational information, thereby creating the potential for subjects to mentally rearrange the pictorial information from the cue into a more accurate guiding representation. The relational manipulations included: a no information condition (subjects just saw the target pictures), an orientation condition (indicting whether the target pair would appear horizontally or vertically oriented), an exact alignment condition (indicating the orientation + the left/right/top/bottom alignment of one of the objects), and an identical condition (in which the pictures from the target cue exactly matched their appearance in the search display). We found stronger search guidance when both objects from the target pair were previewed compared to only one, and that guidance generally increased with the level of relational specificity provided about the target objects. These patterns suggest that a target's guiding representation is more elaborate than just a picture; when available, spatial relationships between objects can be used to refine this representation and improve search guidance.

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33.456 **The effect of non-emotional facial changes on time-based selection**

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Previewing one set of stimuli enables increased search efficiency through subsequently presented new items – the preview benefit (Watson & Humphreys, 1997). This benefit occurs with both symbolic (e.g., letters) and valenced facial stimuli (Blagrove & Watson, in press). When changes are made to symbolic previewed stimuli at the same time as new items are added, only those changes that are likely to be of behavioural relevance (e.g., changes to object identity) cause the old items to re-compete for selection with the new items. Other changes (e.g., color or luminance changes) appear to have no effect, and the previewed items remain suppressed (e.g., Watson, Humphreys, & Braithwaite, 2008). Previous work has shown that expression changes made to previewed faces also abolish the preview benefit, with no differential effects of change direction (i.e. neutral to negative or positive changes). In the current work, two experiments examined whether this disruption of the preview benefit was due to 'low-level' feature changes or 'high-level' changes in facial expression. This was achieved by changing the position, but not the shape of the mouth in the previewed faces, when the new faces were added – thus creating a physical change without an associated change in emotion. Under these conditions, we obtained a robust preview search benefit with both negative and positive valenced preview distractors, compared with a full element baseline condition in which all items appeared simultaneously. Thus, as might be expected from an ecological standpoint, changes in expression appear to be more effective than simple 'low-level' physical changes in causing previously suppressed faces to re-complete for selection. In addition, as in previous work with face stimuli, preview search remained less efficient than when only the new items were presented alone, suggesting that faces might be more difficult to suppress than less socially relevant stimuli.

33.457 **The stare-in-the-crowd effect in the real world: is direct gaze really detected faster than averted gaze?**

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Sunday AM

Previous research has given support to the so-called "stare-in-the-crowd effect", the notion that a direct gaze "pops out" in a crowd and can be more easily detected than averted gaze. This processing advantage is thought to be due to the importance of gaze contact for social interactions. However, these studies bore little ecological validity as they used search paradigms in which arrays of two-dimensional pairs of eyes were presented on a computer screen. The purpose of the present research was to investigate whether this processing advantage for direct gaze could be seen in more realistic settings such as in a virtual environment. Participants were required to locate the person with a direct (or averted) gaze presented amongst three other persons with averted (or direct) gaze. This was done either in 2D (on a flat computer screen), in 3D-no context (i.e. a blank virtual world) or in 3D with context (a virtual elevator). For the 3D conditions, participants wore a head-mounted display which immersed them in a virtual world. Results indicated slower reaction times when the task was done in three rather than two dimensions, and even slower RTs with the addition of meaningful context. No overall effect of target gaze was found but an interaction with target position was observed due to faster and more accurate detection of direct over averted gaze when targets were presented in the right visual field. When targets were in the far left visual field, however, the effect was reversed and averted gaze was more quickly detected than direct gaze. These findings suggest that detecting gaze direction in the real world mostly depends on spatial position. In other words, direct gaze does not always "pop-out".

Face perception: Emotional processing

Vista Ballroom, Boards 501–516

Sunday, May 9, 8:30 - 12:30 pm

33.501 Cortical and Subcortical Correlates of Nonconscious Face Processing

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Paradigms that provide independent input to each eye (e.g. binocular rivalry) have been used to test the role of subcortical visual processing streams and establish the boundaries of visual awareness. These methods have advantages over backward masking, which is insufficient for complete disruption of the ventral visual pathway. The current fMRI study presented images of faces and houses that were rendered subliminal via binocular rivalry combined with flash suppression and an orthogonal task – with the ultimate objective of examining subcortical pathways involved in the perception of social stimuli.

During fMRI data collection, 12 young adult participants wore anaglyph glasses and viewed centrally presented supraliminal words on a sharply moving checkerboard. Participants identified the first letter of each word as a consonant or vowel. Fearful faces and houses were presented to the non-dominant eye and suppressed from conscious awareness. Catch trials determined if and when participants perceived the subliminal stimuli; only data acquired prior to onset of awareness were analyzed.

Whole-brain, mixed-model GLM analyses found significantly greater activation for subliminal faces versus subliminal houses in precuneus and left inferior parietal cortices. An a priori ROI analysis of bilateral amygdalae revealed a significantly greater left amygdala response for subliminal faces. Psychophysiological interaction (PPI) analyses of individually-defined left amygdala showed task-dependent correlations with bilateral pulvinar and early visual cortices. Previous findings have implicated the amygdala and pulvinar in subliminal threat and saliency detection, respectively. While spatial resources are typically recruited in supraliminal vision, these data suggest that precuneus and parietal cortices are activated prior to social stimulus awareness. We suggest this response to detection of environmentally relevant stimuli also serves a preparatory role in spatial resource allocation for subsequent behavior. Ultimately, present data cast some doubt on the distinction typically made between subcortical and cortical pathways in subliminal perception of social stimuli.

Acknowledgement: 5R01MH073084-06 (PI: Schultz), NSF Graduate Fellowship

33.502 Separate neural loci are sensitive to facial expression and facial individuation

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A network of several face areas—defined by their greater activation to faces than non face objects--have been reported in the cortices of both macaques and humans, but their functionality is somewhat uncertain. We used fMRI-adaptation (fMRIa) to investigate the representation of viewpoint, expression and identity of faces in the fusiform face area (FFA), the occipital face area (OFA), and the superior temporal sulcus (STS). In each trial, subjects viewed a sequence of two computer-generated faces and judged whether they depicted the same person (1/5 of the trials were in fact different, but highly similar individuals). On all trials, the second face was translated in an uncertain direction even when the faces were identical. Among the images of the same person, the two images could vary in viewpoint (~15^o rotation in depth) and/or in expression (e.g., from happy to angry). Critically, the physical similarity of a view change and an expression change for each face were equated by the Gabor-jet metric, a measure that predicts almost perfectly similarity effects on discrimination performance. We found that a change of expression, but not a change of viewpoint, produced a significant release from adaptation (compared to the identical, translated face) in FFA. In addition, a change of identity produced an even stronger release. In contrast, OFA was not sensitive to either expression or viewpoint change, but did show a release from adaptation to an identity change. These results are consistent with Pitcher et al.'s (2009) finding that TMS applied to OFA disturbs face identification, but are not consistent with a model (Haxby et al., 2000) that assumes that FFA is insensitive to emotional expression.

33.503 Affective Information Affects Visual Consciousness

Erika Siegel[1](siegelea@bc.edu), Eric Anderson[1], Lisa Feldman Barrett[1]; [1]Boston College

Gossip can be thought of a form of affective information about who is friend or foe. Recent evidence indicates that, as a way of learning about the "value" of a person, gossip influences how human beings evaluate each other. In the current research, we show that gossip does not just impact how a face is evaluated – it impacts whether or not a face is seen in the first place. Structurally neutral faces were paired with negative, positive, or neutral gossip. When viewed later, faces previously paired with negative (but not positive or neutral) gossip were prioritized in consciousness using a binocular rivalry procedure. These findings demonstrate gossip as a form of affective information can influence vision in a completely top-down manner, independent of the basic visual features of a face.

Acknowledgement: Army Research Institute

33.504 Contrast-Negation Impairs Gender but Not Emotion Discrimination

Pamela Pallett[1](ppallett@ucsd.edu), Ming Meng[1]; [1]Dartmouth College

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). To further investigate the proposed dichotomy between expression perception and the encoding of other facial attributes, we systematically measured threshold sensitivity to differences in gender and emotion in positive contrast vs. contrast-negated faces. Previous studies have shown that gender perception is mediated primarily by the fusiform gyrus, inferior occipital cortex, and cingulate gyrus (Ng, Ciaramitaro, Anstis, Boynton, & Fine, 2006), which largely overlap with the neural pathways underlying face recognition. In contrast, processing of facial expression involves both cortical and subcortical pathways (e.g. amygdala). We predicted that, like recognition, contrast-negation may impair gender discrimination. However, contrast-negation may not necessarily impair emotion discrimination. Accordingly, our participants displayed substantially decreased sensitivity to variation in gender with contrast-negation, but no change in sensitivity when discriminating levels of anger or fear. Although a t-test indicated a significant decrement in sensitivity to levels of happiness with contrast negation, the decrement was significantly less than that observed with gender and not significantly different from the non-significant decrements observed with anger and fear.

Moreover, response times decreased with contrast-negation only for gender discriminations. Contrast negation destructs the otherwise highly stable ordinal luminance relations between a few face regions (Gilad, Meng, & Sinha, 2009). Our results suggest that these luminance relations may be important for gender discrimination but not necessarily for emotion discrimination, highlighting separated visual processing of facial expression.

33.505 **Dynamic Shifts in the Criteria for Facial Expression Recognition**

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An individual's ability to recognize facial expressions is influenced by exposure to a certain emotional expression over a long period or by the prolonged exposure to a prototypical facial expression. This study revealed that the recognition of facial expressions varied according to the exposure to non-prototypical facial expressions for a relatively short period. After being exposed to the faces of anger-prone individuals, whose morphed faces frequently expressed anger, the participants more frequently perceived the expression on the face as happy. On the other hand, after being exposed to the faces of happiness-prone individuals whose morphed faces frequently expressed happiness, the participants more frequently perceived the face as angry. In addition, we found a relative increase in the social desirability for happiness-prone individuals after the exposure. These results proved that people dynamically became sensitive to the change in facial expressions by adapting to the exposed facial expressions over a short period.

33.506 **How fast can we recognize facial expressions of emotion?**

Aleix Martinez[1](aleix@ece.osu.edu), Shichuan Du[1]; [1]The Ohio State University

We use a set of 161 images, corresponding to a total of 23 individuals, each displaying one of six emotions (anger, sadness, fear, surprise, happiness and disgust) in addition to neutral. All images were of 80x120 pixels. We extended this set by reducing all the images to 40x50 pixels, yielding a total of 322 images. We then designed a staircase procedure as follows. A fixation cross appeared for 500 ms, followed by a randomly selected image from our set. The image was first displayed for a total of t=50ms. After a 500 ms mask, subjects were instructed to respond to the perceived emotion. If the subject response is correct, the exposure time t for that particular emotion is decreased. Otherwise, it is increased. To determine these increments/decrements, we assume that the value of t will converge to its right value (i.e., after several trials, the value of t will oscillate about the time threshold required to achieve recognition). The results show that happiness is the fastest to be recognized (23-28ms) and that this value does not change as the image size decreases. Neutral, disgust and surprise form a second group requiring additional time (3 to 4 times longer than happiness) and with a minimal increase of processing time as the size of the percept is reduced. Fear requires the same time as this second group, but its processing time increases dramatically as the percept decreases in size. Finally, sadness and anger constitute the group requiring the longest for recognition – about 10 times slower than happiness. These results show that the recognition of emotions has evolved differently for distinct emotions, suggesting an adaptation to some evolutionary needs.

Acknowledgement: National Science Foundation

33.507 **Image size reveals perception biases of similarity among facial expressions of emotion**

Shichuan Du[1](dus@ece.osu.edu), Aleix Martinez[1]; [1]The Ohio State University.

Recognizing facial expressions of emotion is important in social communication. Humans have the ability to recognize emotions from faces represented by a small number of pixels or at large distances. Where is the limit? Is this limit the same for all expressions of emotion? Or, are we more tuned to reading some specific emotions? We investigate these questions using six basic facial expressions of emotion (happiness, sadness, anger, fear, surprise, and disgust) in addition to neutral. Face images scaled in five different sizes encompassing 10x15 to 160x240 pixels (at increases of factors of 2) are presented in two emotion labeling tasks. Three important aspects of emotion recognition emerge from our study: 1) Recognition accuracy increases nonlinearly with image size in all expressions. 2) Happiness, surprise, disgust and neutral can be recognized at very small sizes (10x15 pixels), whereas fear, sadness and anger cannot (requiring images of at least 40x60 pixels). 3) At low resolutions, there is an asymmetric ambiguity in recognizing expressions of emotions – e.g., sadness is perceived as more similar to neutral than anger, while anger is most often confused with sadness; fear is more often misclassified as surprise than disgust, while disgust is typically misinterpreted as fear. This asymmetry is eliminated as the size of the image increases.

Acknowledgement: National Science Foundation

33.508 **Individual differences in empathy and indices of face processing**

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Empathy is vital for social functioning, yet its relationship to lower level processes like face processing remains unknown. We examined whether individual differences in empathy (as indexed by the Interpersonal Reactivity Index; IRI, Davis, 1980) were related to facial expression processing, attentional disengagement from facial expression and reflexive orienting to gaze direction in three separate, but related experiments. In Experiment 1, sensitivity and decision biases in perceiving expression (fear, anger) were examined with a 2-alternative, forced-choice task using morphed facial expressions. While there was no relationship between the ability to detect the intensity of fear or anger alone, particular empathy subscales (perspective taking, personal distress and empathic concern) were significant predictors of how individuals interpreted blends of fear and anger. In Experiment 2, we examined whether individual differences in empathy were predictive of attentional disengagement from irrelevant emotional face distractors (happy, angry, fearful, and neutral faces) during a target detection task and found no relationship between empathy and attentional disengagement from emotional faces. In Experiment 3, we examined whether empathy was related to reflexive orienting to non-predictive gaze cues in emotional faces (fearful, happy). Results indicated that cuing effects at short SOAs were not related to personality differences. In contrast, cuing effects at long SOAs were predicted by individual differences in empathy (fantasy and empathic concern). We conclude that empathy (as indexed by the IRI) does not modulate rapid, sensory-driven perceptual or attentional processes. Rather, individual differences in empathy appear to play a role in decision processes associated with perceiving ambiguous facial expressions and only mediate reflexive orienting to gaze direction when there is sufficient time to process the face cue. Together these results suggest that empathy may influence later stages of processing associated with interpreting facial information.

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33.509 **Laying the foundations for an in-depth investigation of the whole space of facial expressions**

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Facial expressions form one of the most important and powerful communication systems of human social interaction. They express a large range of emotions but also convey more general, communicative signals. To date, research has mostly focused on the static, emotional aspect of facial expression processing, using only a limited set of "generic" or "universal" expression photographs, such as a happy or sad face. That facial expressions carry communicative aspects beyond emotion and that they transport meaning in the temporal domain, however, has so far been largely neglected. In order to enable a deeper understanding of facial expression processing with a focus on both emotional and communicative aspects of facial expressions in a dynamic context, it is essential to first construct a database that contains such material using a well-controlled setup. We here present the novel MPI facial expression database, which contains 20 native German participants performing 58 expressions based on pre-defined context scenarios, making it the most extensive database of its kind to date. Three experiments were performed to investigate the validity of the scenarios and the recognizability of the expressions. In Experiment 1, 10 participants were asked to freely name the facial expressions that would be elicited given the scenarios. The scenarios were effective: 82% of the answers matched the intended expressions. In Experiment 2, 10 participants had to identify 55 expression videos of 10 actors. We found that 34 expressions could be identified reliably without any context. Finally, in Experiment 3, 20 participants had to group the 55 expression videos of 10 actors based on similarity. Out of the 55 expressions, 45 formed consistent groups, which highlights the impressive variety of conversational expressions categories we use. Interestingly, none of the experiments found any advantage for the universal expressions, demonstrating the robustness with which we interpret conversational facial expressions.

33.510 Out of sight, but not out of mind: Affect as a source of information about visual images

Eric Anderson[1](andersix@bc.edu), Dominique White[1], Erika Siegel[1], Lisa Barrett[1,2]; [1]Boston College, [2]Massachusetts General Hospital / Harvard Medical School

Recent evidence suggests that affect influences visual processing. To further explore this, we used Continuous Flash Suppression (CSF) as a technique to suppress stimuli from conscious visual awareness. Previous research has demonstrated that while suppressed images are experienced as unseen, they are still processed by the brain. In this study, we explored to what degree suppressed images are processed and whether suppressed images influence behavior. Consciously seen neutral faces were paired with suppressed angry, happy, or neutral faces rendered invisible with CFS. Participants rated the neutral faces as more unpleasant when paired with an unseen angry face and more pleasant when paired with an unseen happy face. These findings demonstrate that affective information is extracted by the brain from faces rendered invisible by CFS, and that this affective information is readily misattributed to a different, consciously seen face.

33.511 Preferential processing of fear faces: emotional content vs. low-level visual properties

Katie Gray[1](klhg103@soton.ac.uk), Wendy Adams[1], Matthew Garner[1,2]; [1]School of Psychology, University of Southampton, [2]Division of Clinical Neuroscience, School of Medicine, University of Southampton

Behavioural and neurological research suggests that emotional (relative to neutral) faces are more visually salient, with preferential access to awareness, for example in overcoming binocular rivalry suppression. However, it is difficult to determine to what extent such effects result simply from low-level characteristics as opposed to the emotional content of the face per se. Although spatial inversion has been used to control for low-level image characteristics, the extent to which inversion disrupts emotion processing is unclear. We applied both spatial inversion and luminance reversal to fear, happy, angry and neutral faces. These manipulations retained the contrast, mean luminance and spatial frequency profiles of the images but combining them made the emotion impossible to categorise. Observers viewed the normal and the manipulated images under continuous flash suppression: a single face was presented to one eye and high contrast dynamic noise to the other. Fear faces emerged from suppression (i.e. became visible) faster than the other three expressions. However, this pattern was equally apparent for the original and the manipulated faces. The properties that lead to the unconscious prioritisation of fearful faces are thus fully contained in unrecognisable images that share the same low-level visual characteristics. Our findings suggest that some emotion-specific effects may be driven entirely by low-level stimulus characteristics.

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33.512 Properties of a good poker face

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Research in competitive games has exclusively focused on how opponent models are developed through previous outcomes, and how peoples' decisions relate to normative predictions. Little is known about how rapid impressions of opponents operate and influence behavior in competitive economic situations, although such rapid impressions have been shown to influence cooperative decision-making. This study investigates whether an opponent's face influences players' wagering decisions in a zero-sum game with hidden information. Participants made risky choices in a simplified poker task while being presented opponents whose faces differentially correlated with subjective impressions of trust. If people use information about an opponent's face, it predicts they should systematically adjust their wagering decisions, despite the fact that they receive no feedback about outcomes, and the value associated with the gambles is identical between conditions. Conversely, if people only use outcome-based information in competitive games, or use face information inconsistently, then there should be no reliable differences in wagering decisions between the groups. Surprisingly, we find that threatening face information has little influence on wagering behavior, but faces relaying positive emotional characteristics impacts peoples' decisions. Thus, playing against opponents whose faces rank high on subjective impressions of trustworthiness leads to increased loss aversion and suboptimal wagering behavior. According to these results, the best 'poker face' for bluffing may not be a neutral face, but rather, a face that contains emotional correlates of trustworthiness. Moreover, it suggests that rapid impressions of an opponent play an important role in competitive games, especially when people have little or no experience with an opponent.

33.513 Testing emotional expression recognition with an adaptation of the "Bubbles" masking approach

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Classification of facial expressions is thought to require differential allotment of attention to some features and feature regions while limiting the allocation of attention to other features and feature regions. There is some evidence to suggest that adult observers classify expressions using both configural and featural information, however research documenting what information in the human face leads to successful recognition is incomplete. We applied the Bubbles masking approach (Gosselin & Schyns, 2000) to a dichotomous forced choice facial expression classification task. Stimuli consisted of six individual faces, each posing all of six different facial expressions plus neutral. While viewing various faces, participants chose one of two prompts presented below the stimulus to classify the facial image as exhibiting an emotion or the negation of that emotion (i.e. "happy" or "not happy"). In order to determine the regions used for classification, the images were masked using Gaussian windows (bubbles). Obstruction was adjusted adaptively in order to maintain 75% classification accuracy. The classic Gosselin and Schyns task was adapted for future application to testing preschool children, by reducing the number of trials in a test and increasing the N of observers tested. Classification images were calculated for each facial expression, across image identity and within. Results will be presented in terms of a comparison of the diagnostically useful regions for humans to the diagnostic regions used by an ideal observer (following Susskind, 2007). Regions showing an increase, relative to the ideal observer, will indicate regions of increased influence in the interpretation of the expression by human observers, whereas decreased regions will reflect areas of reduced influence in the human observers' decision-making process. Results will direct future explorations as we begin to manipulate expression intensity and test 5-7-year-old children as well as adults.

33.514 The Facial Width-to-Height Ratio as a Basis for Estimating Aggression from Emotionally Neutral Faces

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The facial width-to-height ratio (FWHR), a size-independent sexually dimorphic property of the human face, is correlated with aggressive behaviour in men. Furthermore, observers' estimates of aggression from emotionally neutral faces are accurate and are highly correlated with the FWHR. In a series of experiments we tested if the FWHR is the basis of observers' accuracy in estimating aggressive propensity from emotionally neutral faces. In Experiments 1a-c, estimates of aggression remained accurate when faces were blurred or cropped, manipulations that reduce featural cues but maintain FWHR. Accuracy decreased when faces were scrambled, a manipulation that retains featural information but disrupts the FWHR. The estimates of aggression were highly consistent across observers for all conditions except the scrambled condition. Overall, estimates of aggression were most accurate when all facial features (even if blurred) were presented in their canonical arrangement, allowing for perception of the FWHR, with at most a small contribution from the appearance of individual features. There was no explicit use of the FWHR; 84% of participants indicated that "the eyes" were the basis for their judgement. No participant reported using any kind of configural information, including the FWHR. Nonetheless, in Experiment 1d, participants given instruction about the FWHR were able to accurately estimate the FWHR of faces presented for 39 msec. In Experiment 2, computer-modeling software (FACEGEN) identified eight facial metrics that correlated with estimates of aggression; regression analyses revealed that FWHR was the only metric that uniquely predicted these

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estimates. In Experiment 3, faces were manipulated to create pairs that differed only in FWHR. Participants' judgement of which individual of the pair was more aggressive was biased towards faces with the higher FWHR. Together, these experiments support the hypothesis that the FWHR is an honest signal of propensity for aggressive behaviour.

Acknowledgement: SSHRCC, NSERC

33.515 Visual redundancy enhances face identity perception but impairs face emotion perception

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Nature, artworks, and man-made environments are full of redundant visual information, where an object appears in the context of other identical or similar objects. How is visual perception affected by whether the surrounding items are identical to it, different from it, or absent? This study addresses the role of visual redundancy in the perception of human faces and reveals opposite effects on identity perception and emotion perception. Participants in Experiment 1 identified the gender of a single face presented at fixation. This "target" face was preceded by three types of masked prime displays: a single face at a randomly selected visual quadrant, four identical faces, one in each quadrant, or four different faces, one in each quadrant. All faces had neutral expression. Priming was indexed by faster gender discrimination of the "target" face when it was identical to one of the prime faces, than when it was a different gender. Experiment 1 found that gender priming was greater when the prime display contained four identical faces than when it contained a single face or four different faces, suggesting that face identification was enhanced by redundant visual input. In Experiment 2, participants viewed prime displays containing a single face, four identical faces, or four different faces, but these faces were either neutral or fearful in facial expression. Participants identified the facial expression of a "target" face, whose expression was either consistent or inconsistent with that of the prime display. Facial expression priming was significantly greater when the prime display contained a single face than when it contained four identical faces or four different faces. In fact, priming in the emotion task was eliminated when the prime display contained four identical faces. These results show that visual redundancy facilitates the perception of face identities, but impairs the perception of facial emotions.

Acknowledgement: University of Minnesota Grant-in-aid

33.516 What does the emotional face space look like?

Frédéric J.A.M. Poirier[1](frederic.poirier@umontreal.ca), Jocelyn Faubert[1]; [1]Ecole d'optométrie, Université de Montréal

Humans communicate their emotions in large part through facial expressions. We developed a novel technique to study the static and dynamic aspects of facial expressions. The stimulus consisted of 4 parts: (1) a dynamic face, (2) two smaller versions of the starting and end states, (3) a label indicating the target dynamic expression, and (4) sliders that could be adjusted to change the facial characteristics. Participants were instructed to adjust the sliders such that the face would most closely match the target expression. Participants had access to 53 sliders, allowing them to manipulate static and dynamic characteristics such as face shape, eyebrow shape, mouth shape, and gaze. Preliminary data from 4 participants and 7 conditions revealed interesting effects. Some expressions are marked by unique facial features (e.g. anger given by frown, surprise and fright given by open mouth and open eyes, pain given by partially closed eyes, and happiness given by upwards curvature of the mouth). Some expressions seem to develop non-linearly in time, that is, include an intermediate state that deviates from a linear transformation between starting and ending states (e.g. anger, surprise, pain). This demonstrates the method's validity for measuring the optimal representation of given facial expressions. Because the method does no rely on presenting facial expressions taken from or derived from actors, we believe that it is a more direct measure of internal representations of emotional expressions. Current work is focused on building a vocabulary of emotions and emotional transitions, towards an understanding of the facial expression space.

Acknowledgement: NSERC-Essilor industrial research chair & NSERC discovery fund

Face perception: Social cognition

Vista Ballroom, Boards 517–530

Sunday, May 9, 8:30 - 12:30 pm

33.517 The time course of face-gender discrimination: Disentangling the use of color and luminance cues

Nicolas Dupuis-Roy[1](nicolas@dupuis.ca), Daniel Fiset[1], Mélanie Bourdon[1], Frédéric Gosselin[1]; [1]Département de psychologie, Université de Montréal

In a recent study using spatial Bubbles (Dupuis-Roy, et al., 2009), we identified the eyes, the eyebrows and the mouth as the most potent features for face-gender discrimination (see also Brown & Perrett, 1993; Russell, 2003, 2005; Yamaguchi, Hirukawa, & Kanazawa, 1995). Intriguingly, we found that the mouth was correlated only with rapid correct answers. Given the highly discriminative color information in this region, we hypothesized that the extraction of color and luminance cues may have different time courses. Here, we tested this possibility by sampling the chromatic and achromatic face cues independently with spatial and temporal Bubbles (see Gosselin & Schyns, 2001; Blais et al., 2009). One hundred participants (35 men) completed 600 trials of a face-gender discrimination task with briefly presented sampled faces (200ms). To create a stimulus, we first isolated the S and V channels of the HSV color space for 300 color pictures of frontal-view faces (average interpupil distance of 1.03 deg of visual angle) and adjusted the S channel so that every color was isoluminant (±5 cd/m2); then, we sampled S and V channels independently through space and time with 3D Gaussian windows (spatial std = 0.15 deg of visual angle and temporal std = 23.53 ms). The group classification image computed on the response accuracy shows that in the first 100 ms, participants used the color in the mouth region along with the luminance in the left eye-eyebrow region; and that in the last 100ms, they relied on the luminance information located in the mouth and the right eye-eyebrows. Male and female observers slightly differ in their extraction of the mouth information. Altogether, these results help to disentangle the relative role of color and luminance in face-gender discrimination.

Acknowledgement: FQRNT

33.518 Reconfigurable face space for the perception of inter-gender facial resemblance

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Psychophysical and neurophysiological evidence suggests that faces are represented in a mean-centered multi-dimensional face space. However, the organization of face space is poorly understood. We used a novel markerless morph-vectorization technique, based on the multi-channel gradient model, to investigate the organization and rapid reconfiguration of face space. Face spaces for male and female faces were created via principal component analysis (PCA). Faces' shape and texture were described as vector deviations from populations' mean faces. Novel faces were synthesized by translating these vectors within and between male and female face spaces and then reconstructing to image form. The mathematical basis of perceptual similarity between male and female face spaces was investigated by showing subjects cross-gender pairs of faces which had either similar, unrelated or opposite vector deviations from their population mean. Subjects perceived faces with similar vector deviations from their respective means (sibling-faces) as most similar and faces with opposite vector deviations as least similar. Facial identity aftereffects also transferred between male and female face spaces. Adaptation to a male face yielded a shift in perceived identity of female faces toward the mathematically opposite female face. The perceptual similarity of synthesized sibling-faces indicates that face space can be dynamically partitioned into mean-centered subspaces e.g., male and female. This ability may underpin the perception of "family resemblances" in disparate groups of faces with widely varying underlying image statistics. Cross-sibling adaptation indicates the existence of relational as well as absolute coding in face space.

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33.520 Perception of gender is a distributed attribute in the human face processing network

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Face perception is mediated by a distributed neural system in the human brain, but conventional univariate fMRI data analysis has not clearly localized differential responses to male as compared with female faces within this network. We used fMRI and multivariate pattern decoding to test whether we could detect gender-specific neural responses in forty subjects (hetero- and homosexual men and women), who viewed male and female faces and rated their attractiveness. Face stimuli evoked activation in the inferior occipital gyrus (IOG), fusiform gyrus (FG), superior temporal sulcus (STS), amygdala, inferior frontal gyrus (IFG), insula, and orbitofrontal cortex (OFC). Pattern classification with a sparse logistic regression algorithm revealed successful decoding of gender information with above chance accuracies within the IOG, FG, STS, IFG, INS and OFC, but not in the amygdala. We did not find any differences in decoding the gender of face stimuli (male vs. female) as a function of the subject's gender (men vs. women) or their sexual orientation (hetero- vs. homosexual). Our findings suggest that gender information is widely distributed across the face network and is represented in the "core" regions that process invariant facial features, as well as the "extended" regions that process changeable aspects of faces. The lack of gender-specific information in the amygdala is likely due to its role in threat detection and emotional processing.

33.521 **Perception of race and sex differently depends on the low and high spatial frequency channels**

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In VSS2006, we reported a brain-damaged patient whose perception of race was selectively impaired (Koyama et al 2006). The patient also demonstrated that her perception of race largely depends on the surface properties of the face (e.g., convexes and concaves). On the other hand, a study showed that the perception of sex depends on the outline of the face and face parts (e.g., Takahashi et al. 1996). Based on the above studies we hypothesized that the perception of race depends more largely on the low spatial frequency channels whereas the perception of sex depends more largely on the high spatial frequency channels. In order to test the hypothesis, we tested the normal subjects' performance in race and sex classification tasks with high-pass and low-pass filtered pictures. Nineteen subjects participated in the experiment. We used 56 pictures from JACFEE (Matsumoto & Ekman 1988) for the stimuli. There were 3 types of pictures which were made from the same 56 pictures: (1) original grayscale pictures, (2) high-pass filtered pictures, and (3) low-pass filtered pictures. The subjects participated in the race and sex classification tasks. In the race classification task, a picture was presented in a 21-inch LCD display and the subject judged whether the person in the picture would be Asian or Caucasian. The same pictures were used in the sex classification task, and the subject judged whether the person in the picture would be male or female. As predicted, the subjects performed better with the low-pass filtered pictures in the race classification task whereas they performed better with the high-pass filtered pictures in the sex classification task. The results supported the hypothesis that the perception of race depends more largely on the low spatial frequency channels whereas the perception of sex depends more largely on the high spatial frequency channels.

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33.522 **Differential spatial and temporal neural response patterns for own- and other-race faces**

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Humans recognize own-race faces more accurately than other-race faces (Malpass & Kravitz, 1969), suggesting differences in the nature of neural representations for these faces. We examined the spatial and temporal patterns of neural responses to own- and other-race faces. Functional magnetic resonance imaging data were obtained while Asian and Caucasian participants viewed blocks of Caucasian and Asian faces. Voxels from high-level visual areas, including fusiform gyrus and lateral-occipital areas were localized in a separate scan using faces (of the same race as the participant), objects and scrambled-images. We first applied a pattern-based classifier to discriminate neural activation maps elicited in response to Asian and Caucasian faces. A low dimensional representation of the brain scans based on their principal components was used as input to the classifier. We measured the ability of the classifier to predict the race of the face being viewed. We found above-chance discrimination of the neural responses to own- versus other-race faces for both Asian and Caucasian participants. Reliable discrimination scores were obtained only when the voxel selection process used a localizer that presented "own-race" faces. Next, we examined differences in time-course of neural responses to own- and other-race faces and found evidence for a temporal "other-race effect". The neural response to own-race faces was larger than to other-race faces, but only across the first few time points in the block. The magnitude of the neural response to other-race faces was lower at first, but increased across the block to ultimately overtake the magnitude of the own-race response. This temporal activation pattern held across the broader range of ventral temporal areas, and for the FFA alone. Spatial discrimination, however, was reliable only across the broader range ventral temporal areas. The results highlight the importance of examining the spatio-temporal components of face representations.

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33.523 **Poor memory for other race faces is not associated with deficiencies in holistic processing**

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Introduction. Recent studies using standard tests of holistic face processing (part-whole and composite effects) have suggested the other-race effect on memory is associated with poor holistic processing for other-race faces (Tanaka et al 2004; Michel et al 2006). Yet, this was found only in Caucasian subjects, with Asians showing equally strong holistic processing for own-race and other-race faces; also the studies did not test an inverted control condition, meaning effects for upright faces might not have been fully face-specific in origin. Here, we re-examined the issue. Methods. Asian subjects (recently arrived overseas students) and Caucasians were tested on Asian and Caucasian faces. Memory was measured using the Cambridge Face Memory Test and a new Chinese-face version (CFMT-Chinese). Contact with same- and other-race members was measured via questionnaire. Holistic processing was measured with (a) the 'overlaid faces task' (Martini et al., 2006) – an upright and an inverted face are overlaid in transparency and less contrast is needed to perceive the upright face – in a version which appeared to tap face detection (i.e., faces dissociated from scrambled faces and objects, but face scores did not correlate with memory); (b) the overlaid faces task in a version shown to tap identity-level processing (scores did correlate with memory); and (c) a standard composite task that showed composite effects only for upright faces and not inverted faces. Results. Despite a large other-race effect on memory, and large other-race differences in contact, there was no suggestion of reduced holistic processing for other race faces, for either race of subject, on any of the three holistic processing tasks. Conclusion. There was no support for the holistic processing deficit explanation of the other-race effect, implying that other factors are involved in its etiology.

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33.524 **Race-modulated N170 Response to the Thatcher Illusion: Evidence for the expertise theory of the other race effect**

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It has been suggested that differential use of configural processing strategies may be the underlying cause of racially-based recognition deficits. By employing a well known configural manipulation (thatcherization), we aimed to demonstrate, electrophysiologically, that configural processing is used to a greater extent when viewing same-race faces than when viewing other-race faces. N170 ERP responses were measured for participants viewing normal and thatcherized faces of the same-race (Caucasian) and of another race (African-American). The N170 response was modulated to a greater extent by thatcherization for same-race faces, suggesting that the processing of these faces is, in fact, more reliant on configural information than other-race faces. These findings considered to be the result of greater experience, and thus greater expertise with faces of one's own race as compared to faces of another race.

33.525 **Effect of spatial frequency on other-race effect**

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People are better at recognizing faces of their own race than those of other race. Tanaka and his colleagues (2004) suggested that people processed faces of their own race more holistically than those of other race. In addition, studies have shown that LSF (Low Spatial Frequency) information is more important in the holistic process of faces than HSF (High Spatial Frequency; Goffaux & Rossion, 2006). To parametrically measure the effect of LSF information on other-race effect, we used binocular rivalry paradigm. In Experiment 1, we made two kinds of filtered faces by applying different cut-off frequencies (above 16 cycles/image for HSF filtered faces; below 8 cycles/image for LSF filtered faces) per each race. Two different faces from each race were presented for 90 seconds to separate eyes. Each face was either HSF or LSF filtered. Perceived duration of own-race face was significantly longer than that of other-race face. This trend was more pronounced in HSF filtered faces, producing the significant interaction between the race and the spatial frequency. Moreover, this significant advantage of own-race face was observed over the effect of eye dominance. Experiment 2 tested whether other-race effect was generalized to full spectrum faces undergoing rivalry. Again, the perceived duration of own-race was significantly longer than that of other-race. Finally, we tested the effect of spatial frequency on binocular rivalry in Experiment 3. Only the same-race faces were used in this experiment and we found that HSF filtered faces were always perceived longer than LSF filtered faces. The results of three experiments suggested that LSF information played an important role in other-race effect by influencing holistic process of faces. Furthermore, for the first time we introduced more parametrical method to measure this effect.

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33.526 Race-specific norms for coding face identity and a functional role for norms

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High-level perceptual aftereffects have revealed that faces are coded relative to norms that are dynamically updated by experience. The nature of these norms and the advantage of such a norm-based representation, however, are not yet fully understood. Here, we used adaptation techniques to get insight into the perception of faces of different race categories. We measured identity aftereffects for adapt-test pairs that were opposite a race-specific average and pairs that were opposite a 'generic' average, made by morphing together Asian and Caucasian faces. Aftereffects were larger following exposure to anti-faces that were created relative to the race-specific (Asian and Caucasian) averages than to anti-faces created using the mixed-race average. Since adapt-test pairs that lie opposite to each other in face space generate larger identity aftereffects than non-opposite test pairs, these results suggest that Asian and Caucasian faces are coded using race-specific norms. We also found that identification thresholds were lower when targets were distributed around the race-specific norms than around the mixed-race norm, which is also consistent with a functional role for race-specific norms.

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33.527 Own-race Effect: an Attentional Blink Perspective

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Own-race effect is the tendency that people can better identify members of their own race than other race. In the present study, own-race effect was studied in attentional blink (AB) paradigm. AB studies have found that the second of two targets is often poorly discriminated when presented within about 500 ms from the first target. In 2 experiments, Chinese participants were asked to identify Caucasian and Asian faces in a simplified two-target RSVP paradigm (Duncan et al., 1994) and stimuli onset asynchrony between two faces were manipulated on four levels: 0ms, 235ms, 706ms, and 1176ms. In Experiment 1, only cross-race orders were adopted: C-A (Caucasian as T1, Asian as T2) and A-C (Asian as T1, Caucasian as T2). We hypothesized that AB effect might decrease or even disappear in C-A condition because of own-race effect. Contrary to our prediction, the same amplitude of AB effects was observed in C-A and A-C conditions, although the overall accuracy for identifying own-race faces was better than other-race faces. In Experiment 2, besides cross-race orders, same-race orders (A-A and C-C) were added. AB effects were found in four race orders. Again, AB effects in C-A and A-C conditions were shown to have similar pattern and similar effect size. But the advantage of identifying own-race faces over other-race faces was absent. Analysis of the first half data revealed similar result to that of the whole data set, indicating the absence of the own-race advantage could not be due to practice effect. In sum, perception of own-race and other-race faces were studied in a simplified AB paradigm and our results suggest that own-race faces and other-race faces have no differences in competing for attentional resource considering the same pattern of AB effect observed in both experiments.

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33.528 When East meets West: gaze-contingent Blindspots abolish cultural diversity in eye movements for faces

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Eye movement strategies deployed by humans to identify conspecifics are not universal. Although recognition accuracy is comparable, Westerners predominantly fixate the eyes during face recognition, whereas Easterners fixate the nose region. We recently showed with a novel gaze-contingent technique - the Spotlight - that when information outside central vision (2° and 5°) is restricted, observers of both cultures actively fixated the same face information during face recognition: the eyes and mouth. Only when both eye and mouth information were simultaneously available by fixating the nose region (8°), did East Asian observers shift their fixations towards this location - a strategy similar to natural viewing conditions. Therefore, the central fixation pattern deployed by Easterners during face processing suggests better use of extrafoveal information while looking at faces, an issue that remains yet to be clarified.

Here, we addressed this question by monitoring eye movements of Western Caucasian and East Asian observers during face recognition with a novel technique that parametrically restricts central vision information: the Blindspot. We used both natural vision and Blindspot conditions with Gaussian apertures of 2°, 5° or 8° dynamically centered on observers' fixations. Face recognition performance deteriorated with increasing Blindspot apertures in both observer groups. Interestingly, Westerners deployed a strategy that shifted progressively towards the typical East Asian central fixation pattern with increasing Blindspot apertures (see supplementary figure). In contrast, East Asian observers maintained their culturally preferred central fixation location pattern, showing better performance under unnatural viewing conditions relative to Westerners.

Collectively, these findings show that restricting foveal information induces an Eastern-style strategy amongst Westerners while restricting extrafoveal information induces a Western-style strategy amongst Easterners. Overall, these observations show that the central fixation pattern used by Easterners relies on a better use of extrafoveal information. Cultures shapes how people look at faces and sculpts visual information intake.

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33.529 Social judgments from faces are universal

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There is a growing body of evidence showing that humans make automatic and reliable personality inferences from facial appearance. Interestingly, it has been robustly shown that the recognition of other-race faces is impaired compared to same-race faces (the so-called other-race effect), with categorization of gender and age also achieved inefficiently. However, the extent to which the ability of making reliable inferences from faces generalizes across cultures and faces from different races is poorly understood. This issue is even timelier considering recent studies that have challenged the universality of face processing. For instance, we recently showed that Westerners predominantly fixate the eyes during face recognition, whereas Easterners fixate the central region of the face (i.e., nose) (Blais et al., 2008). Culture also modulates the strategy observers use to gather visual informa-

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tion during facial expression categorization (Jack et al., 2009). Therefore, asking whether social judgments from faces generalize across cultures is a natural question to be addressed. To this aim, we tested Western Caucasian and East Asian observers performing visual and social judgments from all the combinations of face pairs sampled from 40 Western Caucasian and 40 East Asian unfamiliar faces. Observers from both cultures first evaluated the physical and the social similarity of each face pair. Subsequently, observers performed binary social evaluations on the same face pairs for attractiveness, competence, trustworthiness and warmth. All binary decisions were paired with a measure of confidence. Finally, we represented the face space for each of the judgments in matrices of dissimilarity weighted by confidence levels for each observer and culture. Mantel correlations performed on the matrices of dissimilarity indicated a fairly robust agreement across cultures for all judgments, both visual and social. Our data show that humans rely on universal rules to perform trait inferences from facial appearance.

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33.530 **Is Social Categorization Alone Sufficient to Induce Opposing Face Aftereffects?**

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Adults encode individual faces in reference to a distinct face prototype that represents the average of all faces ever encountered. The prototype is not a static abstracted norm but rather a malleable face average that is continuously updated by experience (Valentine, 1991); for example, after prolonged viewing of faces with compressed features, adults rate similarly distorted faces as more normal and more attractive (simple attractiveness aftereffects). Recent studies have shown that adults possess category-specific face prototypes (e.g., based on race, sex). After viewing faces from two categories (e.g., Caucasian/Chinese) that are distorted in opposite directions, adults' attractiveness ratings shift in opposite directions (opposing aftereffects). Recent research has suggested that physical differences between face categories are not sufficient to elicit opposing aftereffects and that distinct social categories are necessary (Bestelmeyer et al., 2008). For example, opposing aftereffects emerge when participants adapt to faces from two distinct sex categories (female and male) but not when participants adapt to faces from within the same sex category (female and hyper-female). The present set of experiments was designed to investigate whether social categorical distinctions in the absence of salient physical differences are sufficient to induce opposing aftereffects. In each experiment, physical appearance was held constant (all Caucasian female faces) while social categorical information differed (university affiliation in Experiments 1 and 2 and personality type in Experiment 3), such that half the faces purportedly belonged to participants' in-group while half the faces belonged to their out-group. Across all three experiments, there was no evidence for opposing aftereffects, despite the fact that participants showed better recognition memory for in-group faces than for out-group faces (Experiment 3). These results suggest that both physical differences and a social categorical distinction are necessary in order to elicit category-contingent opposing face aftereffects.

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Scene perception: Categorization and memory

Vista Ballroom, Boards 531–541

Sunday, May 9, 8:30 - 12:30 pm

33.531 **Tiny Memory: How many pixels are required for good recognition memory?**

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We can remember hundreds of pictures given only a few seconds of exposure (Standing,1973). How much stimulus resolution is necessary for successful picture memory? Torralba (2009) reported that 32x32 pixel photographs can be categorized with 80% accuracy, but can these thumbnails be effectively coded into memory? In Experiment 1, observers saw a sequence of natural scene images, and gave a new/old keypress response after each image. We varied picture resolution across blocks (16x16, 32x32, 64x64, or 256x256 pixels). Old and new pictures within a block had the same resolution. The second (old) presentation of an image could lag 2, 4, 8, 16, 32, 64 or 128 trials after the first. Higher resolution produced better performance, longer lags worse performance. However, performance was well above chance even at 16x16: 89% correct at lag 2, 52% at lag 128, d' of 2.52 and 1.18, respectively (using the 16% overall false alarm rate). Similar performance was obtained whether lower resolution images were presented as smaller, thumbnail versions of 256x256 images or as highly blurred 256x256 images. Is resolution more important at encoding or at recall? In Experiment 2, the first presentation of a picture could be 32x32 or 256x256 pixels. The second (old) presentation of an image was always at a different resolution from the first. Results were strikingly asymmetric. Encoding at 256x256 produced good memory at 32x32 (d'=1.80). Encoding at 32x32 produced very poor memory at 256x256 (d'=0.15), far worse than encoding and testing at 32x32 (Exp 1: d'=2.04). We conclude that the representations of highly degraded images can support robust recognition memory. However, when observers see full resolution images they are unable match them to degraded representations of the same picture in memory.

33.532 **Do expert searches remember what they have seen?**

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Previous research has shown that humans have a massive and robust ability to recognize objects and scenes that they have seen before (Brady, Kongle, Alvarez, and Oliva, 2008). Do experts have similarly impressive memory for the unusual stimuli with which they are expert? We tested cytologists who search "scenes" filled with cells for signs of cervical cancer on memory for those scenes. We tested the same observers on memory for images of objects and real scenes. We compared their results to non-cytologist control subjects. In all conditions, participants viewed 72 images and were told that they should remember them. During the testing phase, they were shown 36 old and 36 new images and were asked to label image as new or old. Expert cytologists were no better than controls for object memory (d' 1.99 and 1.97, respectively) or scenes (d': 3.44 vs. 3.20). They were significantly better than naives at remembering images of cells (d' .62 vs. .12). Note, however, that their memory for cell scenes was quite poor, significantly worse than their memory for objects and for scenes. We conclude that expertise with stimuli does not convey massive memory for those stimuli nor does expertise with one set of stimuli notably increase memory for stimuli in general. On the practical side, these results mean that, with some caution, one can reuse stimuli in studies of cytology in ways that would not be wise in studies of memory for natural scenes.

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33.533 **A taxonomy of visual scenes: Typicality ratings and hierarchical classification**

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Research in visual scene understanding has been limited by a lack of large databases of real-world scenes. Databases used to study object recognition frequently contain hundreds of different object classes, but the largest available dataset of scene categories contains only 15 scene types. In this work, we present a semi-exhaustive database of 130,000 images organized into 900 scene categories, produced by cataloguing all of the place type or environment terms found in WordNet. We obtained human typicality ratings for all of the images in each category through an online rating task on Amazon's Mechanical Turk service, and used the ratings to identify prototypical examplars of each scene type. We then used these prototype scenes as the basis for a naming task, from which we established the basic-level categorization of our 900 scene types. We also used the prototypes in a scene sorting task, and created the first semantic taxonomy of real-world scenes from a hierarchical clustering model of the sorting results. This taxonomy combines environments that have similar functions and separates environments that are semantically different. We find that man-made outdoor and indoor scene taxonomies are similar, both based on the social function of the scenes. Natural scenes, on the other hand, are primarily sorted according to surface features (snow vs. grass, water vs. rock). Because recognizing types of scenes or places poses different challenges from object classification -- scenes are continuous with each other, whereas objects are discrete -- large databases of real-world scenes and taxonomies of the semantic organization of scenes are critical for further research in scene understanding.

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33.534 **Predicting object and scene descriptions with an information-theoretic model of pragmatics**

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A picture may be worth a thousand words, but its description will likely use far fewer. How do speakers choose which aspects of a complex image to describe? Grice's pragmatic maxims (e.g., "be relevant", "be informative") have served as an informal guide for understanding how speakers select which pieces of information to include in descriptions. We present a formalization of Grice's maxim of informativeness ("choose descriptions proportional to the number of bits they convey about the referent with respect to context") and test its ability to capture human performance.

Experiment 1: Participants saw sets of four simple objects that varied on two dimensions (e.g., texture and shape) and were asked to provide the relative probabilities of using two different adjectives (e.g., polka-dot vs. square) to describe a target object relative to the distractor objects. Participants' mean probabilities were highly correlated with the information theoretic model's predictions for the relative informativeness of the two adjectives (r=.92,p<.0001).

Experiment 2: Participants described street scenes from a database of hand-segmented and labeled images (LabelMe). In the context condition, participants were presented with a set of six scenes, one target and five distractors, and were asked to name five objects in the target scene so that another observer could pick that scene out of the set. In the no-context condition, another group of participants performed the same task without seeing the distractors. The information-theoretic model was strongly correlated with differences in object labeling between context and no-context conditions (r=.67,p<.0001), suggesting that the model captures the effect of context on descriptor choice.

Our results suggest that speakers' image descriptions conform to optimal pragmatic norms and that information theory can define norms for the linguistic compression of visual information. This constitutes a first step towards understanding how the visual world is captured and communicated by language users.

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33.535 **Humans in the Midst: Evidence for Top-Down Facilitation in Visual Search**

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Observers can efficiently pick out early visual features to make sense of a dynamic environment. However, they may also rely on top-down information to facilitate scene processing. For example, when observers search for friends on a street, they may use prior information about their friends (e.g., how they move) to facilitate search. To test for top-down facilitation in scene processing, we combined a category search task we used previously with modelling. There is accumulating evidence that observers are highly efficient at processing biological targets such as humans. When searching for biological targets, observers may be able to use both early and category-specific visual features, and only early visual features for non-biological targets. On separate blocks observers searched for grayscale videos containing humans or machines while their eye movements were tracked. In Experiment 1, the distractors were videos from the other category. In Experiment 2, natural-scene videos (e.g., waterfalls and trees) were used as distractors for both targets. We found a category advantage in both experiments: Observers detected humans more quickly than machines. Importantly in Experiment 2, observers detected the absence of humans more quickly than the absence of machines on target-absent trials although the search arrays were identical for both target categories. Thus, category-specific visual features in memory may help observers efficiently eliminate distractors. Consistent with search times, we also found that observers fixated more briefly on human targets than on machine targets. There was no category advantage when contrasting two biological categories (humans and animals). To further rule out the contribution of early visual features to this category advantage, we tested our paradigm on Itti and Koch's bottom-up visual saliency model. We found that this model did not reproduce our results. In sum, our results point to possible top-down information that facilitates observers' sensitivity to biological categories.

33.536 **Describing locations from memory: Effects of spatial reference direction on reference object selection**

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Spatial descriptions can specify the location of an object (located object) by spatially relating it to a reference object that is selected from surrounding objects. Previous research with currently viewed scenes has shown a preference for selecting reference objects on the basis of spatial features such as proximity and alignment. However, we often talk about scenes that are not in current view. Two experiments demonstrated that the spatial features defined by the perspective from which a scene was learned influenced reference object selection in later descriptions of the scene from memory. Specifically, participants learned an array of objects, and judgments of relative direction verified the perspective with which the object locations were encoded. Participants then moved to a new location from which the scene was no longer visible, and completed a reference object selection task by describing the scene from memory, using the sentence frame, "The is near the ____". Results of JRD task showed that object locations were represented with respect to a specific intrinsic reference direction, as determined in Experiment 1 by learning direction and in Experiment 2 by the dimensions of a rectangular table on which the objects were placed. For the reference object selection task, participants were significantly more likely to choose reference objects along the intrinsic reference direction that corresponded to the way that the objects were represented as reflected in the JRD task. These findings were also supported at the individual level as a correlation between the strength of the organizational bias with respect to particular axes in memory and the likelihood of selecting reference objects along these axes in the spatial language task. These findings extend the prioritization of spatial features for selecting reference objects to memory representations, and are consistent with claims of correspondence between memory and linguistic representations.

33.537 **Is Boundary Extension Different When You've Been There? Memory for Familiar and Unfamiliar Campus Pictures**

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Boundary Extension (BE), the memory distortion whereby viewers remember larger expanses of scenes than they actually saw in photographs, has been attributed to the activation of mental layout representations. However, the effect of viewer's familiarity with the actual scene has never been explored. Three possible outcomes were predicted. First, familiarity with a scene could help viewers memorize the view boundaries, reducing the distortion. In contrast, familiarity could help people build a more expansive mental representation, increasing the distortion. Third, it is possible that boundary extension is linked to low level processes affected by the photograph's spatial layout alone and is not affected by familiarity with the real world scene. In two experiments, participants from two distant colleges viewed a series of pictures (28 Experiment 1; 32 Experiment 2) that included common locations from each campus. Pictures were presented for 15s, during which participants rated their familiarity with the location depicted in the scene. Immediately after the presentation, a forced-choice memory test was administered using four distractor pictures depicting from 20% larger to 20% smaller expanses. In both experiments, participants rated pictures from their own campus as more familiar and significant boundary extension was obtained in all conditions. However, there was no interaction between familiarity and BE scores. One of the campus picture sets seemed to elicit more BE for all viewers, and so an attempt was make to equate the two picture sets in term of the types of scenes used and the layout and crowding within the scenes. With these changes, equivalent levels of BE were obtained for the pictures from both campuses, but again BE did not interact with familiarity. Overall, the results indicate that boundary extension is linked more closely to scene layout than to any familiarity the participant might have with the environment.

33.538 **Broadening the Horizons of Scene Gist Recognition: Aerial and Ground-based Views**

Lester Loschky[1](loschky@ksu.edu), Katrina Ellis[1], Tannis Sears[1], Ryan Ringer[1], Joshua Davis[1]; [1]Psychology Department, Kansas State University

Numerous studies in the last decade have used ground-based views of scenes to investigate the process of scene gist recognition. Conversely, few if any studies have investigated scene gist recognition of aerial (i.e., satellite) views. This study asks the question, how much of what we know about scene gist recognition from ground-based views directly translates to aerial views?

Fifty-two participants were randomly assigned to Aerial and Ground-based conditions, with processing times (SOA) and scene categories varied within-subjects. Stimuli were monochrome photographs from 10 categories: 5 Natural: coast, desert, forest, mountain, river; 5 Man-made: airport, city, golf-course, residential, stadium. Aerial images were from Google Earth©. Both target and mask images were presented for 24 ms, with SOAs of 24-94 ms plus a no-mask condition. Participants then chose between all 10 categories.

As predicted, ground-based views were recognized more accurately than aerial views. However, contrary to predictions, aerial view recognition did not benefit more from additional processing time than ground-based view recognition. Aerial view performance with no mask was worse than ground-based view performance at 24 ms SOA. Thus, gist perception of aerial views is more data (information) limited than resource (time) limited, perhaps because they are "accidental views" (Biederman, 1987). An additional analysis collapsed all 10 basic level categories into 2 superordinate level "Natural" and "Man-made" categories. For ground-based views, Natural categories were consistently high, whereas Man-made categories benefited from additional processing time. However, for aerial views, both Natural and Man-made categories benefited equally from additional processing time. Nevertheless, confusion matrices for the 10 basic level categories and responses showed a correlation of .80 across the Aerial and Ground-based views, suggesting that discriminability between categories is similar across aerial and ground-based views. Further research will investigate what information both aerial and ground-based views contain, and what information aerial views lack.

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33.539 **Adaptation for landmark identity and landmark location on a familiar college campus**

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Familiar landmarks have both an identity (e.g., White House) and a location in space (e.g., 1600 Pennsylvania Ave.). How are these two kinds of information represented in the brain? We addressed this issue by scanning University of Pennsylvania students with fMRI while they viewed images of 10 landmarks from the Penn campus. Images (22 views of each landmark; 220 total) were presented at 0.33 Hz in a continuous carry-over design (Aguirre, 2007). We observed two different kinds of adaptation effects relating to repetition of (i) landmark identity and (ii) spatial location. First, scene-responsive parahippocampal place area (PPA) and retrosplenial complex (RSC), as well as medial retrosplenial cortex, showed reduced response when two different images of the same landmark were shown on successive trials, suggesting that these regions represent individual places with some generalization across views. Second, the left anterior hippocampus exhibited adaptation corresponding to real-world distances between landmarks; specifically, response was more strongly reduced when the landmarks shown on successive trials were closer together on campus. Importantly, there was a dissociation between these two effects: PPA, RSC, and medial retrosplenial cortex did not show distance-related adaptation and left anterior hippocampus did not show adaptation for landmark identity. The landmark adaptation effect in PPA, RSC, and medial retrosplenial cortex is consistent with previous work implicating these areas in the coding of real-world places. The unexpected distance-related response in the left anterior hippocampus may reflect the retrieval of episodic memories about these locations in a way that is shaped by their positions in a larger spatial map.

Acknowledgement: This research was funded by NIH grant EY-016464 to R.A.E.

33.540 **How Accurate is Memory for Familiar Slope?**

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Geographical slant is generally overestimated. It has been reported that these overestimations are even greater in memory than in perception (Creem & Proffitt, 1998). However, these prior studies have used imagery instructions, which may encourage biased responding. We asked two groups of undergraduates to provide verbal, and pictorial or proprioceptive slope estimates of 5 familiar campus paths ranging in actual slope from 0.5 to 8.6 deg. One set of 30 participants was led to the base of each path and made their estimates while looking at it (Perception Condition). The other set of 30 participants made estimates from memory (Memory Condition). Maps, satellite photos and verbal names for the paths were used in the memory condition to ensure that participants understood the location of the path to be judged. Half the participants in each condition were asked to hold out their unseen hand to represent the slope of the path. Hand orientation was measured precisely with a micro-inclinometer. Following this they made verbal estimates. The other half of the participants adjusted a 2D line on a computer screen to represent the slope of the path prior to making verbal estimates. All three measures showed the same patterns. For one of the shallower paths (1.2 deg), proprioceptive estimates from memory were slightly lower (2.3 deg) than the proprioceptive estimates of those viewing the path (4.0 deg), $t(28) = 2.08$, $p = .046$. For all other paths and measures, there was no evident or consistent difference between memory and perception on any of the measures. Non-verbal estimates were lower than verbal estimates, but all estimates overestimated all hills both in perception and in memory. We conclude that memory for familiar paths includes unbiased (normal) perceptual information about path inclination. Creem, S.H., & Proffitt, D.R. (1998). Psychonomic Bulletin and Review 5(1):22-36.

33.541 **Does experience with a scene facilitate spatial layout judgments?**

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In many perceptual domains, enhanced sensitivity to discrimination relevant dimensions, or perceptual learning, develops with repeated exposures. On one hand, layout perception maybe relatively direct, requiring no familiarity with a scene for efficient processing. In contrast, familiarity with a scene may allow for the rapid extraction of scene properties that support layout judgments. A series of experiments investigated whether scene-specific perceptual learning develops as a function of experience with a given photographic or synthetic scene. Subjects were instructed to indicate the closer of two cued locations within a given scene. Neither of these cued locations within a scene repeated. Savings accrued across the experiment such that responses were faster overall. Further, the savings were greatest with repeated scenes. However, this learning was greater with photographic stimuli.

Object recognition: Selectivity and invariance

Vista Ballroom, Boards 542–556

Sunday, May 9, 8:30 - 12:30 pm

33.542 **Object selective responses without figure-ground segregation and visual awareness**

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It is well known that neurons in the temporal lobe classify objects, such as faces, and it is generally assumed that the activity of such neurons is necessary for conscious awareness of these objects. However, object categorization may also occur unconsciously, as has been shown by the selective activation of object selective neurons by masked objects. So what distinguishes conscious from unconscious object recognition? We constructed schematic images containing objects such as faces and houses while keeping local retinal stimulation between conditions identical. Using a dichoptic fusion paradigm, we manipulated stimulus visibility such that objects were

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either visible or not visible. Confirming earlier results, we found that both consciously perceived and non-perceived objects result in category specific BOLD activation. Critically however, we show that only consciously seen objects show a distinct neural signature of figure-ground segregation in early and midlevel visual areas, which is completely absent when objects are not seen. Although counterintuitive, this implies that consciousness is more intimately related to processes of figure-ground segregation and perceptual organization than to object categorization. We propose that figure-ground segregation is a prerequisite for visual awareness, and that both phenomena share part of their neural correlate, which is recurrent processing in visual cortex.

33.543 Decoding of object position using magnetoencephalography (MEG)

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Contemporary theories of object recognition posit that an object's position in the visual field is quickly discarded at an early stage in visual processing, in favor of a high level, position-invariant representation. The present study investigated this supposition by examining how the location of an object is encoded in the brain as a function of time. In three experiments, participants viewed images of objects while brain activity was recorded using MEG. In each trial, subjects fixated a central point and images of objects were presented to variable locations in the visual field. The nature of the representation of an object's position was investigated by training a linear classifier to decode the position of the object based on recorded physiological responses. Performance of the classifier was evaluated as a function of time by training the classifier with data from a sliding 10ms time window. The classifier's performance for decoding the position of the object rose to above chance levels at roughly 75ms, peaked at approximately 115ms, and decayed slowly as a function of time up to 1000ms post-stimulus onset. Within the interval of 75 to 1000ms, classification performance correlated with the angular distance between targets, indicating a metric representation of visual space. Notably, prior to the time that classification performance returned to chance, object category information could be decoded from physiological responses; and, participants were able to accurately make high level judgments about the objects (i.e. category and gender for faces). These findings suggest that position may be a fundamental feature encoded in the representation of an object, in contrast to the notion that position information is discarded at an early stage of visual processing.

33.544 Perceiving and representing the orientation of objects: Evidence from a developmental deficit in visual orientation perception

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Perceiving and representing the orientations of objects is important for interacting with the world. For example, accurate orientation information allows us to interpret visual scenes, comprehend symbols and pick up objects. Despite its importance, little is known about how the visual system represents object orientation. One potential clue, however, comes from the tendency to confuse mirror images. In previous work we explored mirror image confusion in normal adults' memory for orientation. The present study probes perceptual representations of object orientation by investigating the mirror image confusions made by AH, a woman with a remarkable developmental deficit in perceiving the locations and orientations of objects. We describe a framework that conceives of orientation as a relationship between reference frames. The COR (coordinate-system orientation representation) framework assumes that object orientation representations map an object-centered reference frame onto a reference frame extrinsic to the object, which may in turn be related to additional extrinsic frames. Moreover, for each of these mappings, the representations are compositional, involving several parameters. According to COR, mirror image confusions result from failures in encoding, retaining or processing specific parameters. We present new data from AH in support of COR assumptions. AH's systematic pattern of mirror reflection errors in copying pictures of objects provides evidence for the compositionality of orientation representations, and the role of object-centered frames and mappings between extrinsic frames in representation of orientation. AH makes similar mirror reflection errors when reaching for objects, suggesting the hypothesized orientation representations also play a role in visually-guided action. Finally, the fact that AH's errors arise at a perceptual level, in contrast with errors made by adults in memory, supports the idea that orientation representations have similar structure at multiple levels of processing.

33.545 The "Inversion Effect" and Cortical Visual Processing

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The investigation of stimulus inversion can reveal important insights into the nature of visual object processing. Many studies have examined inversion with respect to faces, and have consistently demonstrated a large cost in the recognition of inverted compared to upright faces. Imaging studies have also demonstrated higher activation within the fusiform face area (FFA) for upright than for inverted faces. However, the inversion effect is not unique to faces, and costs of inversion on recognition are also observed for objects and scenes, although generally to a lesser extent than for faces. Here, we used functional magnetic resonance imaging (fMRI) to investigate the effect of inversion on visual processing for multiple categories of visual stimuli across multiple regions of visual cortex. Specifically, upright and inverted faces, objects, and scenes were presented to subjects, and the patterns of response within FFA, object-selective cortex (Lateral Occipital, LO), and scene-selective cortex (Parahippocampal Place Area, PPA) to each stimulus type and orientation were compared. In all high-level visual areas the patterns of response could be used to discriminate between the different categories of upright stimuli. Within the FFA, while the effect of inversion was strongest for faces, there was also an effect for non-preferred stimuli, demonstrating that face-selective cortex shows a general effect of inversion. PPA showed a strong inversion effect only for scenes, suggesting a specialization for its preferred category. In contrast the generally object-selective LO showed inversion effects for all stimulus classes. Collectively, these results demonstrate robust effects of inversion for multiple object categories in cortical visual processing and suggest that category is not the only factor contributing to the inversion effect in specialized cortical regions. Additionally, these results complement behavioral studies of inversion by demonstrating inversion effects for faces, objects, and scenes in their preferred and non-preferred regions of processing.

33.546 The viewpoint debate revisited: What drives the interaction between viewpoint and shape similarity in object recognition?

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Previous reports have shown (a) viewpoint-dependent time costs in object recognition and (b) that shape similarity affects these viewpoint costs. However, it remains unclear which aspects of shape similarity interact with viewpoint effects (e.g., to what extent similarity is computed from solely 2D image-based shape properties and/or 3D geometric structure). In this study we examined the relative contributions of these factors to viewpoint related time costs in order to elucidate the nature of the shape representations mediating recognition. Using a series of sequential matching experiments (same shape/different shape) we measured recognition performance for 3D novel objects or their silhouettes at the same or different viewpoints. The results showed a significant interaction between viewpoint and similarity. When participants matched objects at the same viewpoint, responses for different objects sharing the same 3D configuration (but not local features) were slower than those for different objects sharing local shape features alone. The same pattern of results was also found with silhouettes suggesting that this time cost may be attributed to the similarity of the 2D global outline rather than to internal 3D configuration per se. Further, when participants compared different rotations of objects a viewpoint-dependent time cost was found. This cost was greater for different objects sharing only local shape attributes than for different objects sharing only 3D configuration. These findings are consistent with previous proposals that recognition is mediated by 2D image-based representations. However, in addition, they further suggest that access to these representations involves the parallel operation of two perceptual mechanisms: a rapid analysis of global shape outline at a coarse spatial scale, and a relatively slower analysis of internal local shape features at a fine spatial scale. Thus, shape similarity interacts with viewpoint over different time courses depending on the spatial scale at which similarity is computed.

33.547 **Differential viewpoint preference for objects and scenes reflects encoding and retrieval efficiency**

J. Stephen Higgins[1](higgins3@uiuc.edu), Ranxiao Frances Wang[1]; [1]Psychology Department, University of Illinois

Canonical views are different between objects and scenes. Previous research, using a stimuli set that equated all visual features between objects and scenes except for connectedness between the parts, has demonstrated that participants prefer oblique views for objects while they prefer straight-on views for scenes. These preferences are apparent by measuring either participants dwell time while studying different views of the stimuli or the view that participants chose as their favorite. Viewpoint preferences stayed constant across different tasks requiring the use of identical visual information between objects and scenes. The present studies explored whether this preference reflects encoding or retrieval efficiency. Participants either explored oblique or straight-on views (45º or 0º, respectively) of objects or scenes and were tested on an intermediate view between the two types of study views (22.5º or 202.5º), or studied objects or scenes from the intermediate views and were tested on the oblique or straight-on views. In all tasks participants were faster at recognizing oblique views than straight-on views of objects, and were faster at recognizing straight on than oblique views of scenes. These results suggest that people's canonical viewpoint preferences reflect the ability to determine which view is most beneficial for both encoding and recognition even though the stimuli types provide the same visual information, except for connectedness between parts.

33.548 **Large Perspective Changes (>45°) Allow Metric Shape Perception Used to Recognize Quantitatively Different Objects**

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Background. Previous object recognition studies have shown that observers could not recognize objects using quantitative (metric) properties. The finding of a relative inability to detect the metric differences is consistent with numerous previous perception studies in which observers are unable to perceive metric 3D shape accurately. However, Bingham & Lind (2008) found large perspective changes (≥45°) allowed accurate metric shape perception. We now investigated whether such information can yield the ability to detect quantitative properties and use them to recognize objects.

Methods. 10 Ss participated in a small rotation (20°) condition and 10 Ss participated in a large rotation (70°) condition. 24 octagonal objects were used. There were 4 qualitatively different objects and each object had 5 quantitatively different variations. Every observer performed three sessions in the same order, namely 2D quantitative difference, 3D quantitative difference and 3D qualitative difference tasks. Observers viewed computer generated displays of objects with stereo and structure-from-motion information and performed a same-different task. Judgments were to be as accurate and quick as possible.

Results. When information from large perspective changes was available, the ability to recognize quantitatively different objects was comparable to that for qualitatively different objects both in respect to accuracy of judgments and reaction times.

Conclusions. The two visual systems theory suggests that the ventral system which is responsible for object recognition deals with and requires only qualitative properties. In contrast, our results showed that metric properties also can be used to recognize objects if information from large perspective changes was available. Thus, we challenged the idea that the ventral system only uses qualitative properties to perform object recognition. We suggested that use of metric shape perception is not determined by anatomically distinct visual systems, but instead it is a function of information.

33.549 **The role of visual orientation representation in the mental rotation of objects**

David Rothlein[1](david.rothlein@jhu.edu), Michael McCloskey[1]; [1]Department of Cognitive Science, Johns Hopkins University

Mental rotation tasks classically involve participants deciding whether two pictures of objects, presented at different orientations, are the same or mirror images. Reaction time in these tasks increases more or less linearly with the angular difference in orientation between the two objects. This finding has led many researchers to conclude that mental rotation is performed in a manner that is (somehow) analogous to the physical rotation of the object in question. This interpretation implies, for example, that the processes underlying 90° and 180° mental rotations are qualitatively the same, differing only quantitatively. In the present study participants reported (by drawing or selection from a forced-choice array) the orientation that would result from rotating a stimulus picture 0°, 90°clockwise, 90°counterclockwise, or 180°. Analyses of participants' errors revealed qualitative differences in the distribution of error types across the different rotation conditions, suggesting that mental rotation processes may vary qualitatively and not just quantitatively as a function of rotation angle. We interpret the results by reference to specific assumptions about the form of mental orientation representations and the processes that transform these representations in mental rotation tasks.

33.550 **State-dependent TMS reveals rotation-invariant shape representations in Lateral Occipital Cortex and Occipital Face Area**

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Human extrastriate visual cortex contains functionally distinct regions where neuronal populations exhibit signals selective for visually presented objects. How such regions might play a causal role in underpinning our ability to recognize objects across different viewpoints remains uncertain. Here, we tested whether two extrastriate areas, the lateral occipital (LO) region and the occipital face area (OFA) contained neuronal populations that play a causal role in recognizing two dimensional shapes across different rotations. We used visual priming to modulate the activity of neuronal populations in these areas, and then applied TMS before presentation of a second rotated shape to which participants had to respond. Surprisingly, we found that TMS applied to both LO and OFA modulated rotationally invariant shape priming, but in a fashion that differed depending on the degree of rotation. Our results thus demonstrate that both the LO and OFA contain neuronal representations which play a causal role in rotation-invariant shape processing.

33.551 **View-point dependent representation of objects in peripheral visual fields**

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Peripheral vision shows poorer performance than central vision for various visual tasks. Although there are many studies that have used artificial stimuli or human faces, little is known about the recognition of daily objects in peripheral visual fields. In the present study, we investigated recognition of facing direction of objects in peripheral vision. The task was to judge the facing direction (left or right) of static objects briefly presented at the location either in the left or right peripheral visual field along the horizontal meridian. Stimuli were daily objects (humans, animals, cars, motorcycles, and arrows), presented at either 5 or 20deg of eccentricity, and sizes 3 or 6deg visual angle. The results showed that participants judged facing direction of objects correctly when their size was relatively large. However, decreasing stimulus size made the recognition performance worse when the objects faced toward participants' point of gaze than when the objects faced away. In an additional experiment, we investigated whether the phenomenon occurred only in peripheral visual fields along horizontal meridian or not. Stimuli were presented at a total of eight peripheral locations; left, right, upper, lower, and upper / lower left and right from the participants' point of gaze. An arrow and bar figure was used in this experiment. We adopted the bar figure to examine the judgements for objects with no directional information. The results showed that recognition performances were lower for the arrow facing toward the point of gaze than for that facing away at all eight peripheral locations, and that the bar appeared as the arrow facing away. These results indicate new interesting characteristic of object recognition in peripheral vision; in peripheral visual fields, representation of object is view-dependent, or more precisely, dependent on viewer's point of gaze.

33.552 **Conspicuity of Object Features Determines Local versus Global Mental Rotation Strategies**

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Most studies describe mental rotation as a top down process where the time to discriminate between identical or mirrored objects increases linearly with the angular deviation between them. Although mental rotation is regarded as a distributed processing task, its dependence on object features is still not well understood. Therefore, we investigated the effect of structured color cues on an object's surface with a mental rotation task. Observers viewed two side-by-side images of Shepard Metzler type objects rendered for the following conditions: (1) objects had distinctively colored surfaces (these surfaces had the same color from different viewpoints), (2) objects had distinctive yet differently colored surfaces (colors of the surfaces changed with every viewpoint), (3) objects had distinctive dark gray surfaces (similar to 1 with gray instead of colored surfaces), (4) objects without any color information (uniformly gray). The viewing angle differed between the two objects from an egocentric frame of reference and the task was to determine as quickly as possible if the objects were identical or mirrored. Reaction times and eye movement data were recorded. Rotation effects were seen across all four conditions, but they were largest for condition 2 and the smallest for condition 3. The color cues in condition 2 seemed to make the task less efficient as evidenced by the increased reaction times, number of fixations and number of comparisons made between the images compared to the other conditions. For larger angular deviation in condition 1, the highly distinctive cues seemed to bias the observers' strategy toward comparing the local object structure near the cues, as indicated by more comparisons in further spread-out locations. The results suggest that, particularly for highly demanding rotation tasks, distinctive features induce multiple local comparisons of the object structure whereas the absence of such features tends to induce mental rotation of larger parts of the object or the entire object.

33.553 **Invariant behavioural templates for object recognition in humans and rats**

Ben Vermaercke[1](ben.vermaercke@psy.kuleuven.be), Hans Op De Beeck[1]; [1]Laboratorium of Biological Psychology, university of Leuven, Belgium

The human visual system is expert in object recognition. We can identify objects under different viewing conditions, that is, object recognition shows a great deal of invariance. How the brain accomplishes this complex task is puzzling neuroscientists. Many studies have applied methods that visualize linear relationships between image properties and performance, such as classification images, 'bubbles', and reverse correlation. However, the existence of invariance means that simple relationships between image properties and performance do not exist, except in artificial experimental situations. The validity of results obtained in such situations is not clear. This problem is all the more relevant in studies of other animals that might be prone to rely on simple strategies. Here we extended the bubble technique to explicitly study invariant object recognition in humans as well as rats. We trained humans and five Brown-Norway rats to discriminate two simple shapes (square vs triangle) that were partially occluded with bubbles. At first, the shapes had a fixed position. Behavioural templates from these data were complex, also for rats, and consisted of a few spatially separated spots. Then these shapes were shown at random screen positions to prevent any simple relationship between the content of specific pixels and the stimulus. As expected, we no longer obtained clear behavioural templates with traditional classification image analyses. However, if we adapt the analyses by taking the position shift of the stimulus into account and normalizing the position of bubbles for the position of the stimulus, then again a behavioural template is found - for both species. We conclude that methods to visualize behavioural templates can be adapted to include the full complexity and inherent nonlinearity of object recognition, and allow the investigation of these nonlinearities in humans and even in species that are not typically considered as being 'visual'.

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33.554 **A Theory of Size-Invariance in Human Object Recognition**

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Human observers can recognize an object as small as thumb nail-sized photo or as large as several meter portrait photo. How do human observers realize this remarkable feat? What is the underlying neural mechanism? Some researchers suggested this is achieved by routing neural circuits processing different size objects to a size invariant neuron. However this seems logical circular since even though the researchers knew routing circuits processing different size objects, it is unclear how brain know this in the first place. Here we give a theory for size invariance. We argue that size invariance is logically equivalent to a unique representation for an object, and neural structures count more than learning at least for size invariance.

Human observers can recognize any different sized object after observing a specific size object. This is equivalent to a unique representation for an object. This can be proved mathematically easily. Then the problem becomes what is the unique representation? If we want to get a large obejct representation from a small object representation, some detail information (edges) is not available. On the other hand, we can get a small object representation from a large object representation. Therefore we suggest that the unique representation is the smallest representation for an object. To achieve this, any object projected on the retina is first processed by the nerual system to the smallest object the neural system can represents. Here the smallest object may be the smallest detectable by the human vision system.

Under this theory, all different size objects converge to this smallest object representation. This final convergent connection can be hard-wired by the brain due to neural structures representing the equivalence. This equivalent structure, however, may be partially built from evolution through observing object moving from different distances.

Acknowledgement: Chian Natural Sciences Foundation

33.555 **Robust object and face recognition using a biologically plausible model**

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The human ability to accurately recognize objects and faces after only a single observation is unparalleled, even by state-of-the-art computer vision systems. While performance of computer vision systems has increased dramatically in recent years, the systems tend to be optimized for particular domains (e.g., faces), typically require many training examples, and use features specially engineered for the task. We have developed a Bayesian computational model based on several characteristics of the human visual system: We move our eyes to regions of high salience, sample the image via fixations, and use oriented edge filters as our primary representation. Our model combines a bottom-up salience map, a memory for fixations, and features learned from natural scenes by a sparse coding algorithm (Independent Components Analysis (ICA)). The features developed by ICA share many similarities with simple cells in V1 including the same color-opponent channels. The statistical frequency of each ICA filter is estimated by fitting their responses to generalized Gaussian distributions. Using these statistics, we compute a saliency map to find rare visual features. The saliency map is treated as a probability distribution and sampled to generate simulated fixations. Fixation memory is represented as a probability density using a kernel density model. During recognition, sequentially acquired fixations are used to update a posterior probability distribution using Bayes' rule, representing the model's current beliefs. Our model has a small number of free parameters that are learned on two datasets of Butterflies and Birds. The complete model, then, uses features learned from natural images and parameter settings developed on datasets completely disjoint from the sets it is applied to, which are CalTech 101, CalTech 256, the Flower 102 dataset, and the AR face recognition dataset. Our method produces state-of-the-art results on these sets, and exceeds all other approaches when trained on one example.

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33.556 **Reading words and seeing style: The neuropsychology of word, font and handwriting perception**

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Reading is considered to be primarily a function of the left hemisphere. However, it is also possible to process text for attributes other than the identity of words and letters, such as the style of font or handwriting. Older anecdotal observations have suggested that processing of handwriting style may involve the right hemisphere. There is also some fMRI evidence of sensitivity to style in either right or left visual word form areas in the fusiform gyri. We created a test that, using the same set of text stimuli, required subjects first to sort text on the basis of word identity and second

Sunday AM

to sort text on the basis of script style. We presented two versions, one using various computer fonts and the other using the handwriting of different individuals, and measured accuracy and completion times. For testing we selected four subjects with unilateral fusiform lesions and problems with object processing who had been well characterized by neuropsychological testing and structural and/or functional MRI. We found that one alexic subject with left fusiform damage performed well when sorting by script style but had markedly prolonged reading times when sorting by word identity. In contrast, two prosopagnosic subjects with right lateral fusiform damage that eliminated the fusiform face area and likely the right visual word form area were impaired in sorting for script style, but performed better when sorting for word identity. Another prosopagnosic subject with right medial occipitotemporal damage sparing areas in the lateral fusiform gyrus performed well on both tasks. The contrast in the performance of patients with right versus left fusiform damage suggests an important distinction in hemispheric processing that reflects not the type of stimulus but the nature of the processing operations required.

Acknowledgement: CIHR grant MOP-77615, Alzheimer Society of Canada, Michael Smith Foundation for Health Research, Canada Research Chair program.

Sunday Afternoon Talks

Eye movements: Top-down effects

Sunday, May 9, 2:45 - 4:15 pm
Talk Session, Royal Ballroom 1-3
Moderator: Anna Montagnini

34.11, *2:45 pm*

Anticipatory eye-movements under uncertainty: a window onto the internal representation of a visuomotor prior

Anna Montagnini[1](Anna.Montagnini@incm.cnrs-mrs.fr), David Souto[2,3], Guillaume Masson[1]; [1]Institut de Neurosciences Cognitives de la Méditerranée, CNRS and Aix-Marseille University, Marseille, France, [2]Faculté de psychologie et des sciences de l'éducation, University of Geneva, [3]Cognitive, Perceptual and Brain Sciences, University College London, UK

Predictive information plays a major role in the control of eye movements. When a visual event can be predicted with some confidence the delay to initiate an oculomotor response is reduced and anticipatory movements oriented toward the predicted event can be observed. These effects of predictability unveil the expectancy state (or prior) of the visuomotor system. Here we try to infer some general properties of the internal representation of a visuomotor prior and its trial-by-trial buildup, by parametrically manipulating uncertainty (thus predictability) in a visual tracking task. We analyze anticipatory smooth pursuit eye movements (aSPEM) in human subjects, when the relative probability p of occurrence of one target motion type (Right vs Left or Fast vs Slow target motion, in two experiments) was varied across experimental blocks. We observed that aSPEM velocity varies consistently both as a function of the recent trial-history (local effect) and as a function of the block probability bias p (global effect). A single model based on a finite-memory, Bayesian integrator of evidence allows to mimic both local and global effects. The comparison of model predictions (through numerical simulations) and data suggest that: aSPEM are based on an internal continuous estimate of the probability bias p (as reflected by the unimodal distribution of aSPEM) the estimate of p is updated according to an (almost) optimal model of integration of probabilistic knowledge, accomodating experience-related and newly incoming information (current trial). This integration leads in particular to asymptotic linear dependence of mean aSPEM upon p and aSPEM-variance proportional to p(1-p) an additional gaussian motor noise with variance proportional to the square anticipatory velocity affects aSPEM. We conclude that the analysis of anticipatory eye movements may open a window on the dynamic representation of the Bayesian Prior for simple visuomotor decisions.

Acknowledgement: FACETS IST/FET 6th Framework

34.12, *3:00 pm*

Dynamic integration of saliency and reward information for saccadic eye movements

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Saccade target selection is known to be influenced by bottom-up factors, like salient objects as well as by top-down factors like reward. We wanted to investigate whether saliency and reward can also affect the fine tuning of saccadic landing positions. We presented two luminance-defined, overlapping, blurred patches of opposite contrast polarity in front of a homogeneous gray background. One patch had a fixed contrast of 20%, the contrast of the other was varied to manipulate the saliency. In the saliency baseline condition, we instructed subjects to make saccades to the target configuration. In the reward condition, subjects won points for landing on one target and lost points for landing on the other target. To manipulate the reward, we varied the relative amount of bonus and penalty. 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 saliency and reward influenced the saccade landing positions. Subjects' saccades landed closer to the patches that were more salient and rewarded. A model was able to account for these data by linearly weighting and combining saliency and reward. Saliency was modeled as the average of the two target positions, weighted by their relative contrast. For the reward, we predicted the optimal saccade endpoint that maximizes gain, based on the individual saccade variability and the bonus-penalty ratio. Interestingly, the relative weights were modulated by the latency of the saccades. While fast saccades nearly exclusively used salience to determine the landing point, slower saccades gave a higher weight to reward information. Our results show that rewards do not only affect saccadic target selection, but also the exact landing position within the target. However, integration of this top-down factor is time-consuming and can be overridden in saccades with short latencies.

Acknowledgement: This work was supported by the DFG Forschergruppe FOR 560

34.13, *3:15 pm*

Visual Working Memory Influences the Speed and Accuracy of Simple Saccadic Eye Movements

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Visual working memory exerts top-down control over the allocation attention, typically by biasing attention toward visual objects that share features with those currently maintained in memory. In the present study, we examined the top-down influence of VWM on the dynamics of simple saccadic eye movements, which are traditionally thought to be generated automatically on the basis of low-level stimulus events. Participants held a color in VWM as they executed a saccade to an abruptly appearing colored disk, which either appeared alone or in the presence of a distractor disk. Even when the target appeared alone, the execution of a saccade to the target was faster and more accurate when the target's color matched the color currently held in VWM. This implies that the color of the target disk was compared with VWM prior to saccade execution, and that a match influenced the efficiency of the saccade. This effect of VWM is striking given that the target was an abrupt luminance onset in an otherwise empty field. Even stronger effects of VWM were observed when a single distractor was presented simultaneously with the target. In particular, the presence of a distractor led to large impairments in saccade timing and accuracy when the distractor matched memory but the target did not, and much smaller impairments when the target matched memory but the distractor did not. This interaction held in a global effect paradigm, with saccade landing position biased toward the object that matched memory. It was also observed in a remote distractor paradigm, with a matching distractor capturing gaze on a significant proportion of trials and, in the absence of overt capture, slowing execution of the primary saccade. These findings indicate that VWM influences gaze control under conditions in which eye movements are typically thought to be stimulus driven.

Acknowledgement: NIH R01EY017356

34.14, *3:30 pm*

The effect of previous implicit knowledge on eye movements in free viewing

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We investigated whether previous knowledge about the underlying structure of scenes influence eye movements during free exploration. Subjects (N=6) were presented with a sequence of scenes, each for 3 seconds, consisting of a 5x5 grid and 6 shapes in various cells of the grid. The scenes were composed of two triplet chunks (three element in fixed spatial relation) selected from an inventory of 4 triplets and configured randomly. Two hundred scenes were presented and eye movements of the subjects were recorded, while they performed a two-back comparison: they had to notice any change between the current display and the one before the previous display. Next, a 2AFC task was used to assess how well subjects learned the underlying statistical structure of the scenes by choosing the more familiar of the two presented pattern fragments in each trial. We trained an online probabilistic non-parametric ideal observer model to learn the underlying structure of the scene including the number and identity of chunks com-

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posing each scene. For each trial, we used the model to predict subjects' eye movements based on the estimated reduction in uncertainty about identities of shapes, given previous fixations in the scene and the knowledge of previous scenes. For each subject, we found a significant relationship between saccade length and the reduction of uncertainties produced by the saccade ($p<0.001$). While for very short saccades, there was no relation between model prediction and saccade direction ($p>0.05$), for longer saccades, the average uncertainties reduction was 0.355 ($p<0.01$) following the predictions of the model. Furthermore, there was a positive correlation between the success of prediction, and subjects' performance in the 2AFC test ($r = 0.466$). This provides evidence that eye movements during free exploration are influenced by implicit knowledge about the underlying structure of the scenes.

34.15, *3:45 pm*

A neural model of how rank-selective spatial working memory and the supplementary eye fields control sequences of saccadic eye movements

Matthew Silver[1](mrsilver@bu.edu), Daniel Bullock[1], Stephen Grossberg[1], Mark Histed[2], Earl Miller[2]; [1]Department of Cognitive and Neural Systems, Boston University, [2]The Picower Institute for Learning and Memory and Department of Brain and Cognitive Sciences, MIT

How do working memory circuits store multiple spatial locations for the control of planned sequences of eye movements? How does using rank-sensitive coding contribute to sequence storage and recall when the same movement repeats at multiple list positions, or ranks, during the sequence? We develop a competitive queuing model of working memory to explain and simulate microstimulation, behavioral, electrophysiological, and anatomical data that clarify these processes. The model utilizes rank-sensitive prefrontal working memory representations (Averbeck et al, 2003), which depend upon rank-related activity in parietal cortex (Sawamura et al., 2002, see also Grossberg & Pearson, 2008), to produce spatial sequences in which the same action is repeated several times. The model shows how the supplementary eye fields (SEF; Schlag & Schlag-Rey, 1987) could mediate the selection of saccade plans from sequential working memory by simulating both behavioral results and a number of SEF cell types (Isoda & Tanji, 2002, Lu et al., 2002). In addition, model simulations illustrate how microstimulation (Histed & Miller, 2006; Yang et al., 2008) may alter the order of performance of sequences of eye movements stored in spatial working memory, but not which movements (items) are generated. Finally, the model proposes how SEF interacts with downstream regions such as the frontal eye fields (FEF), during memory-guided sequential saccade tasks. The model explicates a functional role for the SEF and its interactions with interconnected cortical areas, and makes predictions for novel experimental conditions. The explicit circuit model clarifies how rank-order sensitive working memories may solve the problem of representing sequential plans in which component actions repeat at later points in the sequence.

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34.16, *4:00 pm*

Dissociation of eye movement signals and perception during fixation

Laura Pérez Zapata[1,2](lauraperez@ub.edu), Antonio Aznar-Casanova[1,2], Hans Supèr[1,2]; [1]Institute for Brain, Cognition and Behavior (IR3C), [2]Dept Basic Psychology, Faculty of Psychology, University of Barcelona (UB)

We perceive our visual surrounding by continuously making saccadic eye movements. Saccades are guided by visual information that is previously selected by the visual system. Both bottom-up and top-down information guides saccades. The role of top-down control in gaze is demonstrated by studies showing that object perception, task demands, behavioral relevance, memory, and attention are important factors in guiding saccadic eye movements. It is therefore not surprising that many sensory, associational and motor areas of the visual system are involved in the control of oculomotor behavior. In some perceptual illusions the perceived location of a target differs from the physical location. Here we asked the question whether in such a case saccade programming is governed by bottom-up (physical target location) and/or by top-down (the perceived target location) signals. For this we used induced depth stimuli where a target is perceived further away than it in reality is. In this way we can test whether saccades are directed towards the perceptual or to the physical location. At the onset of fixation, observers saccade and converge their eyes towards the perceived target location. Only after fixation (>~200 ms), the visual system is able to correct this 'depth illusion' by a fixational saccade and vergence eye movements. When observers maintain fixation but the target swaps between near and far location no differences in eye gaze and vergence were observed. Thus the saccadic adjustment and vergence are saccade dependent. This adjustment does not represent a correction due to under or overshoot of the saccade. Neither does it reflect an adjustment to vergence related to disturbance to the saccade. Thus eye movements (saccades and vergence) are guided by the perceived stimulus and during fixation eye movement signals are guided by the physical stimulus.

Object recognition: Object and scene processing

Sunday, May 9, 2:45 - 4:15 pm
Talk Session, Royal Ballroom 4-5
Moderator: Gabriel Kreiman

34.21, *2:45 pm*

Contextual associations in the brain: past, present and future

Moshe Bar[1](bar@nmr.mgh.harvard.edu); [1]Massachusetts General Hospital and Harvard Medical School

Objects in our environment tend to appear in typical contexts and configurations. The question of how the brain forms, represents and activates such contextual associations to facilitate our perception, cognition and action is fundamental. In recent years, we have characterized many aspects of the cortical mechanisms that mediate contextual associations, and this topic has received a much needed surge of attention that resulted in numerous findings by our community. The purpose of this talk is to overview what has been achieved in this research program so far; bridge findings that on the face of things may seem contradictory; discuss far-reaching implications that go from vision all the way to the brain's "default network" and to the relationship between associative thinking and mood regulation; and, finally, list critical milestones that should be met in coming years so that vision and memory are better connected, feedforward and feedback processes are better integrated, and more about the contextual cortical network is illuminated.

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34.22, *3:00 pm*

Mechanisms of perceptual organization provide auto-zoom and auto-localization for attention to objects

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Visual attention is often understood as a modulatory field at early stages of processing. In primates, attentive selection is influenced by figure-ground segregation, which occurs at early stages in the visual cortex. The mechanism that directs and fits the field to the object to be attended is not known. We propose here that the same neural structures that serve figure-ground organization automatically focus attention onto a perceptual object. Specifically, we show that an additive attentional input which is spatially broad and not tuned for object scale produces a quasi-multiplicative attentional modulation which is repositioned and sharpened to match the object contours (auto-localization) and tuned for the scale of the object (auto-zoom). The model quantitatively reproduces the changes in attentional modulation caused by the presence of objects observed at the level of V2. The proposed mechanism works with generic, zero-threshold linear neurons, additive inputs and the connection patterns are plausibly related to the statistics of natural visual scenes. We performed a global sensitivity analysis to determine the dependence of the attentional modulation, border ownership modulation and their interaction on several parameters in the model. The pattern and strength of the lateral inhibition are key to obtaining a sharpening of the attention field and a quasi-multiplicative attention modulation with an additive attention input. The strength of reciprocal con-

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nections from neurons representing local features and neurons integrating them, and inhibition between inconsistent proto-object representations are important to repositioning and tuning for scale of the attention field.

Acknowledgement: 5R01EY016281-02 and R01-NS40596

34.23, *3:15 pm*

Robustness to image clutter in human visual cortex

Gabriel Kreiman[1,2,3](gabriel.kreiman@childrens.harvard.edu), Yigal Agam[1], Hesheng Liu[1], Calin Buia[1], Alexander Papanastassiou[4], Alexandra Golby[5], Joseph Madsen[4]; [1]Department of Ophthalmology, Children's Hospital, Harvard Medical School, [2]Center for Brain Science, Harvard University, [3]Swartz Center for Theoretical Neuroscience, Harvard University, [4]Department of Neurosurgery, Children's Hospital, Harvard Medical School, [5]Department of Neurosurgery, Brigham and Women's Hospital

Visual recognition in natural scenes operates in the presence of multiple objects, background and occlusion. How the neural representation of images containing isolated objects extrapolates to cluttered images remains unclear. The responses of neurons along the monkey ventral visual cortex to cluttered images show varying degrees of suppressive effects. Attention could alleviate suppression by enhancing responses to specific features or locations. Yet, it seems difficult to account for the accurate and fast recognition capacity of primates exclusively by serial attentional shifts. Here we recorded intracranial field potentials from 672 electrodes in human visual cortex while subjects were presented with 100 ms flashes of images containing either one or two objects. We could rapidly and accurately read out information about objects in single trials in cluttered images from the physiological responses. These observations could account for human fast recognition performance and are compatible with simple hierarchical architectures proposed for immediate recognition.

Acknowledgement: NIH, NSF, Whitehall Foundation, Lions Foundation, Klingenstein Fund

34.24, *3:30 pm*

Task dependence and level of processing in category-specific regions of the ventral stream

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Several modules along the ventral visual pathway selectively respond to specific image categories: fusiform face area (FFA) to faces, parahippocampal place area (PPA) to scenes, and extrastriate body area (EBA) to bodies. The existence of these category-specific regions suggests that there are distinct branches in the visual-processing hierarchy. The relative levels of processing or abstraction among these category-specific regions are not known. Here we sought to determine the relative levels of processing for FFA and PPA using fMRI. We used noise-masked stimuli consisting of both a face and a scene, transparently superimposed. Subjects performed a face task and a scene task in separate scans using the same set of stimuli. For the scene task, subjects decided whether the scenes in two successively presented images were from the same scenery; for the face task, they determined if the two faces were of the same individual. The transparency of the faces and scenes were adjusted such that the accuracies for both tasks were similar. For each ROI (V1-hV4, LO, pFs, FFA, PPA) and task, we measured BOLD amplitude as a function of image SNR. We found that, for both tasks, the log-log slope of the BOLD response function increased monotonically from low- to high-level visual areas. The log-log slopes of the BOLD response functions of FFA during the face task and PPA during the scene task placed both areas at a similar level of processing as pFs (Tjan, Lestou and Kourtzi, 2006). However, FFA and PPA differed in that FFA was modulated equally by image SNR during both tasks, while PPA was not modulated at all during the face task, but was strongly modulated during the scene task. This suggests that face processing in FFA is involuntary while scene processing in PPA is task-dependent.

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34.25, *3:45 pm*

Examining how the real-world size of objects is represented in ventral visual cortex

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The size of objects in the world influences how we interact with them, but little is known about how known physical size is involved in object processing and representation. Here we examined if the dimension of real-world size is systematically represented in ventral visual cortex. In Experiment 1, observers were presented with blocks of small objects (e.g. strawberry, calculator) and blocks of big objects (e.g. car, piano) displayed at the same visual size (8 degrees) while undergoing whole brain imaging in a 3T fMRI scanner. Contrasts of big and small objects revealed that a region in the parahippocampal gyrus was preferentially active to big objects versus small objects, while a subregion along the lateral occipital cortex was preferentially active to small objects versus big objects. In Experiment 2, objects with big and small real-world sizes were displayed at two visual sizes on the screen (10 degrees and 4 degrees). The same regions were selective for big or small objects, independent of the visual size presented on the screen, indicating that these regions are tolerant to changes in visual size. In Experiment 3, observers were shown blocks of objects grouped by category, with 16 different object categories spanning the range of real-world sizes. We observed parametric modulation of the big and small regions of interest—in the big ROI, activity increased as object size increased ($r=.74$, $p<.01$), whereas in the small ROI the opposite pattern was observed ($r=-.76$, $p<.01$), with no modulation in LOC ($r=-.28$, $p>.1$) or early visual cortex ($r=.05$, $p>.1$). These results suggest that activity in the ventral visual cortex depends systematically on real-world size. Whether this modulation is based on accessing existing knowledge, or by a combination of low-level properties that are correlated with real-world size, these results highlight a new dimension of information processing in ventral visual cortex.

Acknowledgement: NSF Graduate Fellowship to T.K.

34.26, *4:00 pm*

Depth Structure from Shading Enhances Face Discrimination

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To study how the visual system computes the 3D shape of faces from shading information, we manipulated the illumination conditions on 3D scanned face models and measured how the face discrimination changes with lighting direction. To dissociate surface albedo and illumination component of face images, we used a symmetry algorithm to separatethe symmetric and asymmetric components face images in both low and high spatial frequency bands. Stimuli were hybrid male/female faces with different combinations of symmetric and asymmetric spatial content. We verified that the perceived depth of the face was proportional to the degree of asymmetric low spatial frequency (shading) information in the faces. The symmetric component was morphed from a male face to a female one. The asymmetric shading component was manipulated through the change of lighting direction from 0 degree (front) to 60 degree (side). In each trial, the task of an observer was to determined whether the test image was male or female. The proportional of "female" response increased with the proportion of female component in a morph. Faces with asymmetric "male " shading was more easily judged as male than those with "female" shading, and vice versa. This shading effect increased with lighting direction. Conversely, the low spatial frequency symmetric information had little, if any, effect. The perceived depth of a face increased with shading information but not symmetric information. Together, these results suggest that (1) the shading information from asymmetric low spatial frequencies dramatically affects both perceived face identity and perceived depth of the facial structure; and (2) this effect increased as the lighting direction shifts to the side. Thus, our results provide evidence that face processing has a strong 3D component.

Acknowledgement: NSC 96-2413-H-002-006-MY3

Spatial vision: Mechanisms and models

Sunday, May 9, 5:15 - 7:00 pm
Talk Session, Royal Ballroom 1-3
Moderator: Susana Chung

35.11, *5:15 pm*

"Buffy contrast adaptation" with a single Gabor patch

Norma Graham[1](nvg1@columbia.edu), S. Sabina Wolfson[1], Ian Kwok[1], Boris Grinshpun[1]; [1]Dept of Psychology, Columbia University

A few years ago we discovered a rather surprising effect of short-term adaptation to visual contrast, an effect we now call the Straddle Effect (although originally nicknamed "Buffy adaptation"). After adapting for less than a second to a grid of evenly-spaced Gabor patches all at one contrast, a test pattern composed of two different test contrasts can be easy or difficult to perceive correctly. When the two test contrasts are both a bit less (or are both a bit greater) than the adapt contrast, observers perform very well. However, when the two test contrasts straddle the adapt contrast (i.e. one of the test contrasts is greater than and the other test contrast is less than the adapt contrast) performance drops dramatically.

To explain the Straddle Effect, we proposed a shifting, rectifying contrast- comparison process. In this process a comparison level is continually updated at each spatial position to equal the recent (less than a second) weighted average of contrast at that spatial position. The comparison level is subtracted from the current input contrast, and the magnitude of difference is sent upstream but information about the sign of that difference is lost or at least degraded.

In this previous work the test pattern and the observer's task were of the type known as second-order. We began to wonder: Is that necessary? As it turns out, the answer is "no". Here we will show a temporal Straddle Effect with a single Gabor patch having contrast that varies over time (in a two-temporal-interval same/different task). Thus the shifting, rectifying contrast-comparison process may occur in both spatially first-order and second-order vision. The important quantity in human contrast processing may not be something monotonic with physical contrast but something more like the un-signed difference between current contrast and recent average contrast.

35.12, *5:30 pm*

The Role of Temporal Transients in Forward and Backward Masking

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Contrast discrimination is poor when the test contrasts straddle the contrast of a context pattern presented just before and after the test pattern (Wolfson & Graham, 2007). With error feedback, discrimination is much better when both test contrasts are above or below the contrast of the context pattern. My hypothesis is that this phenomenon is caused by transients produced by the rapid stimulus change that are discriminable in magnitude, but not in sign; these transients determine performance when the stimuli are immediately adjacent in time, but not otherwise. I tested this hypothesis in four contrast discrimination experiments using a two-alternative spatial forced-choice task with Gabor test patterns presented between Gabor forward and backward masks. The test interval was constant at 100 msec. For each mask contrast, there was a small fixed test contrast difference. The task was to indicate which contrast was higher. The two test contrasts were either below, above, or symmetrically straddling the mask contrast. Trials were blocked by mask contrast and test contrast pair. The experiments show: 1) In the absence of feedback, when both contrasts are below the mask contrast, responses are usually wrong; with feedback they are usually correct. 2) The phenomenon is produced with either 1 sec or 50 msec masks. 3) Performance in the straddle condition improves as a function of temporal gaps introduced between masks and test. 4) With gaps of 50 msec, performance is good in the straddle condition and gets worse for test contrast pairs below and above the mask contrast, the opposite of the phenomenon. The psychometric function for contrast detection was measured in the same paradigm. Proportion correct increases at very low contrasts, then decreases to a minimum at two times the mask contrast (straddle condition), then increases at higher contrasts. These results are consistent with the hypothesis.

Acknowledgement: NIH EY 12734

35.13, *5:45 pm*

Classification Images in Free-Localization Tasks with Gaussian Noise

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Classification images have become an important tool for understanding visual processing in tasks limited by noise. However, with the exception of a few studies, the technique is currently limited by requiring that targets and distracters be well cued for location in yes-no or forced-choice psychophysical experiments. Here, we investigate the method in free-localization tasks, where subjects search a single contiguous image for a target and respond by indicating the location where the target is believed to be positioned. Subject responses can be acquired by a mouse or other pointing device, or indirectly by an eye-tracker. Free localization tasks have a number of attractive qualities, including controllable incorporation of free search into detection tasks, higher target contrast, and a more informative subject response that results in fewer images needed to estimate a classification image. The approach we propose involves averaging incorrect localizations after alignment and correcting for the correlation structure of the noise.

We have evaluated the proposed methods using linear filter models for a Gaussian luminance target embedded in Gaussian noise having power-law amplitude spectra with exponents from 0 (white noise) to -3/2. We find the result of overlapping (i.e. dependent) locations is a consistent underestimation in the lowest spatial frequencies in the classification images, which becomes more pronounced as the exponent decreases. Small motor errors in the localization response relative to the size of the target have little effect on the resulting classification images. However, as the motor errors exceed the target size, the classification images show consistent underestimation at high spatial frequencies that is also dependent on the exponent of the noise process. We find approximately a factor of two or more reduction in the number of trials needed to obtain a classification image with comparable signal-to-noise ratio to a yes-no task.

35.14, *6:00 pm*

Optimal detection and estimation of defocus in natural images

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Defocus signals are important in many aspects of vision including accommodation, the estimation of scale, distance, and depth, and the control of eye growth. However, little is known about the computations visual systems use to detect and estimate the magnitude of defocus under natural conditions. We investigated how to optimally estimate defocus blur in images of natural scenes, given the optical systems of primates. First, we selected a large set of well-focused natural image patches. Next, we filtered each image patch with point-spread functions derived from a wave-optics model of the primate (human) eye at different levels of defocus. Finally, we used a statistical learning method, based on Bayesian ideal observer theory, to determine the spatial-frequency filters that are optimal for estimating retinal image defocus in natural scenes. We found that near the center of the visual field, the optimal spatial-frequency filters form a systematic set that is concentrated in the range of 5-15 cyc/deg, the range that drives human accommodation. Furthermore, we found that the optimal filters can be closely approximated by a linear combination of a small number of difference-of-Gaussian filters. Cells with such center-surround receptive field structure are commonplace in the early visual system. Thus, retinal neurons sensitive to this frequency range should contribute strongly to the retinal and/or post-retinal mechanisms that detect and estimate defocus. The optimal filters were also used to detect, discriminate, and identify defocus levels for 1 deg natural image patches. Consistent with human psychophysical data, detection thresholds were higher than discrimination thresholds. Also, once defocus exceeds 0.25 diopters, we found that 0.25 diopter changes in defocus can be identified with better than 86% accuracy. The estimated optimal filters are biologically plausible and provide a rigorous starting point for developing principled hypotheses for the neural mechanisms that encode and exploit optical defocus signals.

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35.15, *6:15 pm*

Spatial and Temporal Proximity of Objects for Maximal Crowding

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Crowding refers to the deleterious interaction among objects that are close together. A logical expectation is that crowding is maximal when the target and flankers are closest to one another. But is this so? Here, we examined how crowding depends on the retinal and perceptual spatial/temporal proximity between the target and flankers. We compared the crowding effect with the flash-lag effect, where flashed and moving targets are perceived to be spatially proximal when they are not retinally proximal and vice versa. Stimuli were high-contrast letter Ts (1.1°) presented randomly in one of four orientations. Target-T was presented at 10° right of fixation at the 3-o'clock position. A pair of flanking Ts, one on each side of the target-T, rotated around the fixation target at a velocity of 5 rpm. Target-T, flashed for 22 ms, appeared at different target-flanker delays (TFD) with respect to the instant at which the flankers reached the 3-o'clock position. In separate blocks of trials, observers judged the orientation of the target-T (the crowding task), or its position relative to the rotating flankers (the flash-lag task). Averaged across four observers, maximal crowding (reduction in accuracy of identifying the target's orientation) occurred for TFD of –66±33(SE) ms (target before flanker). This temporal delay for maximal crowding did not correspond to the flash-lag effect, which averaged –34±17(SE) ms. A control experiment showed that when flankers were flashed briefly at the 3 o'clock positions at different TFDs, maximal crowding occurred for TFD of –52±3(SE) ms. Further, when flankers were presented at different angular positions but simultaneously with the target, maximal crowding occurred when flankers were close to the 3-o'clock position and that the "flash-lag effect" was virtually zero. Our results suggest that highest retinal or perceptual spatial/temporal proximity between target and flankers is not a necessary requirement for maximal crowding.

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35.16, *6:30 pm*

Targets uncrowd when they pop out

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The perception of a target usually deteriorates when flanked by neighboring elements, so-called crowding. Explanations of crowding in the periphery and the fovea are often based on local neural interactions, such as spatial pooling, excessive feature integration, or lateral inhibition. In contrast, we proposed that the grouping of the target with the flankers determines crowding. In a visual search task, a target that differed from distractors by its unique color (pop-out) yielded faster reaction times than a target that differed by a combination of color and size (no pop-out; serial search). Identical stimulus configurations, but now presented for only 150 msec, included a vernier target that required the observer's judgment of the direction of the offset. Even though the location of the target within the array was marked in both, the proportion of correct vernier responses was far higher (83.2%) for the pop-out configurations than for the ones requiring serial search (59.6%, $p<0.05$). The results are interpreted as further evidence that perceptual grouping of the target with the flankers plays an important role in crowding.

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35.17, *6:45 pm*

Rapid Natural Image Identification Based on EEG data and Global Scene Statistics

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A wave of recent findings shows that it is possible to classify features, objects or scenes subjects are perceiving by "reading" their brain activity. Going beyond classification, (Kay et al., 2008) showed that a presented natural image can be identified among a large number of candidate images based on fMRI data. In that study a natural image was described by a comprehensive receptive field model consisting of many Gabor wavelets covering retinotopic locations of the visual field. We investigated whether a neural response model based on the two-parameter Weibull contrast distribution (Scholte et al, 2009) permits rapid natural image identification. We measured EEG activity of 32 subjects viewing brief flashes of 700 natural scenes. From these measurements, and from the contrast distribution of these scenes, we derived an across subject Weibull response model. We used this model to predict EEG responses to 100 new natural scenes and to estimate which scene from this set subjects viewed by finding the best match between predicted and measured EEG responses. In 90 percent of the cases our Weibull response model accurately identified the viewed scene. A different experiment with artificial occlusion images resulted in almost 95 percent correct identification. These image identification performances are comparable to the results of (Kay et al, 2009). We conclude that it is possible to identify natural images humans view on the basis of EEG data by establishing a relationship between neuronal responses to and Weibull contrast distribution of these images. The potency of this relationship lies in the ability of the Weibull distribution to structure the space of natural images in a highly meaningful and compact way, based only on two parameters. Our results support the idea that our brain may have evolved, among others, to estimate Weibull statistics of natural images for rapid scene gist extraction.

Search: Eye movements and mechanisms

Sunday, May 9, 5:15 - 7:00 pm

Talk Session, Royal Ballroom 4-5

Moderator: Ruth Rosenholtz

35.21, *5:15 pm*

Predicting contextual locations in natural scenes from neural activity

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Contextual cues guide and facilitate visual search in both synthetic (Chun & Jiang, 1998) and natural images (Eckstein et al., 2006; Torralba et al., 2006). Although studies have identified the neural correlates of the attentional shifts with synthetic cues (Woodman & Luck, 1999; Johnson et al., 2007; Woodman et al., 2009), little is known about the neural basis of contextual cueing in natural scenes. We used multivariate pattern classifiers to analyze neural activity (electroencephalography, EEG) during search for objects in natural scenes and predict the contextual location of the expected target from a single trial. Methods: Ten naive observers searched for a target specified by a word (500ms duration) presented prior to natural scene (100ms). Targets were present in 50% of the 800 images. Critically, target absent images were selected so that a single expected location (left/right lateralized) was consistent with the sought target. Observers reported their decision (target present/absent) using a 10-point confidence rating. Results: The results showed a weak (nonsignificant) N2pc event-related potential (ERP) component, often found in visual search tasks. Classifier performance (area under the ROC) identifying the expected location (left/right) of target absent images from single trial EEG for a 100-700ms time epoch was 0.7 ± 0.02. Classification using the electrooculogram (EOG) was not significantly above chance (50%) suggesting that our results cannot be explained by eye movements to the expected target locations. Analysis using target present images to train the classifier and then predict the expected location in the target absent images resulted in chance performance. Conclusion: Our findings suggest that contextual locations in natural scenes can be predicted reliably from neural activity recorded when observers are searching for targets. The identified neural mechanisms predicting context are distinct from those coding the physical presence of the target.

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35.22, *5:30 pm*

Materials: Easy to identify but hard to find

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Human observers are very good at deducing the material composition of an object from its visible surfaces. Sharan (2009) has shown that a 20 msec exposure is adequate to determine if an object is made of wood, cloth, glass, etc. The visual signatures that define these materials have not been identified ,but it seems likely that some statistical regularities make one surface look like plastic and another like fur. Statistical properties like mean orientation can be extracted from textures without analyzing the orientation of individual contours in the texture. Are the statistical regularities or other properties that define materials used to guide attention? Can observers search efficiently for cloth among stone or glass among paper? To assess this, we used Sharan's stimuli; moderate close-up views of objects made from eight material categories: fabric, glass, leather, metal, paper, stone, water, & wood. Observers searched for targets of one category. On each trial, distractors were drawn from one other category. Search was inefficient (Hits: 35.9 msec/item, Absent: 78.4 msec/item). Perhaps Sharan's stimuli were too heterogeneous. We tried again with simpler surfaces: square, frontal patches of water, wood, skin, stone, fur, and feather. This was still inefficient. We ran three conditions with target and distractor held constant. Feather among wood and fur among water were run in grayscale. Stone among fur was run in color. Of these, only feather among wood was close to efficient (Hit: 8.2 msec/item) but this may have been an orientation artifact. Most of the wood grain was vertically oriented while feathers were horizontally oriented. Thus, while it may be possible to extract material information very rapidly and, perhaps, even to appreciate a material properties without attention, material information cannot be used to efficiently guide attention to targets of one type of material among distractors of another.

35.23, *5:45 pm*

An Ideal Saccadic Targeting Model Acting on Pooled Summary Statistics Predicts Visual Search Performance

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One of the puzzles of visual search is that discriminability of a single target from a single distractor poorly predicts search performance. Last year (Rosenholtz, Chan, & Balas, VSS 2009) we suggested that in crowded visual search displays, the key determinant of search performance is instead peripheral discriminability between a patch containing both target and distractors and a patch containing multiple distractors. Using a model of peripheral vision in which the visual system represents the visual input by summary statistics over each local pooling region (Balas, Nakano, & Rosenholtz, 2009), we predicted peripheral discriminability (d') of crowded target-present and distractor-only patches, and showed that this in turn predicted the relative difficulty of a number of standard search tasks.

Here, our goal is to make quantitative predictions of visual search performance using this framework. Specifically, we model both reaction time vs. set size (RT/setsize) slopes and number of fixations to find the target. To this end, we have derived the ideal saccadic targeter for the case in which the input consists of independent noisy "targetness" measurements from multiple, overlapping pooling regions. The radius of each pooling region is roughly half its eccentricity, in accordance with Bouma's Law. For crowded pooling regions, our predicted d' allows us to compute the likelihood of observing a given amount of "targetness," conditioned on whether or not the given pooling region contains a target. For uncrowded pooling regions, e.g. near fixation, discriminability is maximal. An additional parameter controls the amount of memory from previous fixations.

The model performs well at predicting RT/setsize slopes, and reasonably well at predicting mean number of fixations to find the target. Best predictions come when the model has minimal memory. This suggests that search performance is indeed constrained by the extend to which peripheral vision can discriminate between target-present and distractor-only patches.

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35.24, *6:00 pm*

Active search for multiple targets is inefficient

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Rationale: When the task is to find multiple targets in noise in a limited time, saccades need to be efficient to maximize the information gained (Verghese, VSS, 2008). The strategy that is most informative depends on the prior probability of the target at a location: when the target prior is low and multiple-target trials are rare, making a saccade to the most likely target location is informative, but when the target prior is high and multiple-target trials are frequent, selecting uncertain locations is more informative. Do observers adjust their saccade strategy depending on the prior to maximize the information gained?

Methods. Observers actively searched a noisy display with 6 potential target locations equally spaced on a 3° eccentric circle. Each location had an independent probability of a target, so the number of targets in a trial ranged from 0 to 6. The target was a vertical string of 5 dots among noise dots positioned randomly. Observers searched the display for 350, 700 or 1150ms and subsequently selected all potential target locations with a cursor. We varied the prior probability of the target from 0.17 to 0.67 to determine whether observers adjusted their saccades strategies to maximize information. We performed a trial-by-trial analysis of observers' saccades to determine saccade strategy.

Results & Conclusion: Observers (n=5, 3 naïve) made saccades to the most likely target location more often than the most uncertain location, for all target priors ranging from low to high. Fixating likely locations is efficient only when multiple targets are rare, as in the case of a low target prior, or in the case of more standard single-target search task. Yet it is the preferred saccade strategy in all our conditions, even when multiple targets are frequent. These findings indicate that humans are far from ideal searchers in multiple-target search.

35.25, *6:15 pm*

Neural basis of object memory during visual search

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Current models of selective attention and visual search incorporate two processes believed to be crucial in searching for an item in a visual scene: the selection of locations to be attended and the temporary prevention of re-selecting previously attended locations. In natural situations, the deployment of visual attention is accomplished by sequences of gaze fixations, and the active suppression of recently visited locations can be examined by analyzing the distribution of gaze fixations as a function of time and location. We trained four monkeys to perform a visual search task, in which they could freely search for a target stimulus with a unique conjunction of features. Monkeys made multiple fixations on distracters before foveating the target (mean: 3.1; range: 1-14) and their probability of foveating the target with a single fixation was only 0.25. Performance in this difficult task, however, was generally efficient as monkeys rarely re-fixated previously inspected stimuli. The probability of a re-fixation increased with time and approximated chance levels after 5-6 fixations, suggesting that foveated information is retained across fixations but completely degraded within about 1000 ms of fixation. To investigate the neural mechanisms underlying this behavior, we recorded the activity of superior colliculus (SC) neurons while two animals performed the task. SC sensory-motor activity was sufficient to guide this behavior: activity associated with previously fixated stimuli was significantly lower than that of stimuli not yet fixated. More than two-thirds of neurons retained these differences up to 100 ms following fixation. These results suggest a neural mechanism for suppressing the re-fixation of stimuli temporarily maintained in memory. These findings demonstrate how neural representations on the visual salience map are dynamically updated from fixation to fixation, thus facilitating visual search.

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35.26, *6:30 pm*

Selective conjunctive suppression in visual search for motion – form conjunctions

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Three experiments investigated the mechanism underlying efficient visual search for conjunctions of motion and form (e.g. McLeod, Driver, & Crisp, 1988) using a probe-dot procedure (e.g. Klein, 1988). In Experiment 1 participants completed 3 conditions: 1) conjunction (moving X target amongst moving Os and static Xs), 2) moving feature (moving X target amongst moving Os), and 3) static feature (static X in static Os). Following the search response (target present or absent) all items stopped moving and (after 60 ms) a probe-dot appeared on a distractor, or on the blank background. Probe-dots on static distractors in the conjunction condition were located most slowly, slower than probes on moving distractors, and slower than probes on static distractors in the static feature condition. In contrast a second group who viewed the stimuli passively before locating the dot showed a different pattern: a cost for probe-dots on moving items. In Experiment 2

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we investigated whether suppression applied to all static items regardless of form by adding static Os to the conjunction displays. The results showed that the suppression was specific to distractors sharing the target form (e.g. static Xs) and did not apply to static Os. Experiment 3 investigated the time-course of suppression when searching for a moving X (conjunction condition of Experiment 2). Stimuli moved for between 100 and 925 ms before the probe-dot appeared (60 ms later). The results revealed that the selective suppression of static X distractors was fast-acting, being fully in place after 100 ms of stimulus motion. The results are difficult to account for in terms of feature based guidance of attention, and suggest instead, a mechanism of selective tuning or biasing of competition in the form system by signals from the motion system.

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35.27, *6:45 pm*

Identifying social and non-social change in natural scenes: children vs.adults, and children with and without autism

Bhavin Sheth[1, 2](brsheth@uh.edu), James Liu[3], Olayemi Olagbaju[3], Larry Varghese[1], Rosleen Mansour[4], Stacy Reddoch[4], Deborah Pearson[4], Katherine Loveland[4]; [1]Department of Electrical and Computer Engineering, University of Houston, [2]Center for NeuroEngineering and Cognitive Systems, University of Houston, [3]University of Houston, [4]Department of Psychiatry & Behavioral Sciences, The University of Texas Health Science Center at Houston

Typically developing (TD) children use social cues (e.g. gestural joint attention, observations of facial expression, gaze etc.) to learn about the world. In contrast, children with autism spectrum disorders (ASD) have deficits in joint attention and impaired social skills. Therefore, attentional processes that are under the guidance of social referencing cues should be better developed in TD versus ASD children. We employed the "change blindness" paradigm to compare how the presence, absence, or specific context of different types of social cues in a scene affect TD children, children with ASD, and typical adults in visually identifying change. Forty adults and forty children (22 high-functioning ASDs, 18 TDs) participated. Depending on the presence/absence and nature of the social cues in the scene, change was categorized into one of six conditions: an actor's facial expression or gaze, an object that an actor overtly pointed to or gazed at, an object connected with an actor in the scene, an object unconnected with any actors, an object while an actor pointed to a different, unchanging object, or an object in a scene containing no actors. Percent correct, response time, and inverse efficiency were measured. No significant differences were observed between children with and without autism. Children with autism use relevant social cues while searching a scene just as typical children do. Children (with and/or without autism) were significantly worse than adults in identifying change when an actor pointed to an unchanging object, or when an object changed, whether or not it was connected with an actor. Children were not worse than adults when no actors were present in the scene, or when an actor in the scene pointed to the change. Our findings suggest that compared with adults, children are over-reliant on social cues over other cues. Social cues "capture" the child's attention.

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Sunday Afternoon Posters

Neural mechanisms: Neurophysiology and theory

Royal Ballroom 6-8, Boards 301–314

Sunday, May 9, 2:45 - 6:45 pm

36.301 The role of inhibition in formatting visual information in the retina and LGN

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The processing capabilities of the visual system certainly depend on "nonlinear" computation at multiple levels in the visual pathway. While successful computational vision models generally recapitulate this, validating and constraining such models using physiological data is confounded by two problems: functional characterizations of visual generally rely on linear "receptive fields" that cannot capture nonlinear effects; and most recordings are from single neurons, implicitly entangling characterizations of their own computations with those taking place in preceding areas. We apply a new nonlinear modeling framework to simultaneously recorded pairs consisting of an LGN neuron and the retinal ganglion cell that provides its main input. Because it is nonlinear, this framework can identify multiple processing elements and their associated nonlinear computations for each neuron. Furthermore, by recording from successive stages of the visual pathway simultaneously, we can distinguish the processing that occurs in the retina from processing that occurs in the LGN, and observe how visual information is successively formatted for the visual cortex. We detect nonlinear processing involving the interplay of excitation and inhibition at both levels. Inhibition in the retina is similarly tuned but delayed from excitation, resulting in highly precise responses in time. Oppositely-tuned inhibition is added at the level of the LGN, whose purpose is less clear, but when combined with inhibition inherited from the retina, likely plays a role in contrast adaptation. Thus, we demonstrate a new method to detect nonlinear processing using easily obtained data at multiple levels of the visual pathway. In doing so, we reveal new functional elements of visual neurons that are generally thought of as mostly linear. This has implications for both our understanding of how information is successively formatted for the visual cortex by its inputs, and suggests more general roles of nonlinear computation in visual processing.

36.302 Predicting Orientation Selectivity in Primary Visual Cortex

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Orientation specific cells in V1 organize themselves in either swaths of similar-orientation preferring clusters (iso-orientation domains) or in distinctive singularities where cells representing 180-degrees of orientation specificity center themselves about a blob (pinwheels). The gradient (0 to 180-degrees) of the orientation-specific cells are organized in either a clockwise or counterclockwise direction. However, pinwheels and iso-orientation domains develop with some level of stochasticity, which many computational models have attempted to explain. While many good models exist, our goal was to develop a biologically plausible model incorporating a three-layer approach (representing retina, LGN, and cortex), presynaptic competition for resources, diffusive cooperation of near neighbor cells and corresponding lateral connections, maintenance of retinotopic mapping, and a capped synaptic load per neuron.

We use a Self-Organizing Map as the basis for each of the layers, and a Hebbian-style approach for reinforcing link weights between layer sub-networks. We train our network with an iterative presentation of randomly sized and oriented Gabors. Our data set contained 10 maps of each iteration level: 3500, 5000, 10000. We compare our maps against both real maps and synthetic maps produced via other methods.

We also aim to develop meaningful metrics for comparing maps. In addition to counting clockwise and counterclockwise pinwheels, we use graph theoretic approaches to compute distances between pinwheels and estimate the coefficient of variance for those distances. Pooled distance variance across maps indicates the 10000-map to be closest to the real map. Our method also maintains a counterclockwise/clockwise pinwheel ratio most similar to that in the real map with increasing number of iterations.

Our approach, we think, proposes both a biologically relevant model of pinwheel organization and more statistically relevant methods for making comparisons across maps.

36.303 'Black' dominance measured with different stimulus ensembles in macaque primary visual cortex V1

Chun-I Yeh[1](ciy@cns.nyu.edu), Dajun Xing[1], Robert M. Shapley[1]; [1]Center for Neural Science, New York University

Most neurons in layer 2/3 (not layer 4c) of V1 have stronger responses to 'black' (negative contrast) than to 'white' (positive contrast) when measured by reverse correlation with sparse noise (Jones and Palmer 1987). Furthermore, the degree of the black dominance in V1 depends on the stimulus ensemble – the black dominance is much stronger when neuronal responses are measured with sparse noise than with Hartley stimuli (Ringach et al 1997). Sparse and Hartley stimuli differ in many ways. First, the individual stimulus size of sparse noise is much smaller than that of Hartley stimuli. Second, the dark and bright pixels of sparse noise are present separately in time while those of Hartley stimuli are shown simultaneously. Third, there are spatial correlations along the long axis of Hartley stimuli that are not present in sparse noise. Which of these differences might contribute to the disparity in black dominance? Here we introduced a third stimulus ensemble – a binary checkerboard white noise (m-sequence, Reid et al 1997) to measure the black-dominant responses in sufentanil-anesthetized monkey V1. Both white noise and Hartley stimuli activate a larger population of neurons than sparse noise, and dark and bright pixels appear simultaneously under both conditions. Unlike Hartley stimuli, neighboring pixels of white noise are uncorrelated. Among the V1 neurons with significant responses (signal-to-noise ratio>1.5) to all three ensembles, black-dominant neurons (BDNs) largely outnumbered white-dominant neurons in output layer 2/3 with all three stimulus ensembles (% of BDNs: 76~82%) while the numbers of black and white-dominant neurons were nearly equal in input layer 4c (% of BDNs: 40~60%). The degree of the black-dominant response was significantly stronger for white noise than for Hartley stimuli ($p<0.02$, Wilcoxon signed rank test). These results indicate that the degree of black dominance depends on the spatial structure of the stimulus ensemble.

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36.304 Recurrent amplification in V1 cortex as the mechanism of black-dominant visual perception

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Humans are more sensitive to black than to white targets (Blackwell, 1946; Bowen et al., 1989; Chubb et al., 2004; Chubb and Nam, 2000; Dannemiller and Stephens, 2001; Kontsevich and Tyler, 1999; Krauskopf, 1980; Short, 1966; Tyler and Chan, 1992; Whittle, 1986). Such a bias for negative contrast was also reported in physiological responses in the human primary visual cortex (V1) measured by VEP (Zemon et al., 1988) and by BOLD fMRI signal (Olman et al., 2008). Consistent with human neurophysiology results, we found strong black-dominant responses in layer 2/3 of the Macaque V1 for single neurons' spike activity (Yeh et al., 2009). However the neural mechanisms that cause the black-white asymmetry in perception and neurophysiology have not been investigated before now. In seeking the mechanism of this black-dominance, we recorded visually-driven responses of multi-unit activity (MUA) and the local field potential (LFP) in Macaque V1 to black and white squares at high contrast (~0.2 deg) on a grey background and used track reconstruction to identify the laminar locations of our recording sites.

 See page 3 for Abstract Numbering System

We found a clear laminar pattern of MUA preference for black stimuli: while black-dominant responses were observed in layer 2/3, the black-preference was only seen in layer 4Cb but not in layer 4Ca. Compared to strong and sustained black-dominant responses in layer 2/3, black-dominant responses were much more transient and weaker in layer 4Cb. The dynamic difference of black-dominant MUA and LFP between layer 2/3 and 4Cb implies that black-dominance in layer 2/3 was not generated by a feedforward-plus-threshold mechanism applied to layer 4Cb signals.

We conclude: 1) black-dominance originates in the parvocellular pathway for high contrast condition; 2) black-dominance is significantly amplified by a recurrent excitatory-inhibitory network in layer 2/3 producing the strong black-preference of layer 2/3 neurons and downstream visual perception.

Acknowledgement: NIH-EY001472, NSF-0745253, the Swartz Foundation and the Robert Leet and Clara Guthrie Patterson Trust Postdoctoral Fellowship

36.305 **Relative Disparity in V2 Due to Inhibitory Peak Shifts of Absolute Disparity in V1**

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In humans and primates, streoscopic depth perception often uses binocular disparity information. The primary visual cortical area V1 computes absolute disparity, which is the horizontal difference in the retinal location of an image in the left and the right fovea. However, cortical area V2 computes relative disparity (Thomas et al., 2002), which is the difference in absolute disparity of two visible features in the visual field (Cumming and DeAngelis, 2001; Cumming and Parker, 1999). Psychophysical experiments have shown that it is possible to have an absolute disparity change across a visual scene, while not affecting relative disparity. Relative disparities, unlike absolute disparities, can be unaffected by vergence eye movements or the distance of the visual stimuli from the observer. The neural computations that are carried out from V1 to V2 to compute relative disparity are still unknown. A neural model is proposed which illustrates how primates compute relative disparity from absolute disparity. The model describes how specific circuits within the laminar connectivity of V1 and V2 naturally compute relative disparity as a special case of a general laminar cortical design. These circuits have elsewhere been shown to play multiple roles in visual perception, including contrast gain control, selection of perceptual groupings, and attentional focusing (Grossberg, 1999). This explanation links relative disparity to other visual functions and thereby suggests new ways to psychophysically and neurobiologically test its mechanistic basis. Supported in part by CELEST, an NSF Science of Learning Center (NSF SBE-0354378) and by the SyNAPSE program of DARPA (HR0011-09-3-0001 and HR0011-09-C-0011)

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36.306 **Roles of Early Vision for the Dynamics of Border-Ownership Selective Cells**

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The determination of the figure-ground is essential for visual perception. Computational and psychophysical studies have reported that spatial attention in early vision facilitates the perception of border ownership (BO) that indicates the direction of figure (DOF) with respect to the border so that attended location appears as figures (Wagatsuma, et al. 2008). A recent physiological study has shown that the time course of BO-selective cells in V2 was affected by the ambiguity of the DOF on the previous display (P. O' Herron and R. von der Heydt, 2009). We investigated the mechanism behind this dynamics of the BO-selective cells through a computational model in which the early visual areas play critical roles for the determination of the activities of model BO-selective cells. Our model consists of V1, V2 and Posterior Parietal (PP) modules. The PP module is designed to represent spatial attention that could be considered as a saliency map based on luminance contrast. In the model, spatial attention alters contrast gain in the V1 module so that it enhances local contrast. The change in contrast signal then modifies the activity of model BO-selective cells in V2 because BO is determined solely from surrounding contrast (Sakai and Nishimura, 2006). The model was tested with the stimuli corresponding to Herron's physiological experiment. When new information regarding the DOF is presented, the activities of model BO-selective cells were rapidly modified. In contrast, if instead a new stimulus is presented with an ambiguous DOF, then the responses of model BO-selective cells decayed slowly. This model dynamics appears to depend on the ambiguity of the BO signal on the previous display and reproduce the same tendency found in the physiological study. These results suggest that network among PP and early visual areas could have crucial role for the time course of BO-selective cells.

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36.307 **Chromatic Detection in Non-Human Primates: Neurophysiology and Comparison with Human Chromatic Sensitivity**

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Chromatic detection experiments in humans have been instrumental in elucidating the post-receptoral mechanisms that mediate color vision. To investigate the neural substrates of these mechanisms, we trained Rhesus monkeys to perform a spatial 2AFC chromatic detection task. Our goals were two-fold: First, to assess the utility of Rhesus monkeys as a model for human chromatic detection, and second, to measure the quality of color signals available in cortical area V1 that might subserve detection of isoluminant stimuli.

Monkeys proved to be exquisitely sensitive psychophysical observers – matching or exceeding the sensitivity of human subjects performing the detection task under identical stimulus conditions. The sensitivity of humans and monkeys depended similarly on the spatial frequency and chromaticity of the stimulus: sensitivity was low-pass for isoluminant stimuli and bandpass for achromatic stimuli. When stimuli were equated for cone-contrast, sensitivity was greater for L-M modulations than for S-cone modulations.

In a subset of these experiments, we recorded from individual V1 neurons in monkeys performing the detection task. Stimuli in these experiments were tailored to each neurons' preferred orientation and spatial frequency. Neuronal and psychophysical sensitivities were compared directly via an ideal observer analysis of firing rates during the stimulus presentation period. Although the sensitivity of individual neurons varied considerably, the most sensitive V1 neurons were roughly as sensitive as the monkey. Accordingly, detection thresholds of V1 neurons varied with color direction in qualitative agreement with the monkey's psychophysical behavior. These data demonstrate the existence of individual V1 neurons that are exquisitely sensitive to chromatic stimuli and attest to the value of Rhesus monkeys as a model for human chromatic detection.

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36.308 **Response to motion contrast in macaque V2**

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Motion processing in monkey visual cortex occurs in the dorsal pathway V1 to MT. However, direction-selective neurons are also found in many ventral areas including V2 and V4. Previously we have reported that direction-selective neurons are clustered in V2 and form patches of direction maps. These maps were observed mainly in V2 thick stripes and never colocalized with color-activated thin stripes. The functional significance of these direction-selective neurons and their maps remains unclear. One possibility is that these neurons contribute to motion defined features and their clustering may facilitate interactions among different direction-selective neurons. Using intrinsic optical imaging methods, we imaged V2 response to motion contrast stimuli in both anesthetized and awake macaque monkeys. These stimuli contain drifting random dots (RD) moving on different backgrounds including 1. homogeneous gray, 2. stationary RD, 3. oppositely-moving RD. We found that V2 direction domains were more strongly activated by the third stimulus (which contains the strongest motion contrast) than to the other two conditions. Random dots moving on stationary RD background elicited weaker response but still stronger than that to

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pure drifting RD patterns. Combined with the presence of motion contour response in V2, these observations support the idea that V2 plays important roles in analyzing figure-ground segregation based on motion contrast.

36.309 Encoding of brief time interval judgments in single neurons

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Our knowledge of the psychophysics of brief interval time perception currently outweighs our knowledge of its neuronal basis. Of particular interest are the neuronal mechanisms for temporal judgments in frontal cortex, the region of the brain thought to underlie conscious perception. One ubiquitous neuronal phenomenon, adaptation, is intimately tied to temporal processing and could play a role in perceiving time intervals. Neuronal adaptation results when two visual stimuli are presented in close succession, yielding a normal first neuronal response but a diminished second response. The amount of time between the first and second stimuli governs the magnitude of the second response, with longer interstimulus intervals resulting in less adaptation and therefore larger second responses. In previous work (Mayo and Sommer, 2008), we quantified the dynamics of neuronal adaptation during passive fixation at two stages of visual processing in the brain: the frontal eye fields (FEF) in prefrontal cortex, and the superficial superior colliculus (SC) in the midbrain. We found robust neuronal adaptation in both areas with a similar time to recovery, even in the superficial SC located one synapse away from the retina. Here, we ask if the relative magnitude of successive neuronal responses contains useful information about the amount of time between successively-presented stimuli at naturalistic time intervals (<500 ms). Monkeys were trained to decide whether the amount of time between two brief, identical flashes was greater or less than a learned reference interval (300 ms). They reported their decision by making a saccade to one of two choice targets. Stimuli were presented in the receptive field of a single isolated FEF or SC neuron. We compare neuronal activity in correct versus incorrect trials in both brain areas to determine what role, if any, the magnitude of sensory responses (as opposed to latency alone) plays in temporal processing.

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36.310 Direction selectivity of center-surround interactions in macaque MT

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One of the primary functions of neurons in the extrastriate cortex is to integrate motion signals from lower visual areas. In addition to this integrative function, many extrastriate neurons appear to respond best to motion stimuli that differ across space. These neurons are suppressed by visual motion stimuli placed outside of their classical receptive fields. To gain a better understanding of these center-surround interactions, we recorded from neurons in visual area MT of the alert macaque during presentation of stimuli that moved in different directions in the receptive field centers and surrounds. In the first set of experiments, neurons were tested using one direction for the center while the surround direction was varied. We quantified the strength of suppression as the reduction in response evoked by each direction of the surround relative to the response evoked by only the center stimulus moving in the preferred direction of motion. Surprisingly, a large proportion of cells showed the strongest suppression when the surround motion was orthogonal to the center direction of motion Most of these cells were classified as lacking surround suppression when tested only with surround stimuli moving in the direction preferred by the receptive field center. This suggests that the vast majority of MT cells are surround-suppressed provided that the appropriate stimulus is used to drive the surround. In another set of experiments, we varied the contrast of the center and the surround stimuli independently. When looking at conditions with a low contrast center and high contrast surround, the tuning of the center stimulus for the cell shifted with the changes in motion direction of the surround stimulus. This suggests that the surround direction affects the tuning of the center stimulus. Supported by CIHR and MDEIE.

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36.311 Responses of MT neurons to type II plaid stimuli

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The dorsal pathway of the primate visual cortex contains a hierarchy of areas involved in the processing of motion signals that are useful for perception and behavior. Motion direction is first detected by V1, which sends specialized projections to cortical areas such as MT and MST. Motion processing in these extrastriate areas is often tested by stimulating individual neurons with plaid stimuli comprised of two drifting gratings. When the perceived direction of the plaid stimulus is rotated clockwise or counterclockwise relative to both of the component gratings, the stimulus is categorized as a “Type II” plaid. Although much previous work has examined the perceptual aspects of “Type II” plaids, nothing is known about the underlying neurophysiological responses. Unikinetic plaids (constructed by summing a moving and a stationary grating) are Type II plaids stimuli that have been used in psychophysical experiments to measure short-latency ocular following (Masson, 2002). These stimuli present a unique challenge to the motion processing stream, as their velocity can only be recovered by taking into account information from stationary components of the stimuli. We have therefore compared the responses of MT neurons to unikinetic plaid stimuli and more standard “Type I” plaids, by recording spikes and LFPs from 38 MT neurons to both types of plaids from two awake, behaving macaque monkeys. Consistent with previous results, we found that 13/38 (34%) MT neurons were component-selective in response to Type I plaid stimuli, while 9/38 (24%) were pattern-selective. Surprisingly, many neurons that exhibited strong component tuning when stimulated with Type I plaids exhibited robust pattern-selective responses to Type II unikinetic plaids. As a result the majority of MT neurons were pattern-selective when tested with unikinetic plaids. This suggests that the processing of Type II plaid stimuli may involve additional cues that enable the detection of two-dimensional motion signals.

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36.312 How STS recognizes actions: Predicting single-neuron responses in higher visual cortex

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Computational models of visual processing make quantitative, testable predictions, and the accuracy of these predictions can be used to objectively gauge model goodness. Such quantitative validation is common at the behavioral and neural population levels. However, this is less common at the single-neuron level, partly because of difficulty in data collection, but more importantly because the large variability among neurons requires models to be specific enough to predict the response of a single neuron, yet flexible enough to be fitted to all individual neurons within the recorded population. Such validation has been done for V1 (see Olshausen & Field, 2005), V4 (Cadieu et al, 2007; David et al, 2006) and MT (Rust et al, 2006). Here, we test a model for spatio-temporal processing of action sequences in the primate superior temporal sulcus (STS). The relatively higher position of STS in the visual processing hierarchy (Felleman & Van Essen, 1991) makes this a harder task. Using computer-generated humanoid action sequences, we trained monkeys to recognize multiple actions and recorded from the temporal lobe (Singer & Sheinberg, in press). We then used computational models of the ventral (Serre et al, 2005) and dorsal (Jhuang et al, 2007) streams of visual cortex, coupled with a simple parameter-search procedure to fit either model to 100+ individual neurons, predicting the firing rate of each neuron in response to 64 action sequences, for 90 bins of duration 10ms each. We performed leave-one-out cross-validation, and both models achieved good test-set performance comparable to previous work in V4 and MT, while controls performed significantly worse and close to chance. To the best of our knowledge, this is not only the first instance of quantitative modeling for single neurons this far downstream, but also the first instance of time-series prediction for neurons beyond V1.

36.313 Origins of Shape Selectivity in the Lateral Intraparietal Area (LIP)

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Recent evidence indicates that LIP is sensitive to object shape. To further explore this shape selectivity, two monkeys were trained on arbitrary shape-action associations, where a centrally presented shape was associated with

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a saccade to or away from an LIP neuron's response field. Each day the monkeys learned the meaning (to or from RF) of four novel shapes, and were retrained on four previously learned old shapes. In a second task, the monkeys simply viewed the shapes. This passive task established that LIP neurons indeed responded selectively to certain shapes, even meaningless novel shapes. The shape selectivity, however, did not seem to be invariant to changes in location. The shape-action association task revealed an interaction between novelty (old vs. novel shapes) and meaning (to vs. from RF). Somewhat surprisingly, early in the trial, novel 'to RF' shapes showed a lower response than 'from RF' shapes. The old shapes showed the opposite pattern, with initial 'to RF' responses higher than 'from RF' responses. The effect for old stimuli quickly reversed again so that 'to RF' responses became lower than 'from RF' responses. Finally, when the monkeys were allowed to saccade, both old and novel stimuli had higher responses in the 'to RF' condition, but the difference was more pronounced for old shapes. These results suggest that LIP shape selectivity is unlikely to be part of a representation of object structure, because it should be little affected by meaning. That the meaning of the shapes can affect even the earliest LIP responses raises the possibility that they reflect a best guess of how to react to an object. Even novel shapes have points of interest that may bias looking patterns. With extensive training, as in the case of old shapes, these initial responses may be overridden to represent an arbitrarily associated action.

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36.314 Virtual Multi-Unit Electrophysiology: Inferring neural response profiles from fMRI data

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We present a method for determining the underlying neural code from population response profiles measured using fMRI. This technique uses orientation tuning functions for single voxels in human V1 (Serences et al., 2009; Kay and Gallant, 2008), which superficially resemble the electrophysiological tuning functions of V1 neurons. However, a voxel tuning function (VTF) is a summed population response, and does not specify the underlying neural responses. For example, the same bell-shaped VTF may arise from a population of neurons that are (1) tuned to a range of preferred stimulus orientations, with each preferred orientation present in varying proportions, or (2) uniformly distributed across preferred orientations, but neurons with a particular preferred orientation are tuned more sharply. The reported technique gains traction on this "inverse problem" by modeling the underlying neural responses across a range of tested orientations, and can be used to model task-induced changes in VTFs. We assume a set of underlying neural tuning curves, centered on orientations spaced evenly between 0° and 180°, and sharing a common standard deviation (SD). For a given SD, we use least-squares linear regression to solve for the 'coefficients' of the neural tuning curves (i.e., the relative weighting of each neural tuning curve present in the voxel) underlying the BOLD responses of an experimentally observed voxel. We find coefficients at a range of SD values, then determine the best-fitting SD to give the best estimate of the SD and coefficients. In future work, we will scan human subjects performing visual attention tasks, then use the present method to generate and test models of how the population response in visual cortex changes (e.g., Scolari and Serences, 2009). The technique effectively extracts "virtual" simultaneous multi-unit recordings from fMRI data – albeit with the usual fMRI limitations – and may help to address fundamental questions of neural plasticity.

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Perception and action: Pointing and hitting

Royal Ballroom 6-8, Boards 315–332

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36.315 Sequence effects during manual aiming: A departure from Fitts's Law?

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In 1954, Paul Fitts forwarded a formal account of the relationship between the difficulty of an aiming task and movement time associated with its completion. While most models used to explain this speed-accuracy tradeoff have been based upon visual feedback utilization and target-derived uncertainty, the idea that speed-accuracy constraints can also be dictated by previous aiming history has been largely ignored. In order to examine whether sequential movements are interdependent, we utilized a sequential-discrete aiming paradigm where the target changed difficulty mid-sequence, but between reaches. Individuals performed an adapted Fitts's task by performing discrete manual aiming movements between two equidistant targets from the midline. Responses were produced in sequences of 20 manual aiming movements separated by a fixed inter-trial-interval of 1 s. Four trial sequences were used in the experiment: in two of the sequences the target widths remained constant throughout trial (wide or narrow), in two sequences the target width changed (wide to narrow, narrow to wide) between the 7th to 12th movements of the sequence. Our main area of interest was in the trials immediately following the change in target width. Namely, we wanted to see if there were any carry-over effects from the preceding target width on the subsequent movements to a different target width. The extant sequential aiming literature suggests individuals plan several movements in advance during sequential movements, as compared to a single movement in isolation. In accord with this view, we demonstrated a gradual change in movement times and movement endpoint distributions following a switch in target width during a reciprocal aiming task. Importantly, this necessitates a transient departure from Fitts's law and highlights the role of visuomotor memory for the planning and execution of movements even in the presence of vision.

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36.316 The effect of target visibility on updating rapid pointing

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During rapid, goal directed hand movements, eye and hand position are usually yoked. The saccade typically leads the hand. Visual and proprioceptive feedback can also be used to update the movement online. However, it is not yet clear what effect the new, high resolution image of the target location gathered by this first saccade has on online control of the hand and eye-hand coordination. If this lately acquired visual information significantly modulates performance, it would have significant implications for theories of eye-hand coordination. We investigated the impact of the visibility of the goal at different times during the reach on endpoint precision and accuracy. If visual information about the target gathered by the first saccade is used to update a movement online, endpoint precision and accuracy should decrease if target visibility decreases late in the movement. Target contrast can significantly affect visual localization thresholds. In our experiment, we varied target contrast and duration in the reach to manipulate the quality of the visual information gathered by the first saccade. The target could appear at one of 8 different locations, each 8 degrees eccentric to initial fixation. In Experiment 1, participants pointed to targets of varying contrast and varying duration. We measured pointing precision, accuracy and movement time. Contrast significantly affected pointing precision. Pointing accuracy for low contrast targets was significantly better at longer target durations. In Experiment 2, participants pointed to a target that either reduced or increased its contrast either early or late in the reach. Low contrast targets resulted in longer movement times. The results demonstrate that target contrast significantly impacts on pointing performance, and suggests that aggregation of information can affect rate of movement, perhaps as a corollary of Fitts' law. We will discuss the implications of these findings for theories of eye-hand coordination.

36.317 Comparing chromatic and luminance information in online correction of rapid reaching

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Humans update goal-directed reaches online. There are additional delays in integrating location changes for chromatic (parvocellular or koniocellular) targets compared to luminance (magnocellular) targets. This may reflect the chromatic pathways' slower conduction velocities. But the chromatic information may also take a longer route to the parietal cortex. Integration times increase with stimulus intensity. Comparing different stimulus types directly is problematic. Circumventing this problem in different ways has produced different results. Veerman et. al. (2008) found additional chromatic delays of ~50ms, while White et. al. (2007) found a negligible difference. We compared integration times for for pointing chromatic and luminance targets of equal intensity. We used identical stimuli in setting subjective equiluminance and detection thresholds, and in the final experiment. The stimuli were gaussian blobs (SD ~.5o) on a grey background. Participants first adjusted red, green, yellow and blue blobs (defined in DKL color space) to be equiluminant to the background. Next, we measured detection thresholds for these chromatic stimuli and for two luminance contrast blobs for each participant. This produced stimuli of equal salience that primarily stimulated the parvocellular, magnocellular or koniocellular geniculate pathways. Finally, participants made fast pointing responses towards a fixation cross on a touchscreen. In one-in-three trials, the blob appeared 6o left of the cross, 12-106ms after movement onset. Participants were instructed to touch the blob in under 410 ms or the trial was repeated.'50% Integration time' (IT50) is the 'threshold' time the blob was present during the reach for participants to correct more than half way towards it. Generally, IT50 was shortest for magnocellular blobs and longest for koniocellular blobs. IT50 for parvocellular targets varied between participants. The small additional integration delays for chromatic stimuli are best explained by slower conduction velocities.

36.318 **Effect of speed overestimation on manual hitting at low luminance**

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Previous studies have reported an overestimate in the perceived speed of moving objects at low luminance (Hammett et al 2007, Vaziri-Pashkam & Cavanagh 2008) and we have shown that this overestimate is a result of the longer blurred trajectory left by the moving stimulus at low luminance. Here we investigate whether this cue of extended motion trace affects action as well as perception by testing the accuracy of hand motion to a translating target at low luminance. We first verified the low-luminance effect on perception with two stimuli presented successively, one at high (mean luminance 75 cd/m2) and one at low luminance (0.15 cd/m2). Subjects had to decrease the speed of the low luminance stimulus by approximately 30% to match the apparent speed at high luminance. In the second experiment, subjects were asked to make rapid hand movements towards the moving targets so that their fingertip would land on the center of the moving random dot pattern. Vision of the hand was blocked to prevent visual feedback so that the accuracy of the landing depended on the speed estimate for the moving target. Results showed that the landing position of the finger was significantly farther ahead of the target at low luminance suggesting that the programming of the hand motion was based on an overestimated target speed. Based on the timing of the hand movement and its landing position, we derived the target speed used to plan the hand movement and found it to be about 10-15% too fast at low luminance compared to high luminance. We suggest that overestimation of perceived speed based on the extended blur cue affects our motor performance at low luminance conditions.

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36.319 **Extrapolation of target movement is influenced by the preceding velocities rather than by the mean velocity**

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Purpose: Previous studies have suggested that the extrapolation of an occluded target movement is influenced by the target velocity of the preceding trial, (Lyon and Waag, 1995, de Lussanet et al, 2001, Makin et al, 2008) and the overall mean velocity of the target (Brouwer et al., 2002, Makin et al, 2009). However, those studies may fail to isolate the effect of the preceding trial's velocity from the effect of overall mean velocity, and vice versa. We examined the significance of the two effects. Method: In a virtual environment, a moving target disappeared behind an occluder and subjects hit the target at the impact zone when the target is supposed to be in the zone had it moved with a constant velocity. Seven velocities (6 deg/s to 18 deg/s) and four occluded distances (6 deg to 18 deg) were used and the exposure duration of the target was fixed at 800ms across all conditions. Results: A model was developed to predict the hitting time which is the duration from the moment of the target disappearance to the moment of a subject's hitting on the impact zone. Velocities of the first preceding trial, the second preceding trial, and the overall mean velocity, and the mean hitting time were considered as possible factors influencing the performance on the current trial. A cross validation technique was used to select a model. The model with the best fit includes the first preceding velocity and the second preceding velocity terms but does not include the overall mean velocity and the overall mean hitting time terms. Conclusion: Results suggest that extrapolation of target movement is influenced by the preceding velocities rather than by the overall mean velocity.

36.320 **Perceiving and controlling actions: Visually perceived distances map onto different forms of throwing as a function of the ball's weight and constraints on throwing actions**

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People control their own actions and judge the results of other's actions from the action's kinematics. We study the psychophysics when children & adults vary the forms of their throwing to accommodate for varying target distances, ball weights, and constraints on whether they can rotate elbow, shoulder, waist or step forward. People control the forms of their throwing to fit with the different ranges of visually perceived distance. For a 1m target they swing from the elbow alone, to a 5m target from elbow & shoulder, and so forth out to 30m targets. They know how many of the available degrees of freedom in the throwing action are needed to generate enough force to reach the target's vicinity. In Study 1 4-6 year olds & adults were video taped while throwing to visual targets ranging from 1-30m. Throw dynamics/kinematics were constrained by varying the ball's weight, wrist weights, & constraining movements across some swing points. How would people adapt, we ask, when tossing to nearby targets with their elbow constrained? How would they adapt when tossing to far away target without stepping or waist rotation? Study 2 was aimed at investigating the accuracy with which 4-6 year olds and adults can judge the thrown distance by observing the kinematics of others' throws. People viewed videotapes of throws up to the instant of release; they judged the throw's distance & trajectory from the hand/ball's velocity. Weber fractions were used to describe the thrown distances across target distances. Children & adults alike coped with the constraints in sensible ways, always varying the form of throw in ways that let them control the hand/ball's velocity. Finally, children & adults were not accurate at judging the thrown metric distance from videotapes, but were remarkably accurate at rank ordering the thrown distances.

36.321 **Noise Modulation in the Dorsal and Ventral Visual Pathways**

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The human visual system responds differently to the same stimulus depending on type of task. These differences may be due to how the stimulus is encoded; action-tasks utilizing an observer-based encoding, and perceptual-tasks utilizing an object-based encoding. We are interested in how the systems modulating these different outputs process extrinsic noise. Previously, we demonstrated a method allowing subjects to respond to the same visual display via hand-eye coordination or via perceptual-awareness. In the current study, we examined response variance in the two tasks given increasing levels of noise. Noise was defined as a random displacement applied to each frame of a moving target as it traversed the visual display. The magnitude of the displacement corresponded to the standard deviation of the sampled normal distribution. We hypothesized that response variance would be the sum of the intrinsic noise of the system and the applied extrinsic noise. We tested video-game experts and non-experts. All data follow the expected trend in the action-task. Data from non-experts also follow this trend in the perceptual-task, however data from video-game experts show less variability in responses compared to the predicted model, especially at high levels of extrinsic noise. This may suggest that experts are better able to "ignore" noise than non-experts. Further analysis using a LAMSTAR neural network, trained on subject data, was able to determine the threshold at which noise overwhelmed the mechanism for "ignoring" noise in the perceptual-task. We found that the two systems would begin to treat the sum of the intrinsic and extrinsic noise similarly at much higher levels of noise in video-game experts. In sum, these findings suggest that noise may be processed differently according to the type of visual task.

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36.322 **Event-related potential (ERP) reflections of perceptual requirements during the planning of delayed action**

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Kinematic studies have robustly shown that delayed hand actions involve slower and less accurate movements compared to immediate, visually guided actions. Furthermore, converging evidence from neuropsychological and neuroimaging studies suggest that visual perceptual brain mechanisms in the lateral occipital cortex (LOC) are critically recruited during delayed hand actions. In this study we sought to further investigate these issues by directly comparing the amount of perception-based neural activity during the planning phase of visually guided and delayed actions. To this end, twelve paid volunteers were auditorily cued to perform a reaching task to circular targets at varying locations on a nineteen-inch touch sensitive monitor. In the visually guided condition, the targets remained visible for 300 milliseconds after the onset of the auditory movement cue. In the delayed condition, the targets disappeared from view at the same time as the auditory movement cue. We collected scalp recorded event-related potential (ERP) data from 256 electrodes during both conditions of the task, and focused our analysis on the neural activity during the action planning phase of each trial. The behavioral data showed that, as expected, movement time (MT) was slower in the delayed condition compared to the visually guided condition. Moreover, the ERP data showed that the sensory P1 response over occipital electrodes was equivalent in both conditions; and most importantly, the object recognition N170 response was larger during the planning phase of the delayed action condition compared to the visually guided action condition. This effect was robustly observed at 22 electrodes over temporal-occipital sites in both hemispheres. These data suggest that the planning of delayed actions relies more heavily on perception-based information than visually guided action. Furthermore, this difference is not reflected in early visual processing, but involves higher-order perception likely associated with regions in the inferior-temporal cortex.

36.323 **Testing the spatial reference frames used for manual interception**

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While early cortical reach areas are known to represent earth-fixed movement goals in a dynamic, gaze-centered map, it is unknown whether the same spatial reference plays a role in the coding of moving targets for manual interception. We tested the role of gaze-dependent and gaze-independent reference frames in the coding of memorized moving targets, rendered invisible prior to a saccade that intervened before the reach. Gaze-centered coding would require the internal representation of the interception point (IP) to be actively updated across the saccade whereas gaze-independent coding would remain stable. Head-fixed subjects (n = 9) sat in complete darkness and fixated a visual fixation point (FP) presented on a screen in front of them. A target started moving for 2.1 s downward at 7 deg/s at various approach directions (-18, 0, +18 deg), after which it disappeared. Occluded targets passed fixation height in a range from -5 to +5 deg (relative to straight ahead); FP locations ranged from -10 to +10 deg. After a saccade (in saccade trials - as opposed to fixation trials) subjects reached out to intercept the occluded target at fixation height with their index finger (saccade trials). We analyzed the pointing errors using regression analyses. Both initial and final fixation direction, as well as IP relative to these gaze directions affected the pointing errors (fixation trials: R2 = 0.15-0.50; saccade trials: R2 = 0.15-0.62). Importantly, errors in the saccade trials reflected combined effects of fixation direction during target presentation and during the memory period. This suggests that a gaze-dependent representation of the IP is transformed into gaze-independent coordinates before the saccade, but that this transformation is not entirely finished at saccade onset. This explains why the pointing errors reflect a mixture of gaze-dependent and gaze-independent reference frames.

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36.324 **Spider-phobia influences conscious, but not unconscious, control of visually guided action**

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Fear of a stimulus can distort perception of its appearance (e.g., spiders: Rachman & Cuk, 1992; heights: Stefanucci & Proffitt, 2008). These studies have not distinguished between conscious perception versus the control of visually guided action (Milner & Goodale, 1995). In this study we tested spider-phobic (n=15) and non-phobic (n=20) participants in a visually guided pointing task that measured both conscious and unconscious aspects of visual-motor control. Participants made speeded pointing actions on a touch-screen to images depicting either negative or positive emotional content (spiders vs. pets). The pointing task was performed with visual attention either focused on the image (single task) or divided because participants were also identifying letters (dual task). This dual task disrupts the conscious planning of actions (as measured by action initiation time) but not their online control (as measured in movement time, pointing accuracy, and response to target displacement during the action) (Liu, Chua, & Enns, 2008). Pointing was controlled differently by spider-phobic than non-phobic participants. In the dual task, they showed greater interference for letter identification and slower pointing movement. In the single task, they showed less accuracy and greater sensitivity to image content, specifically avoiding the negative images when pointing. Yet, when attention was divided between images and letters in the dual task, measures of unconscious motor control showed no differences related to phobia; pointing speed, accuracy, and sensitivity to target displacement were unaffected by phobia or image content. These findings support the hypothesis that spider-phobia exerts its influence on the conscious, but not unconscious, control of visually guided action. They imply that the automatic pilot of the dorsal stream (Pisella et al., 2000), which is guided by the location of the images, is not influenced by their emotional content.

Acknowledgement: UBC AURA Award, NSERC Discovery Grant

36.325 **Motor output effect of objects presented in the blindspot**

Damon Uniat[1](damon.uniat@hotmail.com), Frank Colino[1], John De Grosbois[1], Darian Cheng[1], Gordon Binsted[1]; [1]University of British Columbia-Okanagan

The physiological blindspot is defined by the junction where the optic nerve exits the eye chamber and the accompanying absence of photoreceptors (Enns, 2004). Despite this absence of retinal input however, perceptual filling of the blindspot has been consistently shown; suggesting visual perception can exist in the absence of retinal drive. Recent examinations by Binsted et al (2007) suggest the converse is also true, whereby conscious visual percept is not a necessary emergent of retinal input – while still supporting motor output. In the current investigation we examined how objects presented in the blindspot could modulate motor output (i.e. pointing) in the absence of conscious awareness. The blindspot of the right eye was mapped using a modification of the protocol developed by Araragi and Nakamizo (2008). Subsequently, participants were asked to point to objects presented either within the blindspot (+/- 40% scotomic diameter) or outside of the blindspot. Specifically, while fixating a stationary point, participants pointed to the target circles briefly flashed (33 ms) either inside or outside the blindspot; on some trials no target was presented to serve as a control. Responding to an auditory tone, the subject was to point to the presented target (whether present/perceived or not) as quickly and accurately as possible. Although participants were ubiquitously unable to detect the presence of targets within the blindspot (and able outside) both endpoint position and variability was sensitive to the occurrence and position of a target. Subjects pointed more to the right/left respectively of the screen corresponding to the target circle despite presentation within the blindspot. Further, they were less variable when pointing to non-conscious targets than when responding in the absence of a target. Thus, despite the absence of conscious percept due to subthreshold retinal input, visuomotor pathways – presumably within the dorsal stream – are able to use target location information to plan and execute actions.

Acknowledgement: NSERC to G. Binsted

36.326 **Extrinsic manipulations of the mental number line do not impact SNARC-related influences on the planning and control of action.**

Jeffrey Weiler[1](jweiler2@uwo.ca), Ali Mulla[1], Taryn Bingley[1], Matthew Heath[1]; [1]School of Kinesiology, The University of Western Ontario

Sunday PM

The spatial numerical association of response codes (so-called SNARC effect) manifests as faster reaction times (RT) to judgments of numerical magnitude in left and right space when cued by low and high numbers, respectively. In addition, Fischer (2003:Vis Cogn) reported that movement times (MT) associated with goal-directed reaching movements are influenced in a direction consistent with the SNARC effect. These findings have been explained by the presence of a mental number line with smaller and larger digit magnitudes preferentially represented in left and right space, respectively. In the present study, we sought to determine whether the magnitude of the SNARC effect for goal-directed reaching is influenced by the premovement manipulation of a real number line. Prior to response cuing participants were briefly (50 ms) presented with an ascending (i.e., digit magnitude increasing from left to right), or descending (i.e., digit magnitude decreasing from left to right) number line. In addition, we included a control condition wherein a number line was not presented in advance of response cuing. Following premovement cuing, low (1,2) or high (8,9) digits were presented and used to visually cue the onset of a left or right space reaching response. Results for RT and MT did not elicit a SNARC effect: a finding consistent across the different premovement visual cuing conditions (i.e., ascending, descending, no number line). Interestingly, however, when total response time was analyzed (RT+MT) a SNARC effect was observed. Based on these findings, we propose that the SNARC effect for reaching responses is represented as an aggregation of the temporal properties of both movement planning and control. Further results suggest that the SNARC effect is refractory to extrinsic manipulations of the mental number line.

Acknowledgement: NSERC

36.327 **Visuomotor mental rotation: Reaction time is determined by the complexity of sensorimotor transformations supporting the response**

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In the visuomotor mental rotation (VMR) task, participants execute a center-out reaching movement to a location that deviates from a visual cue by a predetermined angle. Seminal work from Georgopoulos and Massey (1987) revealed a linear increase in reaction time (RT) as a function of increasing instruction angle, for angles of 5, 10, 15, 35, 70, 105 and 140°. This finding led to the mental rotation model, which asserts that response preparation is mediated by the imagined rotation of the movement vector (Georgopoulos and Massey, 1987). We recently demonstrated that the mental rotation model does not account for RT in all VMR tasks. Specifically, we revealed a RT advantage for the 180° instruction angle relative to 90° (Neely and Heath, 2009, in press). We interpreted this as evidence that 180° is mediated by a vector inversion strategy; however, we were unable to determine whether 90° invoked a mental rotation strategy. The goal of the present work was to examine 90° and 180° in concert with a set of intermediary angles to determine whether 180° is a special case of VMR. To that end, we evaluated two independent sets of instruction angles: 0, 5, 10, 15, 35, 70, 105 and 140° (Experiment One) and 0, 30, 60, 90, 120, 150, 180, and 210° (Experiment Two). The results revealed a linear increase in RT as a function of instruction angle for Experiment One. In contrast, the results for Experiment Two revealed a non-linear relationship between RT and instruction angle; specifically, we observed a RT advantage for 180°, followed by 30° and 90°. Such results provide convergent evidence that response planning in the VMR task is not universally mediated by a mental rotation strategy. Rather, we contend that RT is determined by the complexity of the visuomotor transformations supporting the voluntary response.

Acknowledgement: Natural Sciences and Engineering Research Council of Canada (NSERC)

36.328 **EEG microstates during visually guided reaching**

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The notion that vision's importance in controlling goal-directed reaching movements has been experimentally validated (Woodworth, 1899). Functional MRI and rTMS work has subsequently confirmed that the posterior parietal cortex (PPC) are important for the control of visually guided movements (Culham and Kanwisher, 2001, Desmurget et al, 1999). The temporal resolution is inappropriate to study the cortical dynamics of reaching movements. Therefore, this investigation examined the activation dynamics of movement planning and control as measured by electroencephalography (EEG). Participants completed reaching movements during full-vision (FV), no-vision-delayed (NV) or open-loop (OL). Event-related potential analysis segmented with respect to peak velocity (PV) yielded differences in visual and motor areas following PV. To generate an overall evaluation of the activation across time, ERP waveforms were submitted to a space-oriented field clustering approach (Tunik et al, 2008) to determine epochs of semi-stable field configurations (i.e. microstates) throughout the planning/control of reaches. The results of this micro-state analysis showed that regardless of visual condition, the planning and initiation of movement is characterized by two state transitions: an activation pattern dominated by increasing primary-visual and motor activation (FCz, Oz). NV remained in this early movement state and did not enter any control-based state. During FV, activation shifted following PV to an activation consistent with dorsal (contralateral PPC, frontal and 1o visual areas) guidance of movement. OL transitioned into a bilateral temporal (presumably memory-guided) mode of control that did not exhibit primary visual activation. This had been expected of NV. Thus, even though previous fMRI studies have correctly identified important structures for the control of movement across different visual conditions, they have lacked the temporal resolution to elucidate the pattern of functioning across visually guided reaching movements.

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36.329 **Rapid Visuomotor Integration of flanking valenced objects**

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Significant neurobehavioral evidence suggests a discrete segregation between the pathways associated with visual perception (i.e., ventral projections) and those ascribed visuo-motor functions (i.e., dorsal projections; in humans, see Milner & Goodale 2008; in non-human primates see Ungerleider & Mishkin 1982). In general the dorsal stream appears to be specialized for processing veridical and egocentrically coded cues in a fashion that is independent of conscious awareness (e.g., Binsted et al. 2007). Conversely, the ventral stream considers the relational characteristics of visual objects and scenes to arrive at a richly detailed percept. However, demonstrations of dorsal insensitivity to perceptually driven object features have failed to address valence as an action moderator despite its apparent evolutionary relevance. Moreover, valenced cues have been observed to modify motor behavior in non-human primates (fear conditioning; Mineka et al. 1984). Thus, it follows that the human visuo-motor system should rapidly integrate abstract scene cues (e.g., valence) to reach a goal while avoiding potential dangers (e.g., predation). To examine this we asked participants to point to visual targets that were randomly flanked by valenced images chosen from the International Affective Picture System (IAPS: e.g., bear cub, gun). All pointing movements had 50 cm amplitude; the target was withdrawn upon movement initiation while the valenced flanker remained. Participant endpoint position was driven towards negatively valenced objects and driven away from positively valenced objects. Thus, it appears the visuomotor system does not restrict its visual set. Rather, it appears to rapidly integrate perceptual interpretations of abstract and contextual cues for movement adaptation.

Acknowledgement: NSERC, CFI

36.330 **Digit magnitude does not influence the spatial parameters of goal-directed reaching movements**

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Movement times are advantaged when numerical magnitude is used to prompt the initiation of a goal-directed reaching response. In particular, movement times in left and right visual space are reported to be faster when respectively paired with smaller (i.e., 1, 2) and larger (i.e., 8, 9) digits (Fisher 2003: Vis Cogn). In other words, the well-documented spatial numerical association of response codes (the so-called SNARC effect) can be extended to the movement domain. The present study sought to determine whether the SNARC effect differentially influences not only the temporal properties of a reaching response, but also the spatial properties of the unfolding trajectory. To accomplish this objective, participants completed left and right space reaches following movement cuing via numerical stimuli (i.e., 1, 2, 8, or 9). Importantly, placeholders were used to denote the amplitude of the reaching response and were either continuously visible to participants (Experiment 1) or occluded prior to movement onset (Experiment 2). Results for Experiments 1 and 2 elicited a SNARC effect for reaction time; that is, smaller and larger digits produced faster response latencies when used to cue left and right space reaches, respectively. In terms of movement time, Experiment 1 yielded a reversed SNARC effect: reaches were completed faster to larger and smaller digits in left and right space, respectively. For Experiment 2, movement times were not influenced by digit magnitude and the direction of the reaching response. Further, spatial analysis of movement trajectories (Experiments 1 and 2) did not yield reliable interactions between digit magnitude and reaching direction. In general, our results support the assertion that numerical magnitude influences the planning of a response, but does not reliably influence the temporal or spatial parameters of the unfolding reaching trajectory.

Acknowledgement: NSERC

36.331 **Bimanual Interaction in Pointing to a Common Visual Target with Unseen Hands**

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Although bimanual performance generally involves high correlation between the responses of the two hands, bimanual independence has been achieved by haptic tracking two different targets, indicating that people can maintain two separate movement plans simultaneously. Recently, we found that observers maintained a high degree of bimanual independence when manual heightmatching to a common visual target. In the present experiments, we employed bimanual pointing to a common visual target. Observers in darkness monocularly viewed a visual target either 12o above, 12o below, or at eye level with a 50o-long inducing line pitched either -30o (topbackward), or 20o (topforward) at 25o horizontal eccentricity. Manual pointing to the target was measured by a Polhemus 3-Space search coil with the unseen hand either in the midfrontal plane or with a fully-extended arm. The perceived elevation of a fixed-height target was raised in a pitched-topbackward visual field and lowered in a pitched-topforward visual field. However, manual pointing to the mislocalized target was accurate with the fully-extended arm whereas, with the hand in the midfrontal plane, pointing errors were equal and opposite to the perceptual mislocalization. With the hands at different distances simultaneously, the pointing direction to the target by the second hand was influenced by the prior pointing direction of the first hand. Average bimanual transfer approximated 43%, whether the first pointing was with the left or right hand. Less transfer (bimanual independence) was found with the first hand pointing from the midfrontal plane and the second hand pointing with a fully-extended arm than for the reverse order of manual distances. Similar results were obtained for different target heights. Hand dominance also played an important role: 65% transfer was measured for the dominant to the nondominant hand, 24% transfer was measured for the nondominant hand to the dominant hand.

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36.332 **Quantitative Treatment of Bilateral Transfer**

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The usual means of describing bilateral transfer quantitatively is to measure a response for the modality of interest on one side of the midline (e.g., left arm, left eye, etc.) as a baseline condition, and in a separate condition measure the same response following (or simultaneous with) activity with the same modality on the other side of the midline as a bilateral condition. The deviation of the response in the bilateral condition from the baseline condition divided by the difference between the unilateral responses on the two sides provides the usual measure of % transfer. We show that the % transfer measure is mathematically identical to a linear weighted average of the unilateral responses from the two sides of the midline and that this leads to a decrease in the slope of the function relating the original unilateral response-vs-a-critical stimulus parameter. We have measured manual heightmatching to a visual target in darkness whose perceived elevation is systematically influenced by the pitch of a single eccentrically located line, and also systematically influenced by the distance of the hand from the body. The connection between the % transfer and the slope of the manual heightmatch-setting-vs-hand-to-body distance function noted above was found to hold. This supports a linear weighted average model for bimanual heightmatching. The ecological significance of such bilateral averaging will be described. This significance is general for many bilateral functions beyond the manual heightmatching for which we found it to hold, and suggests that experimental tests of other bilateral functions would provide similar agreement with the linear weighted average model.

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Perceptual learning: Sensory plasticity and adaptation

Orchid Ballroom, Boards 401–414

Sunday, May 9, 2:45 - 6:45 pm

36.401 **Neural correlates of perceptual learning in the human visual cortex**

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Although practice is known to improve perceptual discrimination of basic visual features, such as small differences in the orientation of line patterns, the neural basis of this improvement is less well understood. Here, we used functional MRI in combination with pattern-based analyses to probe the neural concomitants of perceptual learning.

Subjects extensively practiced discriminating small differences in the orientation of a peripherally presented grating. Training occurred in daily 1-hour sessions across 20 days, during which subjects performed the task based on a single orientation at a single location in the visual field. BOLD activity was measured before and after training, while subjects performed the orientation discrimination task on the trained orientation and location, as well as three other orientations and a second isoeccentric location.

Behavioral thresholds showed large improvements in performance after training, with a 40% mean reduction in thresholds for the trained orientation at the trained location, and no significant improvement for any of the other conditions. However, analysis of the amplitude of the BOLD response did not reveal a location- or orientation-specific change in gross activity in early visual areas. To test whether learning nonetheless improved the representation of the trained orientation at the trained location, we used a pattern-based analysis to decode the presented stimulus orientation from cortical activity in these regions. Preliminary analyses indicated better decoding performance in areas V1 and V2 for the trained orientation and location, as compared to the untrained conditions. These results suggest that, when analyzed at the population level, perceptual learning results in an improved early-level representation at the trained location for the trained visual feature.

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36.402 **Perceptual learning recruits both dorsal and ventral extrastriate areas**

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In perceptual learning (PL), behavioral improvement is specific to trained stimuli and trained orientation. Some studies suggest that PL recruits V1 (Schiltz et al., 1999; Yotsumoto et al., 2008) and leads to a large-scale decrease in the recruitment of higher visual areas and of the dorsal attentional network (Mukai et al., 2007; Sigman et al., 2005). However, the designs do not address whether these effects are task-dependent, may result from mere exposure, and could generalize to training stimuli with variability in shape. Twelve participants were trained for 8 hours to search for objects in a target orientation among an array of 8 distracter objects. Within each display, all objects were identical in shape and varied only in orientation, but across displays, a number of similar objects were used. With fMRI, we compared neural activity in response to these objects before and after training. As in prior work (Sigman et al., 2005), behavioral improvement was specific to trained orientation but it generalized to similar objects, and neural activity in early visual areas was higher for objects at the trained orientation after training. Importantly, the neural inversion effect was observed in visual areas well beyond retinotopic cortex, including extrastriate face and object selective areas. These inversion effects were not obtained during shape discrimination with the same objects, or in a separate group of participants undergoing eight hours of naming training with the same object set in the same peripheral visual positions, suggesting that the inversion effects were task-dependent, and were not a result of mere exposure with the objects. Our results extend prior work to suggest that PL can sometimes recruit higher visual areas, possibly depending on the training objects and the variability within the object set.

Acknowledgement: This research was supported by grants to the Temporal Dynamics of Learning Center (NSF Science of Learning Center SBE

36.403 **Top-down attention is facilitati ve, but not obligatory, in perceptual learning to reduce sensory eye dominance**

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Mutual binocular inhibition is unequal in people with sensory eye dominance (SED). We found SED can be reduced using a Push-Pull perceptual training paradigm where the weak eye was cued before the two eyes were stimulated with a pair of orthogonal gratings (Xu et al, Neurosci. Abst, 2009). The pre-cueing ensured the grating in the weak eye was perceived so that the observer could discriminate its orientation, while the strong eye was interocularly suppressed. The impact of the training was limited to the trained retinal location and grating orientation. However it is unknown whether top-down attention, which directs orientation discrimination in the weak eye, is required for the learning. We investigated this by implementing a 10-day Push-Pull training. During the training, two pairs of orthogonal grating discs (vertical/horizontal, 1.25deg, 3cpd, 35cd/m2) simultaneously stimulated two different retinal locations (2 deg from the fovea). While both retinal locations in the weak eye were pre-cued, observers were instructed to attend to and discriminate the grating orientation in one location (attended), and ignore the other (unattended). We found SED gradually reduced with training, both at the attended and unattended locations. This indicates top-down attention is not required for the learning. Top-down attention, however, is facilitative as the reduction in SED was larger at the attended location. The consequences of reduced SED are also evident in two unrelated binocular visual tasks. One, using a binocular rivalry tracking task, we found the predominance of seeing the dominant image in the weak eye was significantly enhanced. The enhanced predominance effect was slightly larger at the attended location than at the unattended location. Two, we found the training caused a similar improvement in stereoacuity at both locations. These findings show that with the Push-Pull training paradigm, top-down attention is not obligatory, but can facilitate perceptual learning.

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36.404 **Short Term Adaptation of Visual Search Strategies in Simulated Hemianopia**

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Objective: In this study we isolated the effects of strategic adaptation of healthy individuals to a simulated homonymous hemianopia (sHH) and studied the time course of early changes in search task performance. Background: Patients with homonymous visual field defects from occipital stroke are known to have impaired visual search performance both clinically and experimentally. Rehabilitation training is often used to improve on such deficits. If improvement occurs it is not clear as to whether it is due to strategic adaptation or recovery through neural plasticity. Moreover, it is not clear how rapidly adaptation occurs. Design/Methods: We used a video eyetracker with a gaze-contingent display to simulate hemianopia. 10 healthy subjects performed a letter search task under conditions of normal viewing, right sHH and left sHH, with 25 trials per condition. We measured search performance in terms of both speed and accuracy, assessed the effect of viewing condition and, to reveal adaptation effects, assessed the time course within a given viewing condition. Results: Visual search was slower and less accurate in the sHH than normal viewing conditions. Search performance was comparable in left and right sHH. In the normal viewing condition subjects showed task-learning improvements in search speed over the first 6 trials, and then maintained a steady asymptotic performance. After the onset of sHH, subjects showed early improvements in search speed that continued over all the 25 trials. This hemianopic adaptation was larger in magnitude than the task-learning displayed in the normal viewing condition. Conclusions/Relevance: Our results indicate that an early and rapid strategic adaptation of visual search to hemianopic limitations on vision occurs in the first few minutes after the onset of visual field deficits. Such strategic shifts may account for the alterations in search behaviour seen in pathologic hemianopia, and may need to be taken into account when evaluating the effects of rehabilitation.

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36.405 **Effects of adaptation on orientation discrimination**

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Adaptation can have an immediate effect on the subsequently viewed stimuli; discrimination thresholds decrease at the adapted stimulus orientation and increase for orientations away from the adapted stimulus (Regan & Beverley, 1985; Clifford et al., 2001). Here we investigated the effects that perceptual adaptation could have for orientation discrimination for trained and untrained orientations. Participants were initially trained in an orientation discrimination task at the adapted orientation. On each trial a Gabor pattern was presented at fixation and the adaptor was followed by the test stimulus. Participants compared the test stimulus orientation to a standard that had the same orientation as the adapting stimulus. Participants completed a total of 10 sessions that were administered in separate days. Thresholds across sessions for the adaptation condition were lower compared to a control condition at a different orientation with no adapting stimulus. In the second part of the study, we examined participants' orientation discrimination at an orientation 10 degree away from the adapted orientation. Two conditions were compared: orientation discrimination at the previously trained orientation and at an untrained orientation. Participants completed 4 sessions for the two conditions. In both cases, adapting to an orientation 10 degree away from the test orientation increased thresholds. However, the threshold increase was larger for the previously trained orientation than for the untrained orientation. Our results are consistent with the idea that training orientation discrimination increases the weights of the neighboring orientation mechanisms relative to the mechanism most sensitive to the test orientation (Blaser et al., 2004).

36.406 **Short-term components of visuomotor adaptation to prism-induced distortion of distance**

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If the adaptive mechanisms to prism-induced lateral deviation have been widely investigated, little is known about prism-induced alteration of distance. The purpose of the present experiment was to study if a similar pattern of visuomotor plasticity applies to a prism-induced distortion of distance. The experimental paradigm involved successively pre-test measures, an exposure phase and post-test measures. The adaptation process was evidenced by a compensatory aftereffect between the pre- and post-tests. During the exposure, subjects had to point quickly to a visual target with their left hand seen through a pair of 5 Δ base-out prisms spectacles. Visuomotor adaptation was assessed by open-loop pointing (i.e. without seeing the hand) to visual targets with the left (exposed) hand. Visual adaptation (an adaptive process common to all effectors) was assessed by open-loop pointing to visual targets with the right (unexposed) hand. Proprioceptive adaptation of the left hand was measured by pointing to the left hand with the right hand while blindfolded. Motor adaptation of the left hand was indirectly inferred by calculating the difference between the visuomotor aftereffect and the algebraic sum of the visual and proprioceptive aftereffects. A significant aftereffect was obtained for both visuomotor and visual components. No aftereffect was found for the proprioceptive component. The fact that the visuomotor aftereffect was significantly greater than the sum of the visual and (null) proprioceptive aftereffects is an indication that a motor adaptation had developed during exposure in addition to a visual adaptation. These findings highlighted short-term adaptive components to prism-induced distortion of distance. The adaptive components differed from those found with prism-induced lateral deviation by their respective contributions to the aftereffect, the latter ones involving little visual adaptation. Such differences in visuomotor adaptation may be attributed to the accuracy of the available error signals, and could rely on different levels of plasticity.

 See page 3 for Abstract Numbering System

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36.407 **Does sleep influence how we see the world around us?**

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Sleep improves learning and consolidates memory. While this view is widely accepted, the notion that sleep can affect our perceptions, the way we view the world around us, has not yet been investigated. Here, we examine if sleep has an effect on visual perception, specifically on classification of stimulus color. On a given trial, a full-field homogeneous stimulus of either slightly reddish or greenish hue was displayed. The observer had to judge if the stimulus was greener or redder than their internal percept of neutral gray. Across trials, the hue was varied using the method of constant stimuli. One pair of monocular tests was run just before the observer went to sleep overnight and the second pair immediately after the person woke up. Sleep duration was monitored with sleep diaries and actigraphy (7.7 hours on average). A comparison of pre- and post-sleep data (n=5 observers) yielded a small but significant change: After sleep as compared to before, the stimulus was significantly less likely to perceptually take on a greenish tint ($p<0.01$, bootstrapping statistics). A closer look at the results reveals that it is not sleep that causes gray to be classified as reddish, but prior wakefulness that causes gray to be classified as greenish and sleep restores perception to achromatic "equilibrium", i.e. following overnight sleep, physical gray is perceived as gray. Overnight full-field monocular stimulation of a flickering red ganzfeld failed to nullify the recalibrating sleep-induced effect: An achromatic stimulus was still less likely to be classified as greenish following sleep (n=9), with no statistical difference in the magnitude of the recalibration in each eye. This suggests that recalibration is an obligatory, internal, sleep-dependent process that external stimulation cannot modulate. Our tentative conclusion is that wakefulness causes color classification to drift away from neutrality and sleep restores it back.

36.408 **External Feedback Networks and Perceptual Learning**

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Perceptual Learning refers to the continuous improvement of performance that follows practice in a perceptual task. Valid external feedback has been shown to enhance perceptual learning (Herzog & Fahle 1997). Here we used functional magnetic resonance imaging to identify cortical and subcortical regions that are activated when negative or positive external feedback is given during perceptual learning. We measured brain activity before and after extensive training of an orientation discrimination task with valid trial-wise external feedback (EF), enabling us to compare post and pre-training activity in regions activated by positive and negative EF. The results reveal two distinct networks. Positive EF engages the posterior and anteriorcingulate cortex, superior frontal gyrus, ventral striatum, bilateral putamen (Globus pallidus), superior temporal gyrus, bilateral parahippocampal gyrus and posterior middle temporal gyrus (all $p < 0.05$ FWE-corrected). Negative EF engages the anterior cingulate cortex, bilateral insula, dorsolateral prefrontal cortex, substantia nigra, anterior thalamus and the right inferior parietal lobe (all $p < 0.05$ FDR-corrected). Examining pre- and post-training differences of positive EF, we find that activity in the fusiform gyrus and orbitofrontal cortex decreases with training ($p < 0.01$ uncorrected), while for negative EF decreased activity is observed in the inferior and medial frontal gyrus ($p < 0.001$ uncorrected). Importantly, for both types of EF, we find increasing activity with training in the parahippocampal gyrus, a region involved in memory formation and the precuneus, which is associated with visuospatial processing. We conclude that the cortical regions most affected by feedback-based perceptual training are not primary sensory regions but frontal and parietal networks.

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36.409 **Perceptual learning increases motion discrimination of low contrast Gabors in older observers**

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This study compared the effect of training on the perception of motion in low contrast Gabor patches between older and younger observers. The stimuli were centrally presented Gaussian filtered sine-wave gratings (Gabors). The Gabors were either 5 or .7 degree diameter (2σ of the Gaussian filter) and had a contrast of .92, .22, or .028. The task was to judge whether the motion direction of the Gabor patch was to the left or to the right. The experiment took place over 5 days. On each day the observer participated in 6 blocks; one for each contrast/size pair. For each block, a duration thresholds estimating 77.5% correct was derived by averaging the results of randomly interleaved 2/1 and 4/1 staircases. The presentation times ranged from 500 (60 frames) to 16.6 (2 frames) milliseconds. Each block ended after 150 trials. Each participant observed a total of 4500 trials over 5 days. The results indicate a reduction in the amount of observation time needed to discriminate the direction of motion of the .028 contrast Gabors after training. The older observer's thresholds for the 5 degree Gabor improved by 66% (day-1 = 169ms, day-5 = 67ms) and by 41% for the .7 degree Gabor (day-1 = 479ms, day-5 = 284ms). The younger observer's thresholds for the 5 degree Gabor improved by 16% (day-1 = 82ms, day-5 = 67ms) and by 67% for the .7 degree Gabor (day-1 = 342ms, day-5 = 111ms). The importance of these results to understanding visual cortical plasticity and aging will be discussed.

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36.410 **Learning subliminal cues for predictive decision making**

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Can predictive yet subliminal cues play a role in human decision-making? To address this question, we combine the paradigms of perceptual learning on Gabor stimuli with perceptual decision making on degraded face/place images. Specifically, our design is an implicitly primed categorization task. Orientations of subthreshold Gabor cues (2 cycles/degree with white noise added) are predictive of the categories of 1800 face/place stimuli whose Fourier phases are scrambled at various levels. In each trial, category-paired, subliminal Gabor stimuli were presented for 300msec as preparatory cues, and were then followed immediately by a degraded face/place stimulus for a categorical judgment that lasted until a participant made a key response, within the time window of 1500msec. We examine if perceptual learning occurs for repeated Gabor stimuli, and further induces associative learning between Gabor orientations and face-place categories. After 3 days of training with auditory trial feedback, participants (N=4) showed learning effects for the face-place discrimination task in terms of increased accuracy and decreased reaction time. The observed result of better decisions for the main task can occur due to the priming from subliminal Gabor cues, and/or the improved face-place judgment. Control experiments are underway to clarify the contribution of Gabor stimuli to the observed learning effects and to examine the potential influence of subliminal cues on decision-making under different uncertainty levels.

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36.411 **Estimating psychometric functions in nonstationary observers**

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The psychometric function relates a physical dimension, such as stimulus contrast, to the responses of an observer. This relation is conveniently summarized by fitting a parametric model to the responses. In fitting such a model, we typically assume the responses to be independent of each others, and to follow the same distribution if recorded at the same stimulus level. However, there is evidence that casts doubt on the validity of this independence assumption: responses in psychophysical tasks are mutually dependent due to factors such as learning, fatigue, or fluctuating motivation. These kinds of dependencies are summarized as nonstationary behavior. From a theoretical point of view, nonstationarity renders inference about psychometric functions incorrect−it can result in rejection of otherwise correct psychometric functions or wrong credible intervals for thresholds and other characteristics of the psychometric function. So far, it is unknown how severe these errors are and how to properly correct for them. We simulated a number of observers with different types of nonstationary behavior. Psychometric functions were fitted for a large number of experimental settings, defined by the number of trials, the number of experimental blocks,

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and the task (2AFC vs yes-no). We present criteria to identify psychometric functions that are influenced by nonstationarity. Furthermore, we develop strategies that can be applied in different statistical paradigms−frequentist and Bayesian−to correct for errors introduced by nonstationary behavior. A software that automates the proposed procedures will be made available.

36.412 Pre-exposure interferes with perceptual learning for ambiguous stimuli

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The perception of a bistable stimulus is influenced by prior presentations of that stimulus. Such effects can be long lasting: e.g. position-dependent learned biases can persist for days, and reversing them requires extensive retraining (Haijiang et al., 2006). The effectiveness of training may therefore be influenced by pre-exposure to the ambiguous stimulus. Here we investigate the role of pre-exposure for learning a position dependent perceptual bias. We used rotating Necker cubes as the bistable stimuli that could be presented either above or below fixation. On training trials, additional cues (binocular disparity and occlusion) disambiguated the rotation direction for the cube. On test trials the rotating cube was presented without disambiguation cues. Subjects reported whether the front face of the cube and a moving dot moved in the same or opposite directions. Subjects received feedback about the correctness of their response. Using 350 training trials, subjects were exposed to different rotation directions for the above and below fixation locations of the cube. Following a 5-minute break a post-test (80 test trials) was performed. Separate subjects either directly started with the training, or were pre-exposed to the ambiguous stimulus in a pre-test (80 test trials). Subjects starting the training immediately, on average perceived the cube to be rotating in the trained direction for both locations on 83% of the post-test trials, replicating previous results. However, for the pre-exposed subjects, consistency with the trained percept-location contingency was only 58% in the post-test. In control conditions we simulated the pre-test using disambiguated trials and initially presented subjects with the reversed contingency than that which they would subsequently be exposed to during training. Post-test consistency with the trained contingency was 78%. This shows that the pre-exposure interference does not necessarily depend on the initial perceptual history, suggesting a fundamental difference between test and training trials.

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36.413 The Role of Gist in Dyslexia

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Dyslexia, a neurological condition that impairs reading, has been associated with advantages for rapid processing in the peripheral visual field (Geiger and Lettvin, 1987; Facoetti, et al, 2000; von Karolyi, et al 2003; Schneps, et al, 2010, in preparation) suggesting enhanced sensitivity to visual gist (Oliva, 2005) in this group. Sensitivities to peripheral gist might be expected to contribute to spatial learning, and Howard et al., (2006) and Schneps, et al., (2010) used the contextual cueing (CC) paradigm of Chun & Jiang (1998) to measure this in those with dyslexia. They found that while people with dyslexia are initially slower than controls at visual search, they are able to effectively improve the efficiency of their search through spatial learning, so that the search times of those with dyslexia become comparable to the controls. Spatial learning in the traditional CC task is dictated by the configuration of cues nearest the target (Brady & Chun, 2005), making scant use of peripheral gist. However, if the task is modified to provide stronger peripheral cues in the gist, we might expect those with dyslexia can outperform controls on searches involving learned configurations. To test this hypothesis, we compared a group of college students with dyslexia against controls using three variants of the CC task: (1) a traditional CC paradigm using L shapes for cues; (2) a variant using realistic scenes for cues (Brockmole & Henderson, 2006); and (3) a new task that uses a context defined by low spatial frequency gist. Our hypothesis is that spatial learning will improve in those with dyslexia compared to controls as the role of gist successively increased in each task. Here, we report preliminary findings from this study.

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36.414 Repeated contextual search cues lead to reduced BOLD-onset times in early visual and left inferior frontal cortex

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Repetition of context can facilitate search for targets in distractor-filled displays. This contextual cueing goes along with enhanced event-related brain potentials in visual cortex, as previously demonstrated with depth electrodes in the human brain. However, modulation of the BOLD-response in striate and peristriate cortices has, to our knowledge, not yet been reported as a consequence of contextual cueing. In an event-related fMRI experiment with 16 participants, we observed a selective reduction of the BOLD onset latency for repeated distractor configurations in these areas. In addition, the same onset latency reduction was observed in posterior inferior frontal cortex, a potential source area for feedback signals to early visual areas. These latency changes occured in the absence of differential BOLD time-to-peak and BOLD-amplitude for repeated versus new displays. The posterior part of left inferior frontal cortex has previously been linked to repetition priming, however in the form of repetition suppression. These studies differ from ours in many respects, such as awareness of stimulus repetition and semantic processing. The overlap of activation found in previous priming studies and in the current experiment does not allow the reverse inference that the same mechanisms are involved in contextual cueing and priming. However, future experiments may investigate the mechanisms that lead to repetition suppression versus BOLD-onset reduction in left posterior inferior frontal cortex and visual cortex, thereby elucidating the commonalities or differences between repetition priming and contextual cueing.

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Color and light: Lightness and brightness

Orchid Ballroom, Boards 415–431

Sunday, May 9, 2:45 - 6:45 pm

36.415 The staircase Kardos effect: An anchoring role for lowest luminance?

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In the staircase Gelb effect, a black surface in a spotlight appears white and becomes darker as four lighter shades of gray are added within the spotlight. Each new square is seen as white until the next square is added confirming that lightness values are anchored by the highest luminance. To explore whether the lowest luminance plays any anchoring role, we tested an inverted version of the staircase Gelb effect. We started with a white target square in a hidden shadow that appeared black (Kardos illusion). Then successively 4 darker squares were added in a row within the shadow: light gray, middle gray, dark gray, and black, each new configuration viewed by a separate group of 15 observers, who matched each square using a 16 step Munsell chart. The target square appeared lighter as each darker square was added, suggesting that the lowest luminance may play some anchoring role. However, as darker squares were added, not only did lowest luminance decrease but the number of squares (articulation) increased as well. In subsequent experiments we varied lowest luminance while holding articulation constant and we varied articulation while holding lowest luminance constant. Separate groups of 15 observers each viewed 6 different displays: 2, 5, and 30 squares with a reflectance range of 30:1 (white to black) and 2, 5, and 28 squares with a reflectance range of 2.25:1 (white to light gray). Articulation level had a major effect on target lightness while lowest luminance affected target lightness in the 5-square configuration, but not in the 2- or 28/30- square configurations. Our results suggest that the staircase Kardos effect is due to the increasing articulation, not the decreasing lowest luminance, consistent with other evidence of the asymmetry between highest and lowest luminance values in anchoring lightness.

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36.416 Bayesian and neural computations in lightness perception

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The task of computing lightness (i.e., perceived surface reflectance) from the spatial distribution of luminances in the retinal image is an underdetermined problem because the causal effects of reflectance and illumination are confounded in the image. Some recent approaches to lightness computation combine Bayesian priors with empirical estimates of the illuminant to compute reflectance from retinal luminance. Here, I argue for a different sort of Bayesian computation that takes local signed contrast (roughly, "edges") as its input. Sensory edge information is combined with Bayesian priors that instantiate assumptions about the illumination and other rules such as grouping by proximity. The model incorporates a number of mechanisms from the lightness literature, including edge integration, anchoring, illumination frameworks, and contrast gain control. None of these mechanisms is gratuitous—all are required to account for data. I demonstrate how the model works by applying it to the results of lightness matching studies involving simple stimuli. Failures of lightness constancy are quantitatively accounted for by misapplying priors that probably favor lightness constancy in natural environments. Assimilation and contrast occur as byproducts. The rules that adjust the priors must necessarily be applied in a particular order, suggesting an underlying neural computation that first weighs the importance of local edge data according to the observer's assumptions about illumination, then updates these weights on the basis of the spatial organization of the stimulus, then spatially integrates weighted contrasts prior to a final anchoring stage. The order of operations is consistent with the idea that top-down attentional feedback sets the gains of early cortical contrast detectors in visual areas V1 or V2, then higher-level visual circuits having larger receptive fields further adjust these gains in light of the wider spatial image context. The spatial extent of perceptual edge integration suggests that lightness is represented in or beyond area V4.

36.417 **Illusory lightness perception due to signal compression and reconstruction**

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We propose a computational model that can account for a large number of lightness illusions, including the seemingly opposing effects of brightness contrast and assimilation. The underlying mathematics is based on the new theory of compressive sensing, which provides an efficient method for sampling and reconstructing a signal that is sparse or compressible. The model states that at the retina the intensity signal is compressed. This process amounts to a random sampling of locally averaged values. In the cortex the intensity values are reconstructed using as input the compressed signal, and combined with the edges. Reconstruction amounts to solving an underdetermined linear equation system using L1 norm minimization. Assuming that the intensity signal is sparse in the Fourier domain, the reconstructed signal, which is a linear combination of a small number of Fourier components, deviates from the original signal. The reconstruction error is consistent with the perception of many well known lightness illusions, including the contrast and the assimilation effect, the articulated enhanced brightness contrast, the checker shadow illusion, and the grating induction. Considering in addition, the space-variant resolution of the human eye, the model also explains illusory patterns with changes in perceived lightness over large ranges, such as the Cornsweet and related illusions. We conducted experiments with new variations of the White and the Dungeon illusion, whose perception changes with the resolution at which the different parts of the patterns appear on the eye, and found that the model predicted well the perception in these stimuli.

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36.418 **Local computation of brightness on articulated surrounds**

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[Purpose] A brightness difference between two identical gray stimuli on uniform light and dark surrounds becomes larger when the surrounds are replaced by the ones composed of many small patches having different luminances ("articulated" surrounds) while keeping the space-averaged luminance constant. To explore visual mechanisms underlying this articulation effect in view of global vs. local processing, the present study introduced the perception of transparency over the dark surround by manipulating global stimulus configuration alone, and investigated its effects on brightness perception on the surround.

[Methods] Light and dark surrounds were placed side-by-side which were either spatially uniform or articulated. By adding a contiguous region of lower luminance to the dark surround, the perception of transparency (i.e., impression of being covered with a larger dark filter or shadow) was produced under the transparency condition. Under the no-transparency conditions, the perceived transparency was eliminated by separating the dark from the light surround and also by introducing a gap at the border of the dark surround. Local stimulus configuration within the surround was kept constant under different conditions. The space-averaged luminances of the light and dark surrounds were 1.16 and 0.38 log cd/m2, respectively. Observers matched the brightness of the test stimulus (1.06 log cd/m2) on the dark surround by adjusting the luminance of the matching stimulus on the light surround.

[Results and Discussion] With the uniform surrounds, the test stimulus appeared brighter under the transparency condition than under the no-transparency conditions. In contrast, the brightness difference was not found with the articulated surrounds, although the manipulation of global configuration substantially changed the appearance of the stimulus on the dark articulated surround. The articulation effect was consistently found under all conditions. These findings suggest that brightness perception on the present articulated surround was determined almost exclusively depending upon local computation of brightness.

36.419 **Can luminance contrast be estimated with real light?**

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In that numerous studies have shown that humans can match the luminance contrast between edges generated on a CRT monitor, it should be possible to match a crisp luminance edge produced by a spotlight to a luminance edge produced by a reflectance edge in a natural scene. In one experiment we had 40 naïve observers match the luminance contrast of a luminance edge produced by a spotlight to one of 20 reflectance edges. In a second experiment we had the same observers match the lightness of the region lit by the spotlight to one of the same 20 reflectance edges. The luminance ratio produced by the spotlight was 15:1, where its luminance was 22.4 cd/m2, and its area was 9.0° X 4.9° visual angle. The size of each of the 20 reflectance papers was 0.72° X 0.72°. We found, first, large inter-individual variations with the luminance match covering a ~15:1 range, suggesting that observers cannot make an accurate luminance match unlike CRT screen performance. 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 averaged ~ 6.33:1 for both luminance contrast matches and lightness matches. This underestimates the actual luminance contrast produced by the spotlight by 42%. These findings suggest that observers cannot estimate the luminance contrast produced by real objects lit by real light sources. Whether these findings conflict with what has been reported for luminance contrast matches with a CRT screen will be discussed.

36.420 **On the relationship between luminanc increment thresholds and apparent brightness**

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It has long been known that the just noticeable difference (JND) between two stimulus intensities increases proportional to the background intensity - Weber's law. It is less clear, however, whether the JND is a function of the physical or apparent stimulus intensity. In many situations, especially in the laboratory using simple stimuli such as uniform patches or sinusoidal gratings, physical and perceived intensity coincide. Reports that tried to disentangle the two factors yielded inconsistent results (e.g. Heinemann, 1961 Journal of Experimental Psychology 61 389-399; Cornsweet and Teller, 1965 Journal of the Optical Society of America 55(10) 1303-1308; Henning, Millar and Hill, 2000 Journal of the Optical Society of America 17(7) 1147-1159; Hillis and Brainard, 2007 Current Biology 17 1714-1719). A necessary condition for estimating the potential effect of appearance on JNDs is to quantify the difference between physical and apparent intensity in units of physical intensity, because only that will allow to predict the expected JNDs. In the present experiments we utilized a version of the

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Craik-O'Brien-Cornsweet stimulus (Purves, Shimpi and Lotto, 1999 Journal of Neuroscience 19 8542-8551) to study the relationship between JNDs and apparent brightness. We quantitatively assessed apparent brightness using a paired comparison procedure related to maximum-likelihood difference scaling (Maloney and Yang, 2003 Journal of Vision 3(8) 573-585), in which observers compared the perceptual difference between two pairs of surface intensities. Using the exact same stimulus arrangement, that is, two pairs of surfaces, we asked observers to detect a luminance increment in a standard spatial 4-alternative forced-choice (4-AFC) task.

36.421 Feedback does not cleanse brightness judmements of contrast and assimilation effects

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Judgments of the brightness of a test patch are strongly influenced by contrast and assimilation. However, the experiments that document these effects typically do not use feedback. We wondered whether observers might have access to strategies that were cleansed of these effects if they were given trial-by-trial feedback. In this study, observers viewed a 3.33º diameter Test-disk surrounded by an annular ring of what appeared to be homogenous visual noise; their task was to judge whether the luminance of the Test-disk was higher or lower than that of the fixed gray background outside the annulus. Although the annulus looked like a ring of visual noise on each trail, it was actually composed of a random, weighted sum of 11, orthogonal basis images: 5 noise images (which were constrained to contributed 94.8% of the energy in the noisy annulus and 6 concentric annuli which collectively covered the same region as each of the noise basis images and which contributed the remaining 5.2% of the energy). Data were collected for four display durations: 13, 27, 53, and 107ms. In each case, logistic regression was used to determine the influence exerted on the participant's judgments by the 11 basis components. Performance was similar for the four display durations. The innermost annulus exerted a contrast effect: Test-disk contrast judgments were negatively correlated with inner-annulus contrast. However, for four of the five participants, judgments tended to be positively correlated with the contrasts of the outermost two annuli. Plausibly, this latter effect reflects assimilation by the Test-disk of annulus brightness induced by contrast of the outer annular strip with the background. Thus the feedback supplied did not enable observers to escape contrast and assimilation effects.

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36.422 Optic flow strongly affects brightness

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It is well known that brightness/lightness is determined by the pattern of luminance within the target's context. Here we report a new phenomenon demonstrating that brightness is also strongly affected by the motion pattern within the context. We found that the optic flow of dots which is consistent with the dots moving in depth modulates their brightness. The brightness of light dots increases while the brightness of dark dots decreases by 30% when the dots appear to move away to twice the original distance from the viewer. The effect reverses when the dots appear to move nearer. The effect persists for a wide range of dot contrasts, velocities, sizes, densities, and background luminances. We also found that the density of dots modulates their brightness in a similar fashion, but the density effect alone is about 3 times weaker than that produced by the optic flow. To explain the phenomenon we suggest that the brain calculates brightness based on the estimated distance to the dots. When the distance appears to increase while the luminance of the dots remains constant, the brain interprets this as an increase in the dots' luminosity and (partially) displays this increased luminosity as the increased brightness. This interpretation is corroborated by the fact that the size of the dots appears to be modulated in the same fashion as their brightness: the receding dots seem to grow, while the approaching dots seem to shrink.

36.423 The Neural Locus Underlying Perception of the Craik-O'Brien-Cornsweet Effect

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Introduction: The Craik-O'Brien-Cornsweet (COC) effect occurs when two adjacent equiluminant regions differ in brightness because of a light-dark border between them. This effect, described more than half a century ago, still has an unknown neural basis. This study localizes the origin of the COC effect to a binocular neural locus. Methods: Experiment 1) Two luminance profiles, with equal baseline luminances, had a central region shaped like an isosceles triangle. One luminance profile had an incremental central region (luminance profile ---^---); the other profile was similar except the isosceles triangle was a decrement. The two luminance profiles were combined; the separation between the two triangles' centers was varied. At certain separations, superposition of the two profiles produced a COC luminance edge. The increment and decrement profiles were either 1) physically summed and presented to one eye (monocular COC border) or 2) presented to separate eyes, so that the COC border existed only after binocular combination (dichoptic COC border). Observers indicated which side of the stimulus appeared brighter. Experiment 2) Monocular and dichoptic COC borders were presented at different contrasts, and observers matched the brightnesses on each side of the COC border. Experiment 3) A monocular COC border was presented to one eye and a grating or moving dots were presented to the other eye so the COC border was suppressed due to binocular rivalry. Observers indicated which side of the stimulus appeared brighter. Results & Conclusion: The COC effect occurred for both monocular and dichoptic borders with brightness matches virtually identical in both cases. The COC effect was absent when the border was suppressed by binocular rivalry. Therefore, a monocular COC border is neither necessary nor sufficient for the COC effect. This implies a binocular neural locus after binocular rivalry is resolved.

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36.424 Filling-in versus multiscale filtering: Measuring the speed and magnitude of brightness induction as a function of distance from an inducing edge

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Early investigations of the temporal properties of brightness induction using brightness matching found that induction was a sluggish process with temporal frequency cutoffs of 2-5 Hz (DeValois et al., 1986; Rossi & Paradiso, 1996). This led Rossi and Paradiso (1996) to propose that a relatively slow "filling-in" process was responsible for induced brightness. In contrast, Blakeslee and McCourt (2008), using a quadrature-phase motion technique, found that real and induced gratings showed similar temporal characteristics across wide variations in test field height and demonstrated that induction was observable at frequencies up to 25 Hz. Here we compare predictions of filling-in versus multiscale filtering mechanisms with data disclosing the phase (time) lag and magnitude of brightness induction as a function of distance from the test/inducing field edge. Narrow probe versions of the original quadrature-phase motion technique (Blakeslee & McCourt, 2008) and a quadrature-phase motion cancellation technique are used to measure the phase (time) lag and magnitude of induction, respectively. Both experiments employ a 0.0625 c/d sinusoidal inducing grating counterphasing at a temporal frequency of 4 Hz and a test field height of 3o. A 0.25o quadrature probe grating is added to the test field at seven locations relative to the test/inducing field edge. The psychophysical task in both experiments is a forced-choice "left" versus "right" motion judgment of the induced plus quad probe compound in the test field. The results show that the phase (time) lag of induction does not vary with distance from the test/inducing field edge, however, the magnitude of induction decreases with increasing distance. These results are inconsistent with an edge-dependent filling-in process of the type proposed by Rossi and Paradiso (1996) but are consistent with multiscale filtering by a finite set of filters such as that proposed by Blakeslee and McCourt (2008).

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36.425 Perception Begets Reality: A "Contrast-Contrast" Koffka Effect

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Eighty years ago Koffka described a fascinating effect: When a contiguous gray ring is placed on a background half of one shade of gray (different from the ring) and half of another shade of gray,the ring appears to be homogeneous. However, if the ring is slightly divided, the two halves of the ring appear different shades of gray with the half of the ring on the darker background appearing lighter than the half of the ring on the lighter background. The Gestalt principle of continuity is invoked to explain this effect with the geometric continuity when the half rings are joined leading to the perception of a homogeneity of shade/color of the ring. In studying this effect we have found a "contrast-contrast" Koffka effect: Single, identical small gray square checks are placed on each of two identical gray half-rings. The half-rings are then placed on a white/light background and a dark/black background, respectively. Both the check on the half-ring on the white background, and the half-ring on the white background appear darker than the check and half-ring, respectively, on the black background--a standard contrast effect. We then join the half rings. The ring now appears homogeneous--Koffka's effect. What about the two checks? They still appear somewhat different with the check on the side of the white background appearing darker. But the difference in the appearance of the checks is less pronounced than when the half-rings were separated! The change in the perception of the half-rings by the Koffka effect has begot a change in the appearance of the checks! We find this a particularly clear demonstration of how perception can influence perception indeed "reality", with different a perception of the ring begetting a new reality of the perception of the checks.

36.426 **Response priming driven by local contrast, not subjective brightness**

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We demonstrate qualitative dissociations of brightness processing in visuomotor priming and conscious vision. Speeded keypress responses to the brighter of two luminance targets were performed in the presence of preceding dark and bright primes (clearly visible and flanking the targets) whose apparent brightness was enhanced or attenuated by a visual illusion. Response times to the targets were greatly affected by consistent vs. inconsistent arrangements of the primes relative to the targets (response priming). Priming effects could systematically contradict subjective brightness matches, such that one prime could appear brighter than the other but prime as if it was darker. Systematic variation of the illusion showed that response priming effects only depended on local flanker-background contrast, not on the subjective brightness of the flankers. Our findings suggest that speeded motor responses, as opposed to conscious perceptual judgments, access an early phase of lightness processing prior to full lightness constancy.

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36.427 **The effect of contrast intensity and polarity in achromatic watercolor effect**

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The watercolor effect (WCE) is a filling-in phenomenon on a surface surrounded by two thin abutting lines with the chromaticity of the interior line. We developed a series of achromatic WCE stimuli and a method to quantitatively compare the lightness of the filling-in region surrounded by lines of various luminances. We define the interior line as "the inducer", the luminance of which is fixed, while the exterior line "the suppressor", the luminance of which varies across different stimuli. The results of a psychophysical experiment for seven subjects (five naive) show that the achromatic WCE exists. Moreover, we found that suppressors with both high and low luminance can induce the WCE with an inducer with a moderate luminance as long as the contrast difference between the inducer and the suppressor passes a certain threshold. All the subjects show a single peak of the effect strength, which is never at the extreme contrast difference, though there are individual differences in the location of the peak. That is, the effect is never the strongest when the suppressor is black or white. Most subjects show an inverted-U curve for suppressors with both higher and lower contrast than the inducer. For most subjects, the suppressor with an opposite contrast polarity to that of the inducer, generates a stronger effect than the suppressor with the same contrast polarity as that of the inducer. These results suggest that the contrast difference affects the existence and the strength of the WCE, but not in a linear way. Moreover, as in the Craik-O'Brien Cornsweet Effect, besides the contrast intensity, the contrast polarity also plays a role in the WCE.

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36.428 **Response classification analysis of the maintenance of contrast for an object**

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Previously Shimozaki, Thomas and Eckstein (1999, JEP:HPP) found that an object's contrast is affected by its previous contrast. In that study observers perceived two moving squares across two intervals through apparent motion. Observers were told to judge the contrast of one square only in the second interval; despite this instruction, contrast changes in the target square from the first to the second interval led to worse performance. This study assessed the spatio-temporal dynamics of this effect through response classification. Three observers performed a yes/no contrast discrimination of 1°uniform central squares (30% signal contrast) presented for 90.9ms (2 frames, 45.4ms/frame) on pedestals varied for each observer for near-threshold performance (15-25%). A non-judged interval of 318.2ms (7 frames, 45.4ms/frame) preceded the judged interval, with two 1° squares (1° apart) in the upper left and right with abutting corners to the target square. Another square (1°) in the second interval (1° to the right or left of the target) led to apparent motion of two squares, either left or right. The contrasts of all squares were randomized (either the pedestal or signal contrast), as well as direction of motion (left or right). For response classification, stimuli were presented in Gaussian-distributed image noise, independently sampled for each frame. The behavioral results replicated the previous study; despite instructions to judge only the second interval, performance was significantly worse when the target contrast changed from the first to second interval (change in d': 0.788 to 0.991). The classification movies during the second (judged) interval found that the target contrast in the second interval affected the judgments, as expected, with the second frame having a larger effect. The classification movies during the first (non-judged) interval found that the effects of the target square were distributed throughout the 7 frames (318.2ms), and began with the second frame at 45ms.

36.429 **Snake illusion, edge classification, and edge curvature**

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The snake illusion is a lightness effect in which identical gray targets embedded in complex displays may look either strongly different ('snake') or very similar ('anti-snake'), depending on the luminance of some non-adjacent patches. It has been suggested (Logvinenko et al., Perception & Psychophysics, 2005, 67, 120-128) that this effect is based on the classification of luminance edges as either reflectance or illumination edges (which also involve a sense of transparency or shadow), and the tendency of the visual system to interpret edges as the former rather than the latter if they are curved rather than straight. To examine these notions, we used five pairs of snake/anti-snake displays (created by switching the luminance levels of certain portions of displays), each containing six targets (a high luminance, a medium luminance, and a low luminance pair). The displays were presented on a calibrated monitor placed in a dark void. Each of our nine naïve observers participated in four individual sessions. They performed lightness matches by adjusting the luminance of comparison patches on the screen. We replicated the basic effect with a snake/anti-snake stimulus pair slightly modified from original, which contained straight luminance edges and a sense of shadow or transparency. However, we obtained an effect of the same strength with a variant display which retained much the same structure as the first, including straight edges, but involved inverted transparency conditions. For displays involving curved or jagged edges we found that the strength of the effect was clearly diminished. Our results confirm previous findings that the shape of luminance edges may affect the strength of this class of illusions, but argue against theories based on edge classification and transparency/shadow perception. We also found that the illusion was strongest for medium luminance targets, weaker for high luminance targets, and weakest for low luminance targets.

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36.430 Impairment of Magnocellular and Parvocellular Visual Processing in Normal Aging: Rehabilitation by Yellow Filters or Placebo Effect?

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The study aimed at evaluating the psychophysical correlates of the magnocellular and parvocellular visual pathways, their evolution and rehabilitation with normal aging. Thirteen young (24.2) and 36 old (71.4) participants were shown with a short version of the psychophysical paradigm (Pokorny and Smith, 1997, JOSA), to bias processing toward magnocellular or parvocellular processing. Observers had to discriminate the location of the higher luminance square within a 33-msec four-square-array. In the steady-pedestal condition (magnocellular-bias), the array was preceded and followed by a four identical squares pedestal whereas, in the pulse pedestal condition (parvocellular-bias), the array was presented alone on a gray background. There were three filters: a control (no filter), a placebo (neutral filters), and an experimental condition (yellow filters, CPF 450). Three target luminance discrimination thresholds were collected for each of the 18 experimental conditions (order counterbalanced): pedestal-contrast (63%; 70%; 75%) x pedestal-condition (pulse and steady) x filters (no filter, neutral, yellow) using an adaptive staircase procedure. The results showed a higher increase of threshold with pedestal contrast in the pulse-pedestal relative to the steady-pedestal condition. A double interaction between group, pedestal contrast and pedestal-condition was observed: the increased discrimination threshold found for old relative to young participants was stronger in the pulse-pedestal than in the steady-pedestal condition, especially for high pedestal contrasts. Moreover, there was no significant main effect of filter and no interaction between filter and the other variables. However, specifically in the steady-pedestal condition and for old group, planned comparisons showed a significant decrease in threshold for neutral or for yellow filters relative to no filter condition, whatever the pedestal contrast. These results replicate the dissociation between the two low-level visual systems in young group and demonstrate a magnocellular and huge parvocellular impairment with normal aging. The yellow filters were inefficient but a placebo effect was found

36.431 Macular Pigment Reduces Visual discomfort

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Purpose: To determine the effect of macular pigment (MP) on the threshold of visual discomfort in young subjects Methods: A Maxwellian-view optical system was used. Six young (<35 yrs.), normal subjects with a wide range of MP densities (0.10-0.71 at 30′ eccentricity) viewed monochromatic disks of light centrally, and parafoveally (7^{o} temporal retina). The psychophysical method of ascending limits was employed to determine discomfort thresholds at each wavelength. After extensive training, subjects were instructed to determine the point at which the intensity of the stimulus produced discomfort sufficient to make it difficult to view the light without an aversive response (e.g., squinting or averting the eyes). Discomfort thresholds were also obtained for xenon-white light (partially absorbed by MP), and a broadband yellow (outside the absorption band of MP). Spatial profiles of MP were measured psychophysically using heterochromatic flicker photometry (HFP). Individual lens densities were determined by subtracting subjects' scotopic sensitivity to lights of 410, 440, and 560 nm from the corresponding rhodopsin extinction coefficients. Results: For the central viewing condition, MP significantly reduced visual discomfort thresholds for short wavelengths (440-500 nm), compared to the parafoveal viewing condition. This reduction was commensurate with a subject's MP level. For the parafovea, a monotonic increase in discomfort sensitivity (1 / threshold) with decreasing wavelength was found for all subjects. In a linear fashion, subjects with higher MP levels were shown to tolerate more xenon-white relative to broadband yellow before reaching discomfort threshold. Conclusions: Short-wave lights produced the greatest visual discomfort, and centrally-viewed light was roughly twice as uncomfortable as light imaged on the parafovea. MP strongly attenuates visual discomfort. The spectral absorption and spatial distribution of MP increase the range of comfortable visual operation for the central retina, thereby facilitating visual performance as well as reducing risk of light damage.

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Attention: Capture

Orchid Ballroom, Boards 432–450

Sunday, May 9, 2:45 - 6:45 pm

36.432 Orientation-specific control of attention

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Many studies have shown that an irrelevant distractor matched to a target-defining color captures attention involuntarily, thus violating either temporal or spatial control of attention. However, whether an irrelevant orientation-matched distractor can capture attention is still unknown. We used a variant of a spatial blink task to examine whether an irrelevant distractor possessing the sought-for target orientation can capture attention. The general method is illustrated in figure 1. Participants were presented with a sequence of letters at fixation, each of which was contained within a gray bar and oriented at the same angle as the gray bar. One-half of the participants were asked to identify the sole target letter in the letter sequence oriented 45˚ clockwise from vertical. The other half of the participants searched for a letter oriented 45˚ counterclockwise from vertical. Six peripheral bars flanked the central letters either shortly before or after the appearance of the target letter. We found that six white vertical bars in the periphery did not impair target performance compared to no peripheral bars at all. However, a peripheral orientation singleton that matched the target orientation captured attention and severely impaired central target identification. More surprisingly, a peripheral orientation singleton that was perpendicular to the target orientation also captured attention and produced a similar impairment in performance as the orientation-matched distractor. And this effect was not due to stimulus-driven saliency of the orientation singleton because a horizontal singleton did not capture attention in this task. The results indicate that orientation-based modulation of attention is not as perfectly selective as color-based selection. Orientations that match the target or are perpendicular to it are both able to capture attention. Our results also are consistent with recent findings showing that a proportion of V2 and V3 neurons in monkeys have bimodal orientation tuning curves with two peaks 90˚ apart.

36.433 Biological Motion Captures Attention

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Across our evolutionary history, detecting potential prey and predators has been a critical aspect of survival. Among the consequences of this evolutionary past, stimuli that resemble animals are preferentially processed; for example, modern humans initiate saccades to, and detect changes more quickly in, pictures of animals over non-animate objects. Animacy is, however, defined by more than just the canonical shapes or forms of animals. Certain types of motion (i.e., biological motion) also signify animacy, and the human visual system may be predisposed to process these types of motion. For example, we can extract surprising amounts of information about walking from just a few points of light. If biological motion is as salient an indicator of animacy as shape or form, can biological motion capture attention? To answer this question, we compared the time to detect targets in objects that were either moving predictably due to collisions with other objects (nonbiological motion) or moving unpredictably with no such collisions (biological motion). All of the experiments used four geometric objects that moved through the display, bouncing into each other or rebounding off the frame in a predictable manner until one object exhibited biological motion. The first two experiments showed that detecting (Exp1a) and identifying (Exp1b) targets were faster in objects exhibiting biological motion. Because previous research has demonstrated that observers rate objects as more animate with greater changes in direction or speed, the basic procedure of the previous experiments was used with the biological motion having three different angles of direction change (Exp2a) or three different

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changes in speed (Exp2b). Observers again detected targets more quickly in objects that exhibited biological motion, and response times decreased with greater changes in direction or speed. Thus, biological motion, in and of itself, appears to be capable of capturing attention.

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36.434 **The effect of motion onset and motion quality on attentional capture in visual search**

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Abrams and Christ (2003, Psychological Science, Christ & Abrams, 2008, Journal of Vision) reported that new motion in a scene (motion onset) captures attention in a bottom-up fashion. This is contradictory to findings by von Muhlenen et al. (2005, Psychological Science), who reported no capture for motion onset, unless the onset represents a temporally unique event. Methodological differences between the two studies make a direct comparison difficult. For example, von Muhlenen et al. looked at slope reductions in the search function to measure the effect of attentional capture, whereas Abrams and Christ looked at simple reductions in Reaction Time (RT). The aim of Experiment 1 was to further explore these differences by employing the same method and design used by Abrams and Christ. However, the result of twelve participants show no RT reduction for motion-onset targets in comparison to static targets, which supports von Muhlenen et al. findings. Another difference between the two studies concerns the quality of motion: von Muhlenen et al. used relatively smooth motion (updating the moving stimulus at 60 Hertz), whereas Abrams and Christ used relatively jerky motion (updating the moving stimulus at 15 Hertz). Experiment 2 addressed this difference by systematically varying motion quality across trials from 100, 33, 17, to 8 Hertz. The results show that motion quality plays a crucial role: motion-onset stimuli only capture attention when motion is jerky (8 and 17 Hertz), not when it is smooth (33 and 100 Hertz), thus, replicating the findings of both studies. Finally, Experiment 3 shows that simple flicker without motion (100, 33, 17, or 8 Hertz) has not the same effect on attention. We conclude that it is the motion onset in conjunction with the continuous stream of transient signals produced by jerky motion that captures attention.

36.435 **Interaction between stimulus-driven orienting and top-down modulation in attentional capture**

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The issue whether attentional capture is determined by top-down factors or it can be purely stimulus-driven remains unsolved. Proponents of the contingent capture hypothesis argue that only the distractor that matches the target characteristics can capture attention, whereas those of the stimulus-driven capture hypothesis argue that attentional capture occurs regardless of distracter-target contingency. We aimed at solving this discrepancy by finding boundary conditions of the two contrast hypotheses and further proposed an interactive model to explain the results. We used a spatial cueing paradigm, in which a color target was followed by an uninformative cue that either matched (a color cue) or did not match (an onset cue) the target to test whether and how the cue captures attention. We added a no-cue condition beforehand to make the very first with-cue trial unexpected to the participants, and analyzed the response to the first with-cue trial to contrast it with the average data. Results showed that the onset cue captured attention to its location when it appeared unexpectedly, but this effect disappeared over repeated trials. In contrast, the color cue did not capture attention when it appeared unexpectedly but did so over repeated trials. We thus demonstrate that, on one hand, the contingent capture hypothesis is supported under the condition that when the same cue is presented repeatedly, top-down modulation determinates the capture effect. On the other hand, the stimulus-driven hypothesis holds true under the condition that when the cue is presented for the first time, the onset cue captures attention even when it does not match with the target defining feature. The proposed interactive model in which stimulus-driven orienting exists at early time course but is later modulated by top-down controls can adequately explain the results by distinguishing attentional capture through stimulus-driven orienting from that through top-down modulation.

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36.436 **Overt and covert capture of attention by magnocellular and parvocellular singletons**

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The generation of rapid saccades has been tied to magnocellular processing, due to direct M-pathway inputs to the superior colliculus as well as the predominance of magnocellular information in the dorsal stream. However, attention can also be guided by information encoded in the slower, but detail-rich, parvocellular processing stream. Although it is clear that input from both pathways can influence behavior, less is known about how salient task-irrelevant stimuli encoded by these two systems may influence covert and overt attentional processing. We used manual RT and oculomotor activity to reveal differences in interference caused by a singleton that predominantly activates the magnocellular system and one that isolates the parvocellular system. Participants performed the irrelevant singleton task (Theeuwes, 1991), searching for a unique shape while attempting to ignore an irrelevant but highly salient singleton distractor. For a third of the trials, the singleton distractor was an isoluminant object of a different color (parvo-singleton); for another third, the singleton distractor differed in luminance from the other objects (magno-singleton); for the remaining third, no singleton distractor was present. We matched the salience of the two singleton distractor types such that there was an equivalent attentional capture effect on manual RT. Despite the equivalent manual RT effects, the magno-singleton distractor was more likely to attract an eye movement than the parvo-singleton distractor. When the first eye movement did go directly to the target, its latency was slowed in the presence of both magno- and parvo- singletons, indicating covert attentional competition. These results provide a more precise understanding of how underlying competitive attentional processes and intermediary saccadic behavior result in the explicit distraction effect found in manual RT.

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36.437 **Attentional capture by objecthood is unaffected by salience in other dimensions**

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Recently, Kimchi and colleagues (Kimchi, Yeshurun, & Cohen-Savransky, PB&R, 2007; Kimchi, Yeshurun, & Sha'shoua, Psychonomics, 2009) presented data demonstrating automatic visuospatial attentional capture by perceptually organized "objects" when a display of nine uniform-sized rotated Ls contained four items arranged to form the corners of a diamond. Specifically, subjects were faster to respond to a cue presented inside the object than they were to respond to a cue presented elsewhere in the display; response times were intermediate when the display elements did not form an object. However, when the display contained an object, the object enclosed a quarter of the display, making it a size singleton. Previous experiments have shown that a size singleton can involuntarily capture attention. By varying the size of the non-object-defining elements in the display, we demonstrate that the status of the object as a size singleton cannot account for the attentional capture found by Kimchi and colleagues. When we made three of the display elements larger than the remaining elements, response times were slowed equally across all object conditions (cue in object, cue outside object, no object), yielding a main effect of size variation. Additionally, we replicated the effect found by Kimchi and colleagues in which the perceptually organized "object" captured attention. Critically, these two effects did not interact—the presence of additional large elements had no effect on attentional capture by the perceptual object. In further experiments, we explore the role of shape in determining attentional capture. Our results suggest elements arranged to form an object do capture attention, even when there is no incentive to allocate attention to the object compared to other parts of the display.

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36.438 **Contingent attentional capture influences performance not only by depleting limited target processing resources, but also by changing attentional control settings**

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In some theories of visual search, detecting a potential target leads to a brief attentional enhancement of that item's representation in working memory, which likely includes information about the top-down attentional set that defines the item as a target. Given that the contents of working memory often guide attentional systems, we investigated whether such enhancements temporarily facilitate the selection of subsequent stimuli whose features match the same attentional set. Data from six experiments, in which multiple attentional sets for color guided target selection in a central RSVP stream, supported this hypothesis. In Experiment 1, a target-colored peripheral distractor produced 68% less capture when its color matched the same attentional set as that of an immediately upcoming target than when its color matched a different attentional set. In Experiment 2, we ruled out bottom-up perceptual priming of the target's color as an alternative account of this enhancement effect. In Experiment 3, the enhancement effect was reversed when a target-colored distractor was presented after (versus before) a target, thereby revealing that a distractor is most disruptive when its color matches a currently-enhanced attentional set. In Experiments 4 and 5, a target-colored central distractor not only facilitated the selection of an upcoming target whose color matched the same attentional set, but also prevented an intervening target-colored peripheral distractor from capturing attention, consistent with models in which only a single working memory representation can be enhanced at any given time. In Experiment 6, the enhancement effect was shown to depend critically on conscious perception of the leading target-colored item, which likely indexed whether that item's representation had been enhanced in working memory. Together, these findings indicate that contingent attentional capture influences performance not only by depleting limited target processing resources, but also by changing attentional control settings.

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36.439 **Attention capture by an invisible flicker not in the middle of gamma range**

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It was recently reported that a subliminalflicker could trigger attentional selection at the target location (Bauer et al, PNAS 2009). They specifically attributed this effect to the middle of gamma range (50Hz) since they failed to find such effect with flickers slower than 35-Hz. However, it is possible that rendering a flicker signal subliminal by lowering its contrast resulted in more severe loss of effective neural contrast for a 30 Hz flicker than a 50 Hz flicker. To test this possibility, we used flicker contrast reduction combined with spatial crowding to render a flicker signal subliminal. This approach allowed a subliminal flicker to maintain substantial contrast. Specifically, a 30 Hz flicker Gabor patch and a non-flickering control were presented one to the left and one to the right of the fixation, both surrounded by four static Gabor patches. Subjects performed at chance level in 2AFC task detecting which side had the flickering signal. However, in a modified Posner cueing paradigm, subjects responded faster to a probe target presented at the 30 Hz subliminal flicker location than the control location. In a follow-up experiment, when the probe target appeared at the non-flickering control location in 80% of the trials and subjects were instructed to use this information to direct their attention, the side with the subliminal flicker still showed a benefit effect. Together these results show that a subliminal flicker can capture spatial attention and the flicker frequency does not need to be in the middle of the gamma range.

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36.440 **Relative Contributions of SPL and TPJ to Object-based Attentional Capture**

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The contribution of object based representations to attentional guidance has been focused almost exclusively within the framework of top-down attentional control, and little is known regarding its contribution to bottom-up, or stimulus driven, attentional control. In our recent behavioral investigation, we demonstrated that attentional capture is in fact object-based, and that the extent to which objects guide attentional capture is modulated by the involvement of top-down attentional orienting. In the present set of two fMRI experiments, we investigated the neural mechanism of object-based attentional capture, namely the involvement of SPL and TPJ in contingent capture (with top-down involvement) and pure capture (bottom-up involvement). Participants viewed a central rapid serial visual presentation (RSVP) stream in which a target letter was either defined by a specific color (Experiment 1, contingent capture) or could be one of four random colors (Experiment 2, singleton capture). The RSVP stream was superimposed onto a set of three objects (a cross like configuration). On critical trials, a task-irrelevant color singleton and three neutral distractors appeared in the periphery. On half of the trials the colored singleton appeared on the same object as the central target, and on the different object on the other half. We observed capture related activations in the SPL/precuneus and TPJ regions for the contingent capture, and TPJ activation exclusively for the singleton capture. Additionally, these capture related activations were modulated by whether the singleton appeared on the same- or different object (i.e, object-based effect). Furthermore, with the use of retinotopic mapping, the effects of such object-related attentional capture were examined in the early visual cortex. These results suggest that object-based representations guide bottom-up as well as top-down attentional orienting, as well as provide further constraints on the mechanisms of attentional guidance and of object-based selection.

36.441 **Covert attention can be captured by an illusory Focus of Expansion**

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Purpose: Covert attention can be captured by sudden stimulus onsets and other salient events. It has recently been shown that the focus of expansion (FOE) of a radial flowfield can also capture covert attention (Fukuchi et al., 2009). We were wondering whether an illusory FOE displaced by a linear flowfield (optic flow illusion; Duffy & Wurtz, 1993) could also capture attention. Methods: We measured the illusory FOE displacement with a 2AFC method, and then presented targets at the actual and illusory FOE and at corresponding locations in the other hemifield, with and without the presence of the linear flowfield. This was done for each observer according to the individual illusion strength. We measured the detection response times for targets appearing with different SOAs between flowfield and target, including 20% of catch trials. Results: A majority of participants showed a pattern of responses that suggested that the illusory FOE had captured attention. Some observers showed a different pattern indicating that the actual FOE had continued to capture attention, even in conditions where they had experienced the illusion. The effectiveness of the illusory FOE for capturing attention was not related to the size of the perceived illusion. Conclusion: Covert attention can be captured by both actual and illusory FOEs. This implies that smooth pursuit eye movements or whole world motions can take part in capturing attention. Thus covert attention can exert its effects at different levels. Fukuchi M. et al. (2009). Journal of Vision, 9(8), 137a; Duffy C. & Wurtz R. (1993). Vision Research, 33(11), 1481.

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36.442 **The interaction between memorized objects and abrupt onsets in oculomotor capture: New insights in the architecture of oculomotor programming**

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Recent evidence has been found for a top-down source of task-irrelevant oculomotor capture, in which an event draws the eyes away from a primary task. In these cases, an object memorized for a non-search task can capture the eyes when it appears during search (Sato, Heinke, Humphreys & Blanco, 2005; Olivers, Meijer & Theeuwes, 2006). Here, an experiment was conducted to investigate the interaction between memory-driven capture, goal-driven search, and capture by abrupt onsets. The use of eye tracking allowed us to determine the rate of capture by the different types of stimuli and explore the temporal dynamics of the various signals driving oculomotor guidance. This is important because we were able to distinguish between potential sources of capture and build a theoretical model of how visual working memory, top-down goals, and abrupt onsets can drive oculomotor orienting.

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The results of our experiments show that memorized objects capture the eyes at a higher rate than abrupt onsets when they are both present in the search display and in competition for the initial saccade. Additionally, when the abrupt onset and memorized color are the same object, this combination leads to even greater oculomotor capture away from the target. However, the degree of capture is less than additive, suggesting these are two independent sources of guidance signals. More importantly, saccade latencies differed between the three potential saccade targets, with saccades to the search target yielding the longest latencies, and saccades to memorized color singletons yielding latencies that were shorter than saccades to abrupt onsets. Results will be discussed in terms of a neural-computational model.

36.443 **Attention to faces: Effects of face inversion**

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Goal-directed behavior requires focusing on important target stimuli and the prevention of attention to irrelevant distracters. According to the load theory of attention (Lavie, 1995, 2000), a factor that modulates whether distracters are attended to is the perceptual load of the relevant task. Following the theory, perception of distracters can be prevented when perceptual load is high. Lavie, Ro, and Russell (2003) showed that face distracters are an exception as they attract attention and are hard to ignore even under high load. Further research suggests that a face advantage may be linked to the upright presentation of faces, however, there is conflicting evidence regarding the role of the orientation of a face and a potential face advantage. We thus investigated the link between face orientation, perceptual load and attention in three experiments using a sex classification task. Experiment 1 tested whether upright and inverted distracter faces attract attention reflexively under low and under high perceptual load conditions to a comparable degree in a flanker paradigm and showed that upright but not inverted faces attracted attention, suggesting that inverted faces were easier to ignore. Experiment 2 proved that inverted distracter faces can lead to congruency effects though, provided that attention is directed volitionally to the peripheral distracters. Experiment 3 showed, using a cuing paradigm, that although participants are slower to discriminate inverted faces, the allocation of attention facilitates face processing and sex discrimination for upright and inverted faces to a similar extent. Our findings suggest a link between mechanisms of face processing and their attention capturing power.

36.444 **Hitting the brakes: Is attention capture reduced with slower responding?**

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How do people resist distraction by salient, irrelevant stimuli? By one account, resistance to distraction carries a concomitant slowing in overall RT, suggesting that observers delay visual processing to avoid distraction. By a competing account, distraction is best avoided during periods of high arousal, when overall RT is fastest. These accounts have been tested via analysis of cumulative RT distributions, in which distraction is measured as a function of overall RT. Unfortunately, the results of such analyses have lacked consensus. Here, we offer a resolution of the conflicting results by first highlighting a critical weakness of the cumulative RT analysis and then correcting for it. Specifically, while RT on a given trial should reflect the observer's control state, incidental stimulus aspects can also influence RT. For instance, if the distractor appears in the same location on consecutive trials, RT will be faster while interference will be smaller (Kumada & Humpreys, 2001). Effects like this distort the RT distributions in a way that is unrelated to the observer's internal control state. To address such confounds, we performed multiple regression to partial out RT variance attributable to an exhaustive array of incidental stimulus aspects, thus generating "corrected" RT distributions. We then carried out the cumulative RT analysis on both the uncorrected and corrected RT distributions. For the uncorrected data, distraction was smallest at the fastest RTs and gradually increased as RT slowed. However, the corrected data revealed a dramatic reversal, in which distraction was greatest at the fastest RTs. These results offer a parsimonious resolution to the debate on how distraction is avoided. In particular, the results support the "slowing" account and argue against the "high arousal" account.

36.445 **Commonality between attentional capture and attentional blink**

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Visual search for a unique target is impaired when a task-irrelevant salient distractor is simultaneously present. This phenomenon, known as attentional capture, is said to occur because attention is diverted to a distractor in a stimulus-driven way before it reaches the target (Theeuwes, 1992). However, another view holds that attention could be directed selectively to a task-relevant feature under an appropriate attentional set (Folk et al., 2002). Recently, Ghorashi et al. (2003) suggested that temporal attentional capture (Folk et al., 2002) represents virtually the same impairment as that observed in the attentional blink. The question is whether these phenomena emerge from a common underlying attentional mechanism. The present study examined this question using correlation studies. If these phenomena share a common foundation, the magnitude of these deficits should show within-subject correlations. In Experiment 1, 135 participants performed three tasks in a counter-balanced order. The tasks for spatial and temporal capture and the attentional blink were identical to those used by Theeuwes (1992), Folk et al. (2002) and Chun and Potter (1995), respectively. A significant attentional deficit was observed in each task. However, no significant correlation was found across these tasks, suggesting that these deficits reflect different aspects of selective attention. In Experiment 2 (N=95), identical results were obtained using the same procedure as that in Experiment 1 except that another attentional blink task, requiring spatial switching between the two targets, was included. Strong correlations emerged only between the two attentional blink tasks (with/without spatial switch). The present results suggest that the attentional capture revealed by the two types of procedures (Theeuwes' and Folk's) reflects different aspects of attention. The results also indicate that the similarity between attentional capture and attentional blink is superficial.

36.446 **Advance Knowledge of Potential Distractors Influences Competition between Color Salience and Perceptual Load**

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Visual salience and perceptual load may both influence the efficiency of visual selection. Previous evidence reported by Gibson and Bryant (2008) suggested that high perceptual load can dominate color salience in a distractor interference paradigm where observers attempted to ignore a salient color singleton under different levels of perceptual load. More recently, Biggs and Gibson (in press) extended this research by investigating whether full vs. no knowledge of the color singleton and/or full vs. no knowledge of perceptual load would modulate the relative operation of these two mechanisms. Consistent with previous findings, Biggs and Gibson found that high perceptual load dominated color salience. However, this result only occurred when advance knowledge of load was not available, and high-load displays were preceded by other high-load displays. More importantly, Biggs and Gibson also found that color salience dominated high perceptual load in other contexts where participants were provided full knowledge of color conditions and display load. This latter finding was unexpected because distractor interference increased as the amount of knowledge provided to the observer increased. The present experiments were designed to further investigate how different forms of knowledge may influence this paradigm; namely, full vs. no knowledge of distractor presence. In the full knowledge condition, the presence or absence of the distractor was fixed within blocks; whereas, in the no knowledge condition, the presence or absence of the distractor was mixed. The results of three experiments suggested that color salience dominated high perceptual load when the observer was able to incorporate this knowledge into a search strategy. Altogether, these findings suggest that the competition between color salience and perceptual load can vary based upon the knowledge provided to the observer and how they choose to integrate that knowledge into search. Implications for theories of top-down control will be discussed.

36.447 **Non-contingent attention capture by an onset**

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This set of experiments revisits the issue whether all involuntary orienting is contingent on top-down goals. Specifically, the question was whether an abrupt onset captures attention in a non-contingent fashion. A variation of the Folk, Remington, and Johnston (1992) spatial pre-cueing paradigm was used. Observers searched a letter array for one of two target letters. Attention capture was assessed by the difference in reaction times to valid and invalid trials (target location correctly and incorrectly cued, respectively). To rule out the contingency explanation, one needs to ensure that (a) all features associated with the target, and (b) all visual features accompanying the search array's appearance, are excluded from the putative capture stimulus. We first established that when target location was color-defined, a color cue captured attention. But crucially, an onset cue also captured attention. In separate experiments, we ruled out explanations that (a) were based on the contingency between the onset cue and the transients accompanying the search array; (b) claimed that observers adopted a singleton-search strategy rather than monitoring specifically for the target-defining feature; and (c) assume that observers were monitoring motion, rather than specifically onset, transients. We showed that an onset captured attention even when the search array was not presented as an abrupt onset. We also showed that a color singleton failed to capture attention when the target's appearance may be construed as a singleton, suggesting that singleton-detection could not have been the observers' strategy. Finally, we showed that offset transients failed to capture attention when the target could be localized as a color singleton, implying that observers were not detecting transients per se. The evidence across the experiments support the view that an onset captures attention automatically, even though the top-down control settings may not be tuned specifically to monitoring onset transients.

Acknowledgement: NUS Grant R-581-000-078-750

36.448 **Attentional capture by masked colour stimuli**

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Computational theories of stimulus-driven capture of attention calculate a colour contrast's potential to attract attention as an objective local colour difference within the image. Is that allowed? We tested whether subjective or phenomenal salience of colour contrasts could be a crucial prerequisite for stimulus-driven attentional capture by colour contrasts: Colour singletons were metacontrast masked and, thus, invisible. Under these conditions, colour singletons failed to capture attention in a stimulus-driven way. This was reflected in behavioural responses as well as in attention-related event-related potentials (ERPs). In addition, diverse control conditions corroborated the attention-grabbing power of colour singletons, ruling out that the method was insenstive to the detection of attentional capture by masked colour singletons.

Acknowledgement: German Research Council

36.449 **Invisible causal capture in the tunnel effect**

Gi Yeul Bae[1](freebird71@gmail.com), Jonathan Flombaum[1]; [1]Johns Hopkins University, Department of Psychological and Brain Sciences

Beyond identifying individual objects in the world, the visual system must also characterize the relationships between objects, for instance when objects occlude one another, or when they cause one another to move. Here we explored the relationship between perceived causality and occlusion. Can causality be perceived behind an occluder? Participants watched a series of events and simply had to judge whether a centrally presented event involved a single object passing behind an occluder, or one object causally launching another. With no additional context, the centrally presented event was always judged as a pass, even when the occluded and disoccluding objects were different colors —an illusion known as the 'tunnel effect' that results from spatiotemporal continuity. However, when a nearby context event involved an unambiguous causal launch synchronized with the occlusion event, participants perceived a causal launch behind the occluder. In other words, participants experienced invisible causal capture, perceiving a casual relationship in an occluded location. Crucially, when the context event involved two distinct objects, but no causal relationship between them, no casual launch was perceived behind the occluder. Thus invisible causal capture did not depend merely on the suggestion that two objects might exist behind the occluder, but instead on the causal nature of the context. Perhaps most surprisingly, invisible causal capture was perceived even when the two disks in the central occlusion event shared the same color. Thus spatiotemporal synchrony trumped featural similarity in the interpretation of the hidden event. Related context events illustrate that invisible causal capture depends upon grouping by common motion. Taken together, these results emphasize the inherent ambiguity that the visual system faces while inferring the relationships between objects.

36.450 **The anatomy of superior parietal cortex links everyday distractibility with attentional capture**

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Attention can be voluntarily directed by top-down signals to stimuli of current interest and automatically captured by bottom-up signals from salient stimuli. The interactions between these two types of attentional orienting have been studied using attentional capture (AC) paradigms where the presence of a salient task-irrelevant stimulus interferes with top-down attentional selection. In our first Experiment, we investigated whether individual differences in self-reported distractibility in daily life reflected individual differences in brain structure using a voxel-based morphometry (VBM) analysis. Participants rated themselves for distractibility using the Cognitive Failures Questionnaire. We found that for highly distractible individuals, the grey matter density was higher in the left superior parietal cortex (SPL) – a region that is involved in AC. The overlap suggested a neural mechanism common to AC in the laboratory and distractibility in everyday life. At least two alternative roles could be attributed to SPL: higher SPL density may exert greater control in more distractible individuals to maintain or re-engage attention to task-relevant stimuli and suppressing saliency-driven distraction (compensation hypothesis). Alternatively, higher SPL density may be responsible for more distractibility itself by increasing sensitivity to automatically orienting salient stimuli (orienting hypothesis). To distinguish these possibilities, we applied repetative transcranial magnetic stimulation (rTMS) over the left SPL and measured the amount of AC before and after TMS. The compensation hypothesis predicted that TMS should increase AC whereas the orienting hypothesis predicted the opposite. The results showed that, relative to the control stimulation site, AC increased following TMS over the left SPL, supporting the compensation hypothesis. We conclude that grey matter density in left SPL plays a crucial role in maintaining attention on relevant stimuli and avoiding distraction. In highly distractible individuals, left SPL seems to have undergone structural changes to arm them with necessary top-down control to function in daily life.

Acknowledgement: Wellcome Trust

Attention: Brain and behavior I

Orchid Ballroom, Boards 451–459

Sunday, May 9, 2:45 - 6:45 pm

36.451 **MEG activity in visual areas of the human brain during target selection and sustained attention**

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We combined MEG and magnetic resonance imaging (MRI) to examine evoked activity in visual areas during a task that involves both target selection and sustained attention. During task trials, 9 human subjects were presented with two white moving random dot patterns (RDPs, the target and the distractor), left and right of a central fixation spot on a dark background. After a brief delay, each RDP color changed to red, blue, or green. Subjects were required to select the target using a color rank selection rule (red > blue > green), sustain attention to it, and identify a transient change in either its direction (clockwise/counterclockwise) or color (pink/grey). All possible stimulus configurations were presented randomly. We found that following color cue onset, early visual areas along the cuneus and lingual gyrus (V1 and V2) were activated bilaterally starting as early as 120 ms after cue onset. Activation in other areas such as V3, V3A, and V4 was significantly stronger contralateral to the target stimulus, peaking at ~170 ms from color cue onset. These data demonstrate that target selection becomes evident in early visual cortex with a latency of about 170 ms following cue onset. During the sustained attention period, changes in the direction of the RDPs evoked peak activation in contralateral area MT (Talairach: -40/-64/16; 39/-64/17), while changes in color evoked activity in contralat-

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eral areas V2/V3 (-21/-74/11; 27/-67/5). These activations were stronger (~60%) for targets than for distracters, becoming most pronounced at ~180 ms from change onset. Our results reveal that MEG activity in early visual areas of the human brain reflects target selection, as well as the effects of sustaining attention on that stimulus. This may be the result of interactions of feed-forward and feedback signals originated in different areas of the hierarchy of visual processing.

Acknowledgement: EJLB, CERNEC, CIHR, NSERC

36.452 **Bilateral Visual Orienting with Adults Using a Modified Posner Paradigm and a Candidate Gene Study**

Rebecca Lundwall[1](beckylundwall@rice.edu), James Dannemiller[1]; [1]Department of Psychology, School of Social Sciences, Rice University

Visual orienting represents "the aligning of attention" with a stimulus (Posner, 1980). We examined the associations between multiple genetic markers (DBH, DRD4, DAT1, APOE e4, and COMT) and measures from a cued-orienting task. In previous research using this paradigm, costs have been combined with benefits into an overall validity score, and almost no genetic associations with visual orienting have been found (Fan, Wu, Fosella & Posner, 2001). It could be premature, however, to claim that genes play no role in explaining individual differences in orienting. If costs and benefits are determined by (even partially) distinct neural mechanisms, then they should be analyzed separately. This is consistent with Posner's formulation of orienting as a three-step process of disengaging, moving and then re-engaging attention at a new location. Disengaging attention (which is necessary for invalid but not for valid cues) could have separate genetic influences.

We used a modified cued-orienting paradigm (Posner, 1980) that added bilateral cues with unequal luminances (Kean & Lambert, 2003). Subjects respond with a left or right key press to the location of a small white square (the target) which appeared 150 msec after the brief presentation of a cue. The cue was either bright or dim. Subjects were told that the target had a 50% probability of appearing near the cue (for single cues) or near the brighter cue (for bilateral, asymmetric cues). Each individual's average response time (RT) to neutral cues served as a baseline for determining the costs and benefits of invalid and valid cues, respectively.

In our sample of 161 individuals, the correlation between costs and benefits was low, r = .25. Each of the genetic markers showed significant association with at least one attentional measure, especially with invalid dim cues. The majority of the genes showing associations with orienting code for dopamine.

Acknowledgement: Rice Graduate Student Research Fellowshipto RAL and Lynette S. Autrey Research grant to JLD

36.453 **Neural signatures of local and global biases induced by automatic versus controlled attention**

Alexandra List[1](a-list@northwestern.edu), Aleksandra Sherman[1], Anastasia V. Flevaris[2,3], Marcia Grabowecky[1], Satoru Suzuki[1]; [1]Department of Psychology, Northwestern University, [2]Department of Psychology, University of California, Berkeley, [3]Medical Research Service, Veterans Affairs, Martinez

Two mechanisms have been identified for orienting to local versus global visual information. One mechanism directs attention to a hierarchical level via the persistence of attention to the most recently attended level, i.e., an automatic priming effect. A second mechanism is via voluntary effort, i.e., a controlled shift of attention. Both mechanisms, whether automatic or controlled, bias individuals to attend to either local or global information. In the current experiment, we tested whether these behavioral biases rely on similar neural dynamics. Participants viewed hierarchical stimuli and identified one of two target letters while EEG was recorded from 64 scalp electrodes. In one session, participants identified targets presented equiprobably at either the local or global level. We expected priming to the most recently attended level and confirmed this behaviorally. In a second session, 100%-predictive local or global cues preceded each hierarchical stimulus. We expected participants to shift attention to the cued hierarchical level and also confirmed this behaviorally. Distinct EEG activity patterns emerged depending on whether a bias was generated automatically or from a cue. Specifically, we compared induced oscillatory EEG activity in the ~2-second blank interval following identification of a local or global target (i.e., during a primed state) or following a local or global cue (i.e., during a controlled state). Globally-primed states showed enhanced gamma (high frequencies: 30-50 Hz) oscillations over the right hemisphere compared to locally-primed states, and locally-primed states showed enhanced bilateral posterior alpha and beta (low frequencies: 6-30 Hz) oscillations compared to globally-primed states. In contrast, globally-cued states showed enhanced posterior alpha frequency oscillations compared to locally-cued states. These results reveal that behavioral biases for directing attention to local or global hierarchical levels rely on distinct neural oscillatory states, depending on whether the bias is driven by automatic or controlled attention.

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36.454 **Event-related potential evidence for a dual-locus model of global/local processing**

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We investigated the perceptual time-course of global/local processing using event-related potentials (ERPs). Subjects discriminated the global or local level of hierarchical letters of different sizes and densities. Subjects were faster to discriminate the local level of large/sparse letters, and the global level of small/dense letters. This was mirrored in early ERP components: the N1/N2 had smaller peak amplitudes when subjects made discriminations at the level that took precedence. Only global discriminations for large/sparse letters led to amplitude enhancement of the later P3 component, suggesting that additional attention-demanding processes are involved in discriminating the global level of these stimuli. Our findings suggest a dual-locus time course for global/local processing: 1) level precedence occurs early in visual processing; 2) extra processing is required at a later stage, but only for global discriminations of large, sparse, stimuli, which may require additional attentional resources for active grouping.

Acknowledgement: NSERC, SSHRC, CIHR, MSFHR

36.455 **Finding a salient stimulus: Contributions of monkey prefrontal and posterior parietal cortex in a bottom-up visual attention task**

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The dorsolateral prefrontal (PFC) and posterior parietal cortex (PPC) are known to represent visuospatial information and to be activated by tasks involving the subjects' attention processes. Recent reports have suggested that salient stimuli are encoded first by PPC during bottom-up attention; however, previous experiments have not used tasks driven entirely by bottom-up signals. We developed a behavioral task that orients attention based purely on bottom-up factors and tested the hypothesis that responses to the salient stimuli emerge earlier in PPC than in PFC. Electrophysiological recordings were made in area 46 of PFC and area 7a of PPC which are known to be strongly interconnected. A stimulus array consisting of one target stimulus differing in color from 8 distractor stimuli was presented to monkeys followed by a sequence of single stimuli separated by delay period. We trained animals to identify the salient stimulus 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 conducted on 134 PFC neurons and 71 PPC neurons with significant responses to visual stimuli. We found that the average visual response latency to stimulus arrays was later for PFC neurons (70ms after the stimulus onset) than PPC neurons (50ms) in our experiment. The average time of target discrimination, however, was earlier for PFC neurons (120ms) than PPC neurons (160ms). The results indicate that salient stimuli are represented first in the activity of prefrontal than parietal neurons, although initial latency to the stimulus presentation is shorter for parietal neurons. These findings suggest that prefrontal cortex has a previously unappreciated involvement in the processing of bottom-up factors and plays a role in the guidance of attention to salient stimuli.

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36.456 **The Effect of Spatial Attention on Pupil Dynamics**

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Although it is well known that the pupil responds dynamically to changes in ambient light levels, we show for the first time that the pupil also responds dynamically to changes in spatially distributed attention. Using a variety of exogenous and endogenous orientating tasks, subjects alternated between focusing their attention on a central stimulus and spreading

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their attention over a larger area. Fourier analysis of the fluctuating pupil diameter indicated that: 1) pupil diameter changed at the rate of attention variation, dilating with broadly spread attention and contracting with narrowly focused attention, and 2) pupillary differences required changes in attentional spread; there were no differences in pupil diameter between sustained broad and sustained spread attention. Given that broadly spread attention increases the relative activation of large receptive fields and narrowly focused attention increases the relative activation of small receptive fields (Balz & Hock, 1997), the current results indicate that changes in attention spread can be mediated by changes in pupil diameter. Attention is narrowed in order to extract detailed, high spatial frequency information from a stimulus. This information remains available in the retinal image when attention is narrowly focused because the pupil is constricted, minimizing spherical aberration (blur). Attention is broadened in order to attend simultaneously to stimulus information spread over a large region. The pupil is dilated when attention is broadly spread, so spherical aberration (blur) decreases the activation of small receptive fields by reducing the high spatial frequency content of the retinal image. In effect, the large receptive fields that mediate broad spatial attention are "selected" by the dilated pupil.

36.457 **The Effects of Voluntary Attention on the Event-Related Potentials and Gamma-Band Response of EEG**

Allison E. Connell Pensky[1](allison.connell@berkeley.edu), Ayelet Landau[1, 2], William Prinzmetal[1]; [1]Psychology, University of California, Berkeley, [2]Department of Veterans Affairs, Martinez, CA

Previous research has shown that there are two types of spatial attention, sometimes referred to as voluntary (goal-directed) and involuntary (stimulus-driven) attention. These studies used the spatial-cueing paradigm in which a spatial cue could be predictive of the location of an upcoming target, or not. The target could be in either the cued or uncued location. Within this paradigm, predictive spatial cues engage voluntary attention, while nonpredictive cues capture involuntary attention. Event-related potential (ERP) studies have found no clear difference between the P1 and N1 components for predictive and nonpredictive cues, while studies using time-frequency analysis have found differences in the gamma-band response (30 to 80 Hz). We addressed this disconnect with a direct comparison of these analytical approaches within a single study. Furthermore, in all previous studies target-related activity was confounded with the lingering cue-related response. This is particularly a problem for target-cued trials, which differ in their physical composition from target-uncued trials and, as such, may influence the EEG response to the target. We addressed this overlapping activity in two ways. First, we used a cueing paradigm in which we differentially, but simultaneously, cued both spatial locations. The participants were told that these cues were either random with respect to the target (involuntary attention condition) or that one of the cues would predict the location of the target (voluntary attention condition). This design ensured that every trial was physically identical. Second, we employed a sufficiently long period between the cue and target (600 ms) to allow the ERP signal to return to baseline prior to the appearance of the target. With this design, we were able to separate cue-related and target-related activity both in ERP and time-frequency analyses, and to delineate what aspects of the EEG signal are due to voluntary attention.

36.459 **Interactivity between the left intraparietal sulcus and occipital cortex in ignoring salient distractors: Evidence from neuropsychological fMRI**

Carmel Mevorach[1](c.mevorach@bham.ac.uk), Harriet Allen[1], John Hodsoll[1], Lilach Shalev[2], Glyn Humphreys[1]; [1]Behavioural Brain Sciences Centre, The School of Psychology, The University of Birmingham, [2]School of Education, The Hebrew University

Visual attention mechanisms in the human brain act both to enhance the processing of relevant targets and to suppress the processing of irrelevant distractors. Attentional control mechanisms are typically linked to activity in a fronto-parietal network, but their effect can be measured in extrastriate visual cortex. Previous work indicates that the left intraparietal sulcus (IPS) is particularly critical for the selection of low saliency targets in the presence of higher-saliency distractors. Here we use neuropsychological fMRI to examine how interactions between the left IPS and extrastriate cortex generate selection by saliency. We compared activation patterns in the left IPS and in extrastriate visual cortex for responses to the local and global properties of compound letters. We tested two patients exhibiting distinct patterns of damage to extrastriate visual cortex which differentially affected their ability to select targets at local and global level. In healthy controls there was increased activity in the left IPS, but reduced activity in extrastriate visual cortex, when the target had low saliency and the distractor high saliency. Similar effects were found with the patients but only when distractors at their spared level of processing had high saliency. In contrast, there was increased activation in their intact extra-striate region when the target on their spared level of processing had low saliency. We conclude that the left IPS acts to bias the competition for selection against salient distracting information (rather than in favour of the low-salient target). In addition, in the absence of competition from salient distractors, extra-striate activity reflects target selection. We discuss the implications for understanding the network of regions controlling visual attention.

3D perception: Pictorial cues

Vista Ballroom, Boards 501–512

Sunday, May 9, 2:45 - 6:45 pm

36.501 **Shape from Smear**

Roland Fleming[1](roland.fleming@tuebingen.mpg.de), Daniel Holtmann-Rice[1,2]; [1]Max Planck Institute for Biological Cybernetics, [2]Dept. of Computer Science, Yale University

Over the last few years, I have shown that images of 3D objects contain highly organized patterns of orientation and spatial frequency information ('orientation fields'), which are systematically related to 3D shape. Here we present a novel illusion and an adaptation experiment that provide the first direct evidence that orientation fields are sufficient to drive 3D shape perception.

The logic of the illusion is as follows. If orientation fields play an important role in 3D shape estimation, then it should be possible to synthesize 2D patterns of orientation that elicit 3D shape percepts. We did this by 'smearing' random noise along specific directions in the image (derived from a 3D model). The result is a 2D texture pattern—generated entirely through filtering operations—that appears vividly like a 3D object. We call this illusion "shape from smear". A depth discrimination task showed that naïve subjects reliably perceive specific 3D shapes from such stimuli.

Because 'shape from smear' is an entirely 2D process, we can modify the orientations and scales in the image and measure the effects on perceived 3D shape. The more we 'smear' the noise pattern, the more 3D the image appears, suggesting that we are manipulating the image information that the visual system uses for estimating shape. We also find that orientation variations are more important than spatial frequency variations.

Most importantly, we used shape from smear to induce 3D shape percepts by adaptation. We created 'anti-shape' textures by smearing noise along directions orthogonal to the correct directions for a specific 3D shape. Prolonged viewing induces local orientation adaptation, which makes a subsequently presented neutral isotopic noise pattern appear like a specific 3D shape. Thus, for the first time we can show that local orientation detectors are directly involved in the perception of 3D shape.

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

36.502 **The perception of 3D shape from contour textures**

Eric Egan[1](egan.51@osu.edu), James Todd[1]; [1]Department of Psychology, The Ohio State University

A new computational analysis is described for estimating the 3D shapes of curved surfaces with contour textures. This model assumes that contours on a surface are stacked in depth so that the depth interval between any two points is optically specified by the number of contours by which they are separated. Whenever this assumption is violated, the model makes specific predictions about how the apparent shape of a surface should be distorted. Two psychophysical experiments were 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. In Experiment 1 images of textured surfaces were presented together with a set of red and yellow dots that could be moved along a single horizontal scan line with a handheld mouse. Observers were instructed to mark each local depth minimum on the scan line with a red dot and each local depth maximum with a yellow dot. In Experiment 2 horizontal scan lines on images were marked by a row of five

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to eight equally spaced red 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 of both experiments revealed that observers' shape judgments are close to veridical when surface contours are stacked in depth, but that contour patterns that violate this constraint produce systematic distortions in the apparent shapes of surfaces that are quite consistent with our proposed model.

Acknowledgement: This research was supported by a grant from NSF (BCS-0546107).

36.503 **Haptic learning disambiguates but does not override texture cues to 3-D shape**

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Li and Zaidi (2003) showed that when 3-D developable surfaces are covered by isotropic random-dot textures, fronto-parallel concave surfaces are seen as convex, because orientation flows are absent, and the spatial-frequency gradient is consistent with a convex percept, if image spatial frequency is assumed to vary solely as a function of distance. The percept suggests that deformations of texture elements were not used by the visual system. Haptic feedback can influence priors and weighting of 3-D visual cues (Ernst etal, 2003; Adams etal, 2004)). We tested whether haptic learning can correct the perception of 3-D shape based on spatial frequency cues. Observers were shown four half-cycles of sinusoidal corrugations (Convex, Concave, Right-slant, Left-slant) and a flat surface, all covered with a random-dot pattern. Observers perceived concavities and convexities as convex, both slants as concave, and the flat surface as flat. Using a Phantom force-feedback device, observers were then allowed to "feel" the actual 3-D shapes. After repeated exploration, observers started perceiving the concave and slanted surfaces "correctly". The effect of haptic learning spread over the complete image, but disappeared when the haptic feedback ended. Since the texture in each image is physically compatible with the veridical shape, this may be due to recruiting correct cues or to overriding texture cues. Since the frequency cues are similar for the two curvatures and the two slants, haptic feedback indicating the opposite curvature or slant predictably evoked the percept compatible with haptic information. As a critical test we presented flat-fronto parallel haptic feedback for the textured images of the curved and slanted surfaces. This feedback failed to modify the pre-training percept. In addition, curved or slanted haptic feedback did not alter the percept of the flat stimulus. Consequently, prolonged haptic training can disambiguate texture cues to 3-D shape, but can not override them.

Acknowledgement: EY07556 and EY13312

36.504 **Contributions of orientation and spatial frequency modulations in the perception of slanted surfaces**

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In images of textured 3D surfaces, pattern changes can be neurally characterized as changes in orientation and spatial frequency. Previously, we have shown that correct 3D shape perception is contingent on the visibility of orientation flows running parallel to the surface curvature. However, little is known about the relative contributions of orientation and frequency information in 3D shape perception. We sought to determine the relative contributions of orientation and frequency in the perception of surface slant. Horizontal and vertical gratings were mapped onto planar surfaces that were rotated around a horizontal or vertical axis and then viewed in perspective. We measured the minimum amount of surface slant required to detect the direction of orientation (OM) or frequency modulation (OM) change (pattern detection thresholds) and compared them to the minimum amount of slant required to detect the direction of surface slant (slant detection thresholds) for the same surfaces patterned with horizontal-vertical plaids containing both OM and FM changes. For both horizontally and vertically rotated surfaces, results indicate that 1) For surfaces close to the fronto-parallel plane, steeper slants were consistently needed to detect FM (than OM) changes and to detect surface slant when both OM and FM changes were present. Slant detection thresholds were consistently close to pattern detection thresholds for OM changes. 2) For surfaces at steeper slants, preliminary results show that pattern detection thresholds are consistently low for both OM and FM conditions, and are comparable to slant detection thresholds when both types of information are present. Pattern frequencies will be varied to examine the contribution of effective contrast to FM detection. Our results suggest that 3D slant perception is dictated by OM information at both shallow and steep slants while FM information is efficiently used only at steep slants.

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36.505 **A spherical harmonic model for 3D shape discrimination**

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At VSS 2008, we presented a series of experiments that sought out common mental representation strategies for three-dimensional shape across the modalities of vision and touch. One of these experiments required subjects to physically sculpt replicas of visually and haptically presented objects. While investigating strategies for comparing the depicted shapes to their respective ground-truth we developed a metric based on spherical harmonic decomposition. An unexpected and surprising artifact of this procedure is that it is also highly predictive of performance in our various discrimination tasks. Here, we present the details of this model as well as a reanalysis of results from other haptic and visual discrimination experiments (Norman et al. 2004, 2006) that also show close agreement with our model. Finally, we present a series of experiments intended to test the limits of our model. We use a spherical harmonic decomposition that shares characteristics with traditional Fourier methods. Subjects performed a paired-comparison discrimination task using objects that varied in frequency (complexity) and phase (relative location of features). It is well known that, in the case of two-dimensional visual images, the phase component contains an overwhelming amount of the information needed for identification and discrimination. Is this true for the visual discrimination of three-dimensional objects as well? Our results show that, for particular ranges of 3D spatial frequency, the phase components dominate, while at other frequencies the amplitude carries the information used for discrimination.

36.506 **Depth cue combination in spontaneous eye movements**

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Where we look when we scan visual scenes to obtain an understanding of the 3D world around us is a question of interest for both fundamental and applied research. Recently, it has been shown that depth is an important variable in driving eye movements: the directions of saccades tend to follow depth gradients (Wexler (2008), Janssen (2009)). Whether saccades are aligned with a single depth cue or a combination of depth cues is still unknown. And, in the latter case, it is interesting to ask whether saccades are based on similar combination rules as those that apply to depth perception. Moreover, these scanning eye movements across different depth planes are composed of two distinct components: conjugate shifts of gaze (saccades) and disjunctive movements changing the depth of fixation (vergence). And the same questions about the effect of depth cues still apply to vergence: various studies have reported that vergence is guided by the consciously perceived depth percept, whereas others report that vergence is based on depth cue(s). Here we studied what depth information is used to plan both saccades and vergence. We showed observers surfaces inclined in depth, in which perspective and disparity defined different plane orientations (both small (0°-45°) and large (90°,180°) conflicts). Observers´ eye movements were recorded binocularly, while they scanned the surface. After the stimulus presentation, observers reported the perceived surface orientation using a joystick. We found saccade directions and perceived surface orientation use the same pattern of depth cue combination: a weighted linear cue combination for small conflicts and cue dominance for large cue conflicts. The weights assigned to each cue varied across subjects, but were strongly correlated for perception and saccades, within subjects. This correlation was maintained while manipulating cue reliability. Vergence on the other hand was dominated by the disparity cue.

36.507 **Relative contribution of outline (perspective) and shading cues to monocular depth perception**

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Two important monocular cues to depth in static scenes are perspective/object outline and shading. These cues are widely used among artists to indicate depth in flat images, but knowledge of their relative contributions to depth and shape perception, and their interactions, is limited. In order to explore this issue we rendered (using RADIANCE) physically accurate colour images of folded card stimuli and displayed them in 42-bit colour. One side of the card was a saturated red colour, the other white. The sides were separated by a vertical fold to form a concave 'corner' or a convex 'roof' such that the angle between each side of the card could be varied. A wide range of card angles were produced. Observers viewed stimuli monocularly, through a small circular aperture to exclude other cues to depth, and were asked to match the angle of the folded card stimulus by adjusting the angle between two lines in a 'view-from-above' configuration, displayed on another monitor Observers also performed matches to wire frame stimuli ('outline-cue-only' condition), large card stimuli that extended beyond the field of view ('gradient-cue-only' condition) and stimuli where the angles indicated by the outline differed from that indicated by the gradient ('cue-conflict-condition'). Results for 3 observers (678 trials each) indicate that the information in the shading is a poor depth cue in isolation, and also ambiguous. Angle estimation seems to be dominated by the perspective cue and a prior for flatness, which can be modelled using Bayesian cue-combination. The addition of shading, of any type, to the 'outline-cue-only' improved the accuracy of card angle estimates (linear regression slopes significantly different, $p<0.001$). Greater improvements in accuracy were observed when the gradient cue was congruent with the outline cue. These results suggest that the gradient cue augments perception of shape from object outline.

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36.508 **The influence of shape cues on detecting lighting inconsistencies**

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Shape-from-shading is an ill-posed problem that can only be solved if observers assume or accurately estimate other scene properties such as the lighting. Recent psychophysical work demonstrates that observers often fail to detect lighting inconsistencies in an image, suggesting that the human visual system is often perceptually unaware of the direction of illumination in a scene (Ostrovsky 2005). We present a study that examines how shape cues influence this sensitivity to the direction of illumination. We conducted a visual search task in which we asked subjects to identify the location of an inconsistently illuminated target object among an array of distractor objects. We used a set of smooth, irregular 3D shapes as the objects, and we presented the stimuli for 1.0 second in each trial. We measured the detection threshold angle between the target light direction and the distractor light direction. To examine the influence of shape information, we varied the shape cues used to render the objects. In the cue-rich condition, we rendered the objects using binocular disparity, texture gradients, and shading. In the cue-impoverished condition, we provided only shading information. Five subjects completed the experiment, and we consistently found lower detection thresholds in the cue-rich condition compared to the cue-impoverished condition (average cue-rich threshold: 49.2deg +/- 3.2deg; average cue-impoverished threshold: 57.6deg +/- 6.8deg). These results demonstrate that an observer's sensitivity to lighting inconsistencies depends in part on the shape information available in the image.

36.509 **A transfer-across-depth-cues study of the ability of infants to access a representation of 3-D shape from shading and line-junction information**

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We explored the development of infants' ability to perceive the 3-D shape of an object from pictorial depth cues, using a "transfer-across-depth-cues" method. Our participants were habituated to a 3-D shape, specified by one cue, and then presented with the same shape and a novel-shape, both specified by a different depth cue. Under these circumstances, infants would show a greater preference for the novel shape rather than the familiar one only if they perceived the shapes from the pictorial depth cues and transferred this information across the cues. In this study, we examined the ability of infants to transfer habituation between shading and line-junction cues which uniquely determined the 3-D shape of a display such that it was shaped either as a slice of cake with a flat top or a rocket that came to a conical point. When the display is presented without either cue, the shape of the object is ambiguous. Our results indicated that six- to seven-month-old infants showed a significant novelty preference despite the change in the pictorial cue that specified the shape. On the other hand, four- to five-month-olds did not. A control experiment showed that the younger infants could discriminate between two displays when a single depth cue specified the two different shapes. These results are similar to our previous findings, which indicated that six- to seven-month-old infants show transfer across shading and surface-contour cues, specifying convex and concave surfaces (Tsuruhara et al, 2009). These two studies suggest that the development of a single mechanism may underlie the emerging ability of infants to form representations of surface layout and of object shape from various pictorial depth cues.

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36.510 **Large Amounts of Optical Blur Greatly Reduce Visual Acuity but Have Minimal Impacts upon 3-D Shape Discrimination**

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A single experiment evaluated observers' ability to visually discriminate 3-D object shape, where the 3-D structure was defined by motion, texture, Lambertian shading, and occluding contours. The observers' vision was degraded to varying degrees by blurring the experimental stimuli using 2.0, 2.5, and 3.0 diopter convex lenses. The lenses reduced the observers' acuity from 1.26 min-1 (in the no blur conditions) to 0.13 min-1 (in the conditions with the most blur, 3.0 diopter lenses). This severe reduction in visual acuity (approaching legal blindness) had significant, but not meaningful, effects upon the observers' ability to discriminate 3-D shape (the observers d' values dropped from 3.6 in the no-blur conditions to 3.2 in the most severely blurred conditions). The observers' performance was facilitated by the objects' rotation in depth, regardless of the amount of blur. Our results indicate that high visual acuity is not a requirement for accurate global shape discrimination.

36.511 **The perception of physical stability of 3D objects: The role of parts**

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Research on 3D shape has focused largely on the perception of local geometric properties, such as surface depth, orientation, or curvature. Relatively little is known about how the visual system organizes local measurements into global shape representations. Here, we investigated how the perceptual organization of shape affects the perception of physical stability of 3D objects. Estimating stability is important for predicting object behavior and guiding motor actions, and requires the observer to integrate information from the entire object.

Observers stereoscopically viewed a rendered scene containing a 3D shape placed near the edge of a table. They adjusted the tilt of the object over the edge to set its perceived critical angle, i.e., the angle at which the object is equally likely to fall off the table vs. return to its upright position. The shapes were conical frustums with one of three aspect ratios---either by themselves, or with a part protruding from the side. When present, the boundaries between the part and the frustum were either sharp or smooth. Importantly, the part either faced directly toward the edge of the table or directly away from it.

Observers were close to the physical prediction for tall/narrow shapes, but with decreasing aspect ratio (shorter/wider shapes), there was a tendency to underestimate the critical angle. With this bias factored out, we found that errors were mostly positive when the part faced toward the table's edge, and mostly negative when facing the opposite direction. These results are consistent with observers underestimating the physical contribution of the attached part. Thus, in making judgments of physical stability observers tend to down-weight the influence of attached part---consistent with a robust-statistics approach to determining the influence of a part on global visual estimates (Cohen & Singh, 2006; Cohen et al., 2008).

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36.512 **Visualizing the relations between slices and wholes is facilitated by co-location**

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Cross-sectional 2D images are widely used in medicine to represent 3D anatomy, but even experienced physicians have difficulty visualizing the relationship between the slices and the whole. Three experiments examined whether mental visualization is facilitated by displaying the cross sections in the physical space of the whole object. Subjects used a hand-held tool to scan and expose a hidden 3D object as a sequence of axial cross sections. A non-axial test angle was then indicated within the scanned space, and the subjects were instructed to visualize the corresponding cross section. A 2D test image then appeared, and the subjects indicated whether or not it matched the visualized cross section. The target's cross sections and the test image were either displayed directly at the source locations, by means of an augmented-reality display (in situ viewing), or displaced to a remote screen (ex situ viewing). In Experiment 1, both the target cross sections and the test image were presented in the same display mode, in situ or ex situ. Consistent with the hypothesis, we found that subjects achieved higher accuracy with the in situ than the ex situ display. In particular, displacing the images from the source induced failures to detect geometrical differences between the visualized cross section and test image. In Experiment 2, the test image was always displayed in situ. The disadvantage for ex situ exploration remained, showing that it is the visualization process, not the test, that is undermined by displacing the cross sectional displays from the source location. A third experiment confirmed this result by showing that ex situ viewing at test alone had no negative effect. These findings extend the advantages we have shown for in situ visualization in facilitating perceptually guided action, to the mental construction of complex object representations.

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Face perception: Features

Vista Ballroom, Boards 513–528

Sunday, May 9, 2:45 - 6:45 pm

36.513 **Integration of facial features is sub-optimal**

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How efficiently do we combine information across facial features when recognizing a face? Some previous studies have suggested that the perception of a face is not simply the result of an independent analysis of individual facial features, but instead involves a coding of the relationships amongst features that enhances our ability to recognize a face. We tested whether an observer's ability to recognize a face is better than what one would expect from their ability to recognize the individual facial features in isolation by using a psychophysical summation-at-threshold technique. Specifically, we measured contrast sensitivity for identifying left eyes, right eyes, noses and mouths of human faces in isolation as well as in combination. Following Nandy & Tjan[1], we computed an integration index Φ from these sensitivities, defined as $\Phi = S2_{\text{left eye+right eye+nose+mouth}} / (S2_{\text{left eye}} + S2_{\text{right eye}} + S2_{\text{nose}} + S2_{\text{mouth}})$, where S is contrast sensitivity. An index of 1 indicates optimal integration of information across features (i.e., observers use the same amount of information from each feature when they are shown in isolation as when they are shown in combination with each other). An index <1 indicates sub-optimal integration (i.e., the combination of features prevents observers from using all of the information they were able to use when the features were shown in isolation). An index > 1 indicates super-optimal integration (i.e., the combination of features allows observers to use more of the available information than they were able to use when the features were shown in isolation). Surprisingly, we find that most observers integrate facial information sub-optimally, in a fashion that is more consistent with a model that bases its decisions on the single 'best feature'. [1]Nandy AS & Tjan BS, JOV 2008, 8(13):3,1-20.

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36.514 **There can be only one: Change detection is better for singleton faces, but not for faces in general**

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Change detection is a powerful tool to study visual attention to objects and scenes because successful change detection requires attention. For example, people are better able to detect a change to the only face in an array than they are changes to other objects (Ro et al, 2001), suggesting that faces draw attention. To the extent that such attention advantages depend on experience, they might vary with age. Our study had two primary goals: (a) to explore the nature and limitations of the change detection advantage for faces, and (b) to determine whether that advantage changes with age and experience. Children, ages 7 to 12 years, viewed an original and changed array of objects that alternated repeatedly, separated by a blank screen, until they detected the one changing object. The arrays consisted of varying numbers of faces or houses, any one of which could change to another exemplar from the same category. Consistent with earlier work, in the presence of a singleton face, changes to that face were detected more quickly and changes to houses in the array were detected more slowly, suggesting that the singleton face drew attention. This advantage was specific to faces—singleton houses show no benefit. However, the advantage for faces occurred only for singleton faces—when multiple faces were present in the display, change detection was no better for faces than for houses. This singleton advantage for faces was present for all age groups even though older subjects showed better overall change detection performance. Apparently, people prioritize single faces over other objects, but they do not generally prioritize faces over other objects when multiple faces appear in a display.

36.515 **The SHINE toolbox for controlling low-level image properties**

Verena Willenbockel[1](verena.vw@gmail.com), Javid Sadr[2], Daniel Fiset[1], Greg Horne[3], Frédéric Gosselin[1], James Tanaka[3]; [1]Département de Psychologie, Université de Montréal, [2]Department of Psychology, University of Massachusetts Boston, [3]Department of Psychology, University of Victoria

Visual perception can be influenced by top-down processes related to the observer's goals and expectations, as well as by bottom-up processes related to low-level stimulus attributes, such as luminance, contrast, and spatial frequency. When using different physical stimuli across psychological conditions, one faces the problem of disentangling the contribution of low- and high-level factors. Here we make available the SHINE (Spectrum, Histogram, and Intensity Normalization and Equalization) toolbox written with Matlab, which we have found useful for controlling a number of image properties separately or simultaneously. SHINE features functions for scaling the rotational average of the Fourier amplitude spectra (i.e., the energy at each spatial frequency averaged across orientations), as well as for the precise matching of the spectra. It also includes functions for normalizing and scaling mean luminance and contrast, as well as a program for exact histogram specification. SHINE offers ways to apply the luminance adjustments to the whole image or to selective regions only (e.g., separately to the foreground and the background). The toolbox has been successfully employed for parametrically modifying a number of image properties or for equating them across the stimulus set in order to minimize potential low-level confounds in studies on higher-level processes (e.g., Fiset, Blais,

Gosselin, Bub, & Tanaka, 2008; Williams, Willenbockel, & Gauthier, 2009). The toolbox can be downloaded here: www.mapageweb.umontreal.ca/gosselif/shine.

36.516 **The role of contour information in the spatial frequency tuning of upright and inverted faces**

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Using the spatial frequency (SF) Bubbles technique, we recently revealed that the same SFs are used for the identification of upright and inverted faces (Willenbockel et al., in press; see also Gaspar, Sekuler, & Bennett, 2008). In these articles, the faces were presented through an elliptical aperture hiding contours. Given that contours do contain information useful for face identification, real-world differences between upright and inverted face SF processing might have been missed. Here, we examined the role of contour information in the SF tuning of upright and inverted face identification using SF Bubbles. We created a bank of 20 faces, and each face was randomly assigned either to set A or to set B. Six participants saw the faces from set A with contours and the faces from set B without contours (shown through an elliptical aperture), whereas six other participants saw the faces from set A without contours and faces from set B with contours. On each trial, a face was selected and its SFs were sampled randomly (for details, see Willenbockel et al., in press). Participants completed one thousand trials in each condition. Multiple linear regressions were performed on the random SF filters and response accuracy. Without contours, we closely replicated Willenbockel et al.: the same SFs correlated with accurate identification of upright and inverted faces (a single band beginning at ~6 cycles per face (cpf) and ending at ~15 cpf). The presence of contour information led to a similar increase in the diagnosticity of low spatial frequencies, irrespective of face orientation; and to a decrease in the diagnosticity of higher spatial frequencies for inverted faces (upright faces with contour: a single band beginning at ~2.3 cpf and ending at ~16.5 cpf; upright faces without contour: a single band beginning at ~4 cpf and ending at ~20 cpf).

36.517 **Different spatial frequency tuning for face identification and facial expression recognition in adults**

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Facial identity and facial expression represent invariant and changeable aspects of faces, respectively. The current study investigated how human observers (n=5) use spatial frequency information to recognize identity versus expression. We measured contrast thresholds for the identification of faces with varying expression and for the recognition of facial expressions across varying identity as a function of the center spatial frequency of narrow-band additive spatial noise. At a viewing distance of 60 cm, the peak threshold representing maximum sensitivity was at 11 cycles/face width for identifying the faces of two males or two females with varying expression. The peak threshold was significantly higher for recognizing facial expressions across varying identity: it was at 16 cycles/face width for discriminating between happiness and sadness, and between fear and anger, whether the expression was high or low in intensity. In a second phase we investigated the effect of viewing distance. As viewing distance increased from 60 to 120 and 180 cm, the peak threshold for identifying faces shifted gradually from 11 to 8 cycle/face width, while the peak threshold for recognizing facial expressions shifted gradually from 16 to 11 cycles/face width. The patterns from human observers were different from an ideal observer using all available information, which behaved similarly in recognizing identity and expression. In conclusion, we found, regardless of viewing distance, the optimal spatial frequency band for the recognition of facial expressions is higher than that for the identification of faces. The patterns suggest that finer details are necessary for recognizing facial expressions than for identifying faces and that the system is only partially scale invariant.

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36.518 **Using Spatial Frequency to Distinguish the Perceptual Representations of Identity and Emotional Expressions**

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Recently, there has been more of a focus in the face recognition literature on the perceptual representation of faces, and specifically, a focus on attempting to identify the constituent dimensions of the face space (e.g. Valentine, 1991). Of additional interest is the idea that independent face spaces may exist depending on the task at hand. For instance, is the information required to judge identity independent of the information required to judge facial expression? One approach to investigating this problem is to manipulate what range of spatial frequency information is available to the observer. In the current study, we limited spatial frequency information to one of five frequency bands, from coarse to fine, using band-pass filtering. Observers completed a match-to-sample task where they saw a sample face followed by two alternatives, which were both limited to same one of the five spatial frequency bands. Using the exact same stimuli, observers engaged in two tasks: in one task, they matched identity; in the other, they matched facial expression. This technique allows us to isolate difference between the two types of judgments and thus draw conclusions regarding the underlying representation. Various image measures were investigated to attempt to account for the results, including those based on the Fourier phase spectrum, which we believe carries the alignment information that is critical for these tasks.

36.519 **Facial contrast polarity affects FFA uniquely in humans and monkeys**

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When otherwise-familiar faces are presented in reversed contrast polarity (e.g. as photographic negatives), they are very difficult to recognize. Here we tested fMRI activity in FFA, in response to quantitatively controlled facial variations in contrast polarity, contrast level, illumination, mean luminance, and rotation in plane. Among these, only reversal of contrast polarity affected FFA activity uniquely. Compared to all other cortical areas, reversal of facial contrast polarity produced the highest fMRI signal change in FFA, across a wide range of contrast levels (5.3 - 100% RMS contrast). By comparison, FFA responses were equivalent (invariant) in response to systematic variations in illumination location, mean luminance, and rotation in plane – even though those parameters also affect facial recognition. In greater detail, reversal of facial contrast polarity changes three image properties in parallel: surface absorbance, shading, and specular reflection. In FFA, we found that the polarity bias was produced only by a combination of all three properties; one or two of these properties in isolation did not produce a significant contrast polarity bias. This suggests that the polarity bias arises from subthreshold (non-linear) summation of multiple face image properties. Using fMRI, we found a homologous effect in visual cortex of awake behaving macaque monkeys. Reversal of facial contrast polarity produced decreased activity, confined to the posterior face patch (homologous to FFA), across contrast levels. Apparently, the polarity bias reflects fundamental mechanisms of visual processing, conserved for at least 25 million years.

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36.520 **The Recognition of Faces, Airplanes, and Novel Objects is Impaired by Contrast Reversal**

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Viewing faces in a negative contrast (i.e., a photograph negative) has been shown to produce a significant decrement in recognition performance (Bruce & Langton, 1994; Galper, 1970; Goldstein & Chance, 1981). This finding has been suggested to support the existence of a face-specific module in the brain. Alternatively, the pigmentation, lighting, and shading patterns present in faces, and other object categories, may contribute to this phenomenon (Bruce & Langton, 1994). If this latter explanation is true, we should expect to see contrast reversal effects in categories other than faces, even categories that are novel to the participant. In this experiment, we compared the recognition of faces and other categories of objects, including a novel, nonbiological category ("pengs"), across contrast. Our previous test using a novel category of objects used objects that were perceived

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as biological (e.g., Greebles; Vuong et al., 2005). Consequently, the current experiment tests the robustness of the contrast effect. This is particularly important, because recent data has been reported showing no contrast effect for a set of novel objects (blobs; Nederhauser, et. al, 2007).

36.521 **Hemispheric specialization for the processing of horizontal and vertical manipulations of the eye region in faces**

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At VSS09, we presented experiments in which participants saw an initial face for 3500 ms, a brief probe face (120 ms), and made same/different identity judgments. Inversion of the left eye in probes (initially projected to the right hemiphere) resulted in lengthened same judgment RTs compared to when probes were unaltered, while inversion of the right eye (initially projected to the left hemisphere) did not result in lengthened RTs relative to unaltered conditions. We took these results to show RH sensitivity to manipulations of face configuration. The present experiments used this same technique. First we created a set of highly standardized faces (identical face shape and eyebrow "frames," with internal features swapped to create identities). We made 5 pixel movements of each eye alone and each eye plus eyebrow to the outside of the face (horizontal) and downward (vertical) to uncover potential differential hemispheric sensitivity to horizontal and vertical displacements. We reduced initial face duration to 400 ms. Movements of eye plus eyebrow were more disruptive to same judgment RTs than movements of the eye alone, and horizontal movements were more disruptive than vertical movements. Unlike our previous work, effects of the side of manipulation were weak. We found some evidence that the LH was more negatively affected by eye plus eyebrow movements than eye alone movements but the RH was not. Horizontal movements of the eye plus brow were more disruptive than eye alone horizontal movements, but there was no difference in same judgment RTs for vertical eye plus brow and eye alone vertical movements. In another experiment we lengthened the initial display to investigate "memorial" vs. "perceptual" contributions to hemispheric effects. We relate our results to inversion effect studies revealing a configurational anisotropy of horizontal and vertical displacements of facial features (Goffaux and Rossion, 2007).

36.522 **How first-order information contributes to face discrimination in nonhuman primates**

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Faces are complex visual objects that can be distinguished from other objects that occur in our visual environment using first-order information. The term "first-order information" refers to the basic spatial layout of features that is repeated in all faces (two eyes, above a nose, above a mouth). An outstanding question is how the detection of the first-order, or canonical, configuration interacts with the processes that underlie exemplar discrimination. Here, we begin to address this question by examining how the first-order configuration of a face contributes to an exemplar-based discrimination task in two nonhuman primate species. Twelve subjects (six chimpanzees Pan troglodytes and six rhesus monkeys Macaca mulatta) were trained to discriminate scrambled faces. Subjects were then able to generalize from the learned configuration to both the canonical configuration and a novel configuration. In an alternative condition, the subjects were trained with whole faces (in the canonical configuration) and tested with scrambled faces. A comparison between these two conditions demonstrates that the presence of the canonical configuration changed the perception of local features. These results are, thus, consistent with the concept of holistic processing for whole faces. We also present new data showing that both species tended to match the configuration of the face over-and-above second-order information, the unique variation among faces assumed to be the basis for exemplar discrimination. These data make a valuable contribution by clarifying the definition of terms that have become a source of confusion in face recognition research. We propose that the first-order configuration of a face serves a crucial social function by enabling the involuntary integration of features during the early stages of face perception.

36.523 **Recognizing people from dynamic video: Dissecting identity information with a fusion approach**

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The goal of this study was to measure the quality of identity-specific information in faces and bodies presented in natural video or as static images. Participants matched identity in stimulus pairs (same person or different people?) created from videos of people walking (gait videos) and/or conversing (conversation videos). We varied the type of information presented in six experiments and two control studies. In all experiments, there were three conditions with participants matching identity in two gait videos (gait-to-gait), two conversation videos (conversation-conversation), or across a conversation and gait video (conversation-gait). In the first set of experiments, participants saw video presentations of the face and body (Exp. 1), face with body obscured (Exp. 2); and body with face obscured (Exp. 3). In the second set, they saw the "best" extracted image of face and body (Exp. 4), face-only (Exp. 5); and body-only (Exp. 6). Identification performance was always best with both the face and body, although recognition from the face alone was close in some conditions. A video advantage was found for face and body and body-alone presentations, but not the face-alone presentations. In two control studies, multiple static images were presented. These studies showed that the video advantages could be explained by the extra image-based information available in the videos, in all but the gait-gait comparisons. To assess the differences in the identity information in the experiments, we used a statistical learning algorithm to fuse the participants' judgments for individual stimulus items across experiments. The fusion produced perfect identification when tested with a cross validation procedure. When the stimulus presentations were static, the fusion indicated that there was partially independent perceptual information available in the face and body and face-only conditions. With video presentations, partially independent perceptual information was available from the face and body condition and the body-only condition.

Acknowledgement: TSWG/DOD to A. O'Toole.

36.524 **Face viewpoint aftereffect in peripheral vision**

Marwan Daar[1](mdaar@yorku.ca), Hugh R. Wilson[1]; [1]Centre for Vision Research, York University

Previous research has shown the existence of the face viewpoint aftereffect (Fang & He, 2005), where adapting to a left or right oriented face causes a perceptual shift in the orientation of a subsequently presented frontal face. Thus far, this aftereffect has only been explored in the central region of the visual field. In the current study we used a novel adaptation technique which differs from previous studies in that in each trial there was one adapting stimulus followed by two simultaneously presented test stimuli. Here, the adapting stimulus was displayed in either half of the visual field, and the two test stimuli were displayed in both halves of the visual field, separated by ±3.3 degrees of visual angle. Instead of judging whether a single test stimulus was oriented to the left or to the right (relative to straight ahead), subjects judged whether one test stimulus was oriented to the left or to the right of the other stimulus. Since only one of the test stimuli is presented in the adapted region, this allows us to assess the strength of the aftereffect by measuring the perceived differences between the two stimuli. This technique has the advantage of allowing aftereffects to be probed relative to arbitrary orientations, rather than to those that are exclusively centered around 0 degrees. Using this technique, we discovered that a viewpoint aftereffect occurs in the periphery. An additional finding was a bias in the left visual field to perceive faces in the periphery as facing slightly more towards the observers ($p < 0.006$). The effects of adapting and testing with faces in the upper and lower halves of the visual field were also tested.

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36.525 **Is Face-Space a Solution to the Invariance Problem?**

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According to the face-space framework, face representations are isomorphic to locations in a multidimensional psychological space, in which the distance separating these representations is proportional to the degree of dissimilarity between faces. This similarity-based face-space has empirically accounted for a range of face-processing phenomena. Our aim was to

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test whether the similarity-based structure of face-space could also mediate identity invariance – the fundamental ability to maintain constant identity representations under varying face transformations (e.g., changes in lighting or viewpoint). This invariance can be achieved if similarity relations remain unchanged across different transformations. We therefore examined the extent to which similarity relations among faces were indeed constant under view or lighting transformations. In Experiment 1, subjects rated perceived similarity within a set of facial stimuli, viewing either its frontally-lit variant or its top-lit variant. Two group-averaged face-space configurations were constructed from these ratings, and their degree of concordance was estimated using Procrustean analysis. In Experiment 2, subjects rated perceived similarity both for a frontal-view variant and a 60o-view variant of the same stimuli set, in two separate sessions three weeks apart. Concordance was estimated both for inter-subject and intra-subject spaces. Consistent with our hypothesis, the fit between spaces constructed for different views or lighting transformations was significantly high, indicating that similarity relations were kept constant under these transformations. Furthermore, multidimensional spaces created for relatively similar transformations (e.g., frontal-lighting space and frontal-view space) showed higher concordance than those created for more distant transformations (e.g., top-lighting and 60o-view). Finally, intra-subject spaces were found to be more in accordance with each other than inter-subject spaces, suggesting that similarity across group-averaged spaces was not due to averaging. Overall, our findings suggest that invariant identity processing can be achieved by keeping the distance between face exemplars in face-space similar under different transformations.

36.526 **The role of features and spatial relations in adaptation of facial identity**

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Face recognition may involve qualitatively different mechanisms from other object recognition. One of the markers for that assertion is the face inversion effect, showing that face recognition is more sensitive to orientation than that for other objects. Inversion may particularly disrupt the processing of configural information, such as the second-order spatial relations of facial features. The aim of our study was to further investigate the contribution of features and configuration in facial representations by studying face identity aftereffects.

We used three types of stimuli: whole faces, 'exploded' faces (disrupted second-order relations but preserved first-order relations) and 'scrambled' faces (disrupting first-order relations). Whole and altered faces served as adapting or test stimuli, viewed either both upright or both inverted. We measured perceptual-bias aftereffects in identity judgments regarding ambiguous morphed test face stimuli. Our primary goal was to determine the degree of adaptation that altered faces could induce in whole faces and whether this varied with orientation. Fourteen healthy subjects participated.

Compared to whole-face adaptors, exploded faces induced partial aftereffects in whole test faces and these showed an inversion effect similar to those seen with whole-face adaptors. In contrast, scrambled faces were ineffective at adapting whole-face test stimuli in either orientation, although they could induce aftereffects in scrambled-face test stimuli.

We conclude that disruption of second-order spatial relations does not prevent facial features from engaging facial representations of identity, but that a proper first-order relationship of features is an essential prerequisite. Second-order spatial relations do form an integral part of face representations as disrupting these reduces the magnitude of the face aftereffect.

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36.527 **Visual attractiveness is leaky (2): hair and face**

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Memory-based attractiveness integration is implicit and nonlinear, as we demonstrated with images featuring a central face (FC) and a surrounding natural scene (NS) (Shimojo et al., VSS'09). Here, we aimed to see how the task-irrelevant surround affects attractiveness of the central stimulus and vice versa, using hair (HR) and face (FC). There is evidence that HR is indeed a surrounding, accessory part of the holistic FC perception (Ellis et al., 1980), and both are processed in the face-specific temporal area (Kanwisher et al. 1997).

Eight FC images (4 attractive and 4 less attractive FCs), and 16 HR pictures (4 colors, 2 lengths and 2 shapes) were selected from a pre-rated set. Each FC and HR were combined in the natural spatial alignment, and subjects were asked to rate attractiveness of 1) FC only or 2) HR only in a 7-point scale in separate sessions.

Results of 1) show that, when FC is shown with an attractive HR, the attractiveness of FC was higher than with a less attractive HR, even though subject was asked to focus only on the FC. Results of 2) were symmetrical to those of 1) in that the task-irrelevant FC affects attractiveness of HR. The overall patterns of the results cannot be simply interpreted as the subjects neglecting the "ONLY" instruction, because the "FC only" attractiveness with HR is exceedingly lower than the range predicted from weighted averaging of the pre-rated attractiveness of HR and FC.

These results seem difficult to interpret unless we accept two possibilities: (a) the attractiveness of the task-irrelevant surround is implicitly "imported" into that of the central stimulus, and (b) something more nonlinear than just averaging occurs particularly in the FC only evaluation with HR.

Acknowledgement: Kao Corporation, JST.ERATO Shimojo Implicit Brain Project, Tamagawa-Caltech gCOE

36.528 **An attractiveness function for human faces**

Christopher Said[1](csaid@princeton.edu), Alexander Todorov[1]; [1]Psychology Department, Princeton University

Previous research on facial attractiveness has shown that mathematically average faces are perceived as highly attractive. In this study, we obtained attractiveness ratings for 2000 male and 2000 female faces sampled from a 50 dimensional face space. This face space approximates the shape and reflectance variance in human faces. After collecting the ratings, we used second-order polynomial regression to create an attractiveness function. This data-driven approach allows us to predict the attractiveness of any arbitrary face. The attractiveness function shows that while averageness is important for some dimensions, it is not for others. In particular, attractive male faces have darker skin, darker eyebrows, more beard, and longer jaws than the average male face. Attractive females have upper and lower eyelids that are much darker than those of the average female face. For many other dimensions, however, the theoretically most attractive female is near the mean. Additionally, the attractiveness function confirms the importance of sexual dimorphism for some, but not all dimensions.

Scene perception: Mechanisms

Vista Ballroom, Boards 529–539

Sunday, May 9, 2:45 - 6:45 pm

36.529 **Neural Coding of Scene Volume: the Size of Space Represented across the PPA and LOC**

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Estimating the size of a space is intuitively central to our daily interactions, for example when deciding whether or not to take a crowded elevator. Here, we examined how neural areas respond to scenes that parametrically vary in the volume of depicted space. Observers were shown blocks of indoor scene categories and performed a one-back repetition task while undergoing whole brain imaging in a 3T fMRI scanner. The 18 scene categories varied in the size of depicted space on a 6 point log scale, from small and confined spaces such as closets and showers, to expansive areas such as concert halls and sports arenas. Using a regions-of-interest approach, we found that activity in the lateral occipital complex (LOC) systematically decreased as the size of space increased, showing a preference for smaller spaces ($r=-.64$, $p<.01$). On the other hand, activity in the parahippocampal place area (PPA) did not change as the size of space varied: this region responded equally strongly to all types of scenes regardless of the volume of the space ($r=.14$, $p>.1$). We further examined the multivoxel pattern activity in the PPA using a linear support vector machine. Voxel patterns in the PPA classified the six different volumes of space well above chance (39% performance with leave-one-block-out cross-validation, chance level being

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17%). Importantly, most classification errors were found across scenes that were close in size (within 1-2 scales), and not across scenes that were further in size (within 4-5 scales). Similar results were found in LOC (36% classification performance). These data suggest that scene volume information is coded in a distributed manner over a range of areas in the ventral visual pathway, consistent with the general idea that understanding the size of a space can influence a wide range of our interactions and daily navigation through the world.

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36.530 **Using V1-Based Models to Predict Blur Detection and Perception in Natural Scenes**

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We studied the performance of V1-based models (incorporating both linear and non-linear characteristics) in predicting how observers perceive changes in natural scenes. Pilot studies found that the simplest model was able to predict subjective perception of many types of suprathreshold changes, but consistently underpredicted the actual perceived magnitude of changes in blur. Blur might be perceived differently from other types of changes because it serves as an important cue for accommodation, depth, and motion. This study investigated whether the poor predictions for blur changes arise from differences in higher level processing.

To investigate the role of high-level processing in blur perception, we compared our low-level model's performance for blur in eight normal (N) natural scenes and their distorted (D) counterparts (in which the higher-level cues were removed by blurring only selected portions of the natural scenes). If blur change perception were independent of high-level processing, human and model performance should be similar in both conditions. Blur detection thresholds were collected from 3 observers using a 2AFC protocol. Suprathreshold discrimination measurements were obtained using a matching procedure: the blurriness of a test pair was adjusted to match the degree of change in a "comparison pair". Three-way ANOVAs showed that blur detection and suprathreshold perception were independent of the stimulus type (N versus D): $F(2,10)=1.42$, $P=0.287$ and $F(1,135)=1.42$, $P=0.235$ respectively. This suggests that higher-level cues did not significantly influence the perception of blur differences.

A successful model should give identical outputs for all threshold-level differences. Models of low-level processes in V1 failed to explain the observers' high sensitivities to blur changes (Three-way ANOVA: $F(2,10)=6.21$, $P=0.0177$). However, additional modelling of attention and bias towards high spatial frequencies produced some significant improvements (Three-way ANOVA: $F(2,10)=1.41$, $P=0.288$). These results suggest that purely low-level models cannot readily describe blur perception, and must incorporate more complex mechanisms.

36.531 **Spatiotemporal chromatic statistics of the natural world**

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We measured the spatiotemporal chromatic properties of the natural world using a high speed calibrated digital video camera. Our video clips, each lasting 10 seconds and gathered at 200 Hz with a stationary camera, featured a wide variety of scenes, ranging from temporal texture (such as grass blowing in the wind and waves breaking on the sea) to meaningful spatiotemporal structure (such as people communicating using British Sign Language). The raw video output was calibrated and combined to closely approximate the human luminance, red-green and blue-yellow channels (Lovell et al. 2004). By analysing the videos using the power spectrum of the 3D FFT transform, we characterised the natural world as conveyed to the visual cortex. Examination of spatial characteristics showed that the amplitudes of the various spatial frequencies are, as expected, well characterised by a $1/f^n$ relationship with n close to 1 for the luminance channel. In the temporal domain, the overall statistics follow a $1/\omega^n$ pattern (where ω denotes temporal frequency) with values of n substantially less than 1 for all three channels. However, when examined on a video-by-video basis a markedly different temporal structure can be observed (e.g. peaks in the temporal spectrum for waves in a river at 6Hz). We note that such peaks are invariant to viewing distance and we propose that vision may use this invariant structure to extract temporal gist from a scene. The spatiotemporal sensitivities of visual organisms may well be driven by a need to capture such information optimally.

36.532 **Anisotropic Gain Control Pools Are Tuned In Temporal Frequency As Well As Spatial Frequency And Orientation**

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Masking of a grating by broadband content is greatest for the horizontal orientation and least for oblique orientations (Essock, Haun and Kim, JOV, 2009; Kim, Haun and Essock, VSS, 2007). Thus when viewing oriented content in a natural scene (or other broadband images), oblique content is seen best and horizontal is seen least well (the "horizontal effect" e.g., Essock et al, VisResearch, 2003). We have suggested that his horizontal effect is due to anisotropic suppression that is observed when enough contextual spatial content is present to create a significant response in a gain control pool, thus revealing the anisotropy. Previously we have shown that the anisotropic gain control pools are local (i.e., "tuned") in spatial frequency and orientation. Here we compare these pools (suppression magnitude and anisotropy magnitude) for narrowband tests across the spatio-temporal surface with either spatially or temporally broadband masks. Results show: (1) a horizontal effect anisotropy at all spatio-temporal conditions tested, (2) the magnitude of suppression and of the horizontal effect anisotropy are greatest at middle values (2cpd/10Hz for spatially broadband masks, and 4cpd/.5Hz for spatially broadband masks), and (3) the anisotropic gain control pools are local in not only spatial frequency but also in temporal frequency. This tuning in temporal frequency is in contrast to prior temporal masking studies that show only 2 (or 3) tuned channels when narrow-band masks are used. This suggests that a lower-level suppression exists, that is anisotropic, and becomes significant when driven by many spatial components (i.e., content broadband in spatial, temporal and/or orientation) but is apparently not revealed by a single (narrowband) mask as in prior studies.

36.533 **The Nature of Perceptual Averaging: Automaticity, Selectivity, and Simultaneity**

Alice R. Albrecht[1](alice.albrecht@yale.edu), Brian J. Scholl[1]; [1]Perception & Cognition Lab, Dept. of Psychology, Yale University

Perception represents not only discrete features and objects, but also information distributed in time and space. One intriguing example is perceptual averaging: we are surprisingly efficient at perceiving and reporting the average size of objects in spatial arrays or temporal sequences. Extracting such statistical summary representations (SSRs) is fast and accurate, but several fundamental questions remain about their underlying nature. We explored three such questions, investigating SSRs of size for static object arrays, and for a single continuously growing/shrinking object (as introduced in Albrecht & Scholl, in press, Psychological Science). Question 1: Are SSRs computed automatically, or only intentionally? When viewing a set of discs, observers completed three trials of a 'decoy' task, pressing a key when they detected a sudden luminance change. Observers also reported the discs' average size on the final trial, but could receive these instructions either before the final display onset, or after its offset. Performance for the second ('incidental averaging') group was no worse than for the first ('intentional averaging') group -- suggesting that some SSRs can be computed automatically. Question 2: Can SSRs be computed selectively from temporal subsets? Observers viewed a continuously growing/shrinking disc that changed color briefly during each trial. Observers were asked to average either the entire sequence, or only the differently-colored subset -- via instructions presented either before the display onset, or after its offset. Performance was as accurate with subsets as with the whole -- suggesting that SSRs can be temporally selective. Question 3: Can we simultaneously extract multiple SSRs from temporally overlapping sequences? In the same experiments, there was a small but reliable cost to receiving the instructions after the display offset -- suggesting that SSRs cannot automatically

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compute multiple temporally-overlapping averages. Collectively, these and other results clarify both the flexibility and intrinsic limitations of perceptual averaging.

36.534 **Effective Acuity for Low-Pass Filtering of Real World Images**

Amy A. Kalia[1](kali0080@umn.edu), Gordon E. Legge[1], Christopher S. Kallie[1]; [1]Department of Psychology, University of Minnesota Twin-Cities

Understanding of low-vision mobility problems would benefit from methods for predicting the visibility of environmental hazards such as steps. A useful tool for rehabilitation specialists and architectural designers would blur an image of a space according to a particular acuity level. Although many graphics programs have blurring functions, the relationship between blur filters, clinical measures of acuity, and the information transmitted in the resulting image is unclear. To examine this relationship, we tested the effective letter acuity associated with the bandwidth of two low-pass filters applied to a photograph of an eye chart. A high-resolution camera image was obtained of the Lighthouse Distance Visual Acuity chart at a standard viewing distance of 4 m. The image (with peak resolution of 80 pixels per degree) was filtered with Gaussian and 4th-order Butterworth filters with bandwidths (defined as the frequency at 50% of maximum) ranging from 1.33 to 35 cycles per degree. Five normally sighted subjects viewed the blurred images on a display screen at a distance that allowed easy identification of the 20/20 letters in the unblurred image. For the highest bandwidths, subjects were able to read letters smaller than the 20/20 line. For a lower range of bandwidths (1.33 to 8.78 cycles per degree) there was a linear relationship between filter bandwidth (expressed in degrees per cycle) and the smallest resolvable letter size (in degrees). Effective acuity was worse with the Butterworth filter compared to the Gaussian filter for equal bandwidths; the smallest resolvable letter size for a 1 degree per cycle bandwidth was approximately 1.1 degrees for the Butterworth filter and 0.63 degrees for the Gaussian filter. These results yield functions (effective acuity vs. filter bandwidth) for simulating the effects of reduced acuity on the information available in real-world scenes.

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36.535 **Factors influencing the detectability of pedestrians in urban environments**

David Engel[1](david.engel@tuebingen.mpg.de), Cristóbal Curio[1]; [1]Max Planck Institute for biolgoical Cybernetics

Driver assistance systems based on computer vision modules aim to provide useful information for the driving task to its user. One critical task in such scenarios is avoiding dangerous encounters between cars and vehicles. Classical computer vision systems aim only at finding all pedestrians. We propose that in order to provide the maximally useful information to the driver, it is also necessary to know the probability that the driver will see the pedestrian. This way the system is able to direct and modulate the attention of the driver towards pedestrians that he might not have noticed. Methods: We performed an experiment with 10 subjects. We showed images of urban environments for 120 ms followed by a noise mask. Afterwards, subjects had to indicate positions where they saw a pedestrian. We used the MIT StreetScenes database [1] which contains 3547 photos with hand-labeled pedestrian positions. Each participant was shown a total of 557 images in a random order. 142 images without pedestrians, 245 contained one single pedestrians and the rest contained two or more pedestrians. Results: We counted mouse clicks within a 100 pixel radius of the center of a pedestrian as hits. The average hit rate was 69%. We evaluated how well a classifier can predict the detectability of a pedestrian based on several features such as: compositional features (position and size of the pedestrian), image features (color histograms, contrast and histogram of oriented gradients descriptors of the pedestrian as well as the decision value of a support vector machine trained on a pedestrian classification task) and context features (difference in mean, standard deviation and color histograms between pedestrian and background and distance to other pedestrians in the image). References: [1] S. M. Bileschi. Streetscenes: towards scene understanding in still images. PhD thesis, Massachusetts Institute of Technology, 2006.

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36.536 **Framework and implementation for perception**

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A biologically-inspired framework for perception is proposed and implemented, which helps guide the systematic development of machine vision algorithms and methods. The core is a hierarchical Bayesian inference system. Hypotheses about objects in a visual scene are generated "bottom-up" from sensor data. These hypotheses are refined and validated "top-down" when complex objects, hypothesized at higher levels, impose new feature and location priors on the component parts of these objects at lower levels. To efficiently implement the framework, an important new contribution is to systematically utilize the concept of bottom-up saliency maps to narrow down the space of hypotheses. In addition, we let the system hallucinate top-down (manufacture its own data) at low levels given high-level hypotheses, to overcome missing data, ambiguities and noise. The implemented system is tested against images of real scenes containing simple 2D objects against various backgrounds. The system correctly recognizes the objects in 98.71% of 621 video frames, as compared to SIFT which achieves 38.00%.

Acknowledgement: ARO

36.537 **Black, White, or Neutral Gray Blank Screens Have Differential Effects on Scene Gist Masking**

Tyler Freeman[1](tylerf@ksu.edu), Lester Loschky[1], Ryan Ringer[1], Caroline Kridner[1]; [1]Department of Psychology, Kansas State University

Scene perception research often uses visual masks to vary the time that information is available on a viewer's retina. However, little is known about the effects of spatial and temporal masking parameters when masking real-world scenes. Such studies using visual masking often include blank screens at the start of the trial, during the ISI between target and mask, and following the mask presentation. These blank screens are typically black, white, or a neutral gray matched to the mean luminance of the target and mask, with neutral blank screens presumably intended to minimize luminance contrast with the target and mask. Earlier research (Freeman & Loschky, VSS 2009) showed differences between black and gray blank screens at SOAs <24 ms, using 12 ms target durations, with higher contrast black blank screens producing stronger masking. However, with 12 ms target durations, white blank screens produce a floor effect—a flat slope near chance across SOAs. To avoid that, the present study increased target durations to 24 ms and compared the masking effects of white, black, and gray blank screens, with SOAs from 24-96 ms. Results showed that white blank screens produced far greater masking than both the black and equiluminant gray blank screens at all SOAs, but no difference in masking between the black and equiluminant gray blank screen conditions. However, considering the results of Loschky and Freeman (VSS, 2009) it appears that higher contrast black and white blank screens both produce stronger masking than equiluminant gray screens, with white screens producing the strongest masking that persists at longer SOAs. A possible explanation for these results is in terms of on- and off-channels, with the faster on-channels having a greater impact in masking briefly flashed scenes. Thus, the current study provides important information for scene perception researchers using visual masking.

36.538 **Attention modulates gist performance between central and peripheral vision**

Adam Larson[1](adlarson@ksu.edu), Lester Loschky[1], Ryan Ringer[1], Caroline Kridner[1]; [1]Department of Psychology, Kansas State University

Our previous research using a 'window' and 'scotoma' paradigm suggested that early in processing, scene gist recognition is better for central than peripheral vision, followed thereafter by converging performance, consistent with the hypothesis of attentional expansion over time. However, an alternative explanation is that the 'scotoma' captures attention early in processing, resulting in worse gist performance for peripheral information. We tested these hypotheses by manipulating attention to focus either centrally or peripherally, and examining its effects on scene gist over time.

Scenes were manipulated by presenting imagery only in a central circular region and blocking information outside it (the "window"), or conversely, by blocking imagery in the central circular region (the "scotoma") and presenting information only outside it. A single critical radius divided the circular images into mutually exclusive center and surround regions, which produced equal gist performance in both conditions when unmasked. Images were presented for 24ms with masking SOAs of 36, 70, 105, and 376 ms. Eyetracking ensured central fixation during scene presentation. Attention was manipulated between-subjects by presenting 80% of the trials as either window or scotoma images.

Early use of central versus peripheral information differed significantly as a function of attention. Specifically, at 36ms SOA, when attention was centrally focused, performance was significantly better in the window condition than the scotoma condition, whereas when attention was peripherally focused, there was no difference between either condition. Thereafter, with increasing processing time, gist performance equalized, as predicted by the use of the critical radius to create the stimuli.

Thus, at early processing times, attention moderates gist recognition between central and peripheral vision. However, with additional processing time, performance converges to produce equal gist performance between central and peripheral information, consistent with the hypothesis that attention expands out from the center of a scene over a single fixation.

36.539 **Multi-Event Scene Perception at an Ecologically Representative Scale**

Thomas Sanocki[1](sanocki@usf.edu), Noah Sulman[1]; [1]Psychology, University of South Florida

Research on scene perception is still in its infancy and, in general, has focussed on convergent processes in which scene information is integrated to arrive at a single label denoting category name or animal decision (e.g.,). However, also important in scene perception is the divergent perceptual ability of perceiving multiple events. Little is known about this ability in the context of continuous scene perception. Further, theories make different predictions: Attentional set theory predicts that switching out of a single task set is costly, whereas approaches emphasizing efficient bottom-up processing are consistent with efficient time sharing between multiple events. We developed a continuous event paradigm involving a 60 sec event-stream with an average of 12 simultaneously active events. The events were asynchronous and took time (4 sec average), like events in a typical real world scene. Observers could time share between events, as in real world perception. Experiment 1 examined the cost of switching between multiple events types, relative to single event conditions. The hit rate was 78.4% for single tasking, and fell to 64.3% for switching between multiple events. The 14.1% cost for switching tasks was reliable (and consistent with attentional set theory) but fairly modest in size. In fact, one could say that multiple event perception (MEP) was fairly efficient. Is there a basis for reasonably efficient MEP? A promising hypothesis comes from a principle that pervades designed spaces — that similar functions be grouped together. Is MEP more efficient when event types are organized by location? Experiments 2 and 3 provided strong positive evidence, showing that the cost of MEP (relative to single-tasking) is much higher (34.1% and 32.7% respectively) when event-types are distributed throughout space rather than organized by location. MEP is a significant and theoretically interesting aspect of scene perception.

Binocular vision: Stereo mechanisms

Vista Ballroom, Boards 540–547

Sunday, May 9, 2:45 - 6:45 pm

36.540 **The limit of spatial resolution for joint stereo disparity / motion perception**

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Human spatial resolution for luminance gratings – the ability to distinguish black-and-white stripes from gray – can reach 50 cycles per degree (cpd; Campbell & Green 1965, J Physiol 181:576). The equivalent resolution for stereo disparity is an order of magnitude lower: depth corrugations defined by binocular disparity cannot be perceived beyond about 4 cpd (Tyler 1974, Nature 251:140; Banks et al. 2004, J Neurosci 24:2077; Bradshaw & Rogers 1999, Vision Res 39:3049). Both these limits are believed to be set by the properties of cells in primary visual cortex (V1): stereo resolution by the area of their receptive fields, and luminance resolution by the arrangement of ON/OFF subregions within receptive fields (Nienborg & Cumming 2003, J Neurosci 24:2065). Here, we examine the spatial resolution for perceiving, not motion or disparity alone, but the correlations between both. The stimuli were random-dot stereograms depicting two transparent depth planes made up of dots streaming at constant speed, either left or right. Both directions of motion were always present everywhere in the visual field, but for the target stimulus they were locally segregated into depth planes (e.g. front plane moving to the left, back moving right), while for the control stimulus, both front and back planes everywhere consisted of two transparent directions of motion. This task requires observers to extract disparity contingent upon motion direction. To find the resolution limit, we alternated the motion direction within each depth plane for the target stimulus, i.e. the target consisted of horizontal strips, alternately front-leftwards/back-rightwards and front-rightwards/back-leftwards. We examined how performance on this task varied as we reduced the height of the strips. We compared this with a task with the same motion energy but which could be performed based solely on the disparity. We find that the high-frequency cut-off is lower for the joint motion/disparity task.

Acknowledgement: Royal Society, Institute of Neuroscience

36.541 **Effects of image statistics on stereo coding in human vision**

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Biological visual systems continuously optimize themselves to the prevailing image statistics, which gives rise to the phenomenon of adaptation. For example, post-adaptation color appearance can be explained by efficient coding which appropriately combines the input cone channels into various chromatic and achromatic channels with suitable gains that depend on the input statistics [Atick, J.J., Li, Z. & Redlich, A.N. (1993). Vision Research, 33, 123-129]. In this study we focus on the ocular channels corresponding to the two eyes. We investigated how image statistics influence the way human vision combines information from the two eyes. Efficient coding in ocular space [Li, Z. & Atick, J.J. (1994) Network, 5, 157-174] predicts that the binocularity of neurons should depend on the interocular correlations in the visual environment: As the interocular correlations increase in magnitude, the neurons should become more binocular. In natural viewing conditions, interocular correlations are higher for horizontal than vertical image components, because vertical binocular disparities are generally smaller than horizontal disparities. Thus, adaptation to natural stereo image pairs should lead to a greater level of binocularity for horizontally-tuned neurons than vertically-tuned neurons, whereas adaptation to pairs of identical natural images should not. We used interocular transfer of the tilt illusion as an index of binocularity of neurons with different characteristics. Subjects adapted either to natural stereo pairs or pairs of identical natural images. As predicted, interocular transfer was higher for near-horizontal than near-vertical stimuli after adaptation to natural stereo pairs, but not after adaptation to pairs of identical natural images.

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36.542 **Using numerosity to explore monocular regions in binocular scenes**

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How does the visual system combine the two, slightly different, retinal images to arrive at a single, meaningful percept? Traditional models of stereo matching suggest that we match corresponding points in the two retinal images. However, virtually every scene around us contains regions that only one eye can access. These regions are, in these models, treated as noise and thus ignored.. However, there is some evidence that they form part of our cyclopean percept of a scene (Ono et al. 2003. J. of Exp. Psych.: Gen. 132(2), 253-265), rather than appearing as rivalrous. Here, we sought to explore how items in monocular regions contribute to the representation of pattern and density. Observers viewed a stimulus comprising a random dot pattern viewed via one of 3 conditions: binocularly (all dots visible), behind a set of fence-like vertical occluders (each dot could be seen by only one eye), or behind a set of horizontal occluders (each dot was binocularly visible but only 50% of the dots were visible in total).

In a 2AFC, relative numerosity task, participants were asked to indicate which one of two stimuli was more numerous. We measured thresholds and biases. There was no significant difference between thresholds in the vertical and horizontal occluder conditions, suggesting that monocular regions are not seen as rivalrous. We found no significant bias for any of the conditions. Our results are consistent with the hypothesis that monocular regions contribute fully to the representation of pattern and density.

Sunday PM

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36.543 Neural activity in higher dorsal visual areas relates to the discrimination of disparity-defined depth position

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Neural responses to binocular disparity have been observed throughout the visual cortex. Although it is thought that the ventral and dorsal pathways perform distinct roles in the perception of depth, the nature of this processing is still far from being understood. To investigate the relationship between cortical activity and the perception of depth, we used neuroimaging techniques to test regions for cortical activity that varied in a perceptually-relevant manner and compared this to the behavioural performance from a near-far depth discrimination task which was measured concurrently. Participants viewed random dot stereograms depicting planes with crossed (near) or uncrossed (far) disparity and were asked to judge the depth position (near or far). Performance was manipulated parametrically by changing the correlation of dots presented to the two eyes. When 100% of the dots were correlated (e.g. white dots in one eye match white dots in the other) the task was trivial; however, when 100% of the dots were anticorrelated (white dots in one eye match black dots in the other), discrimination performance was reduced to chance. We measured concurrent event-related fMRI responses and used multivariate analysis methods (SVM: support vector machine) to determine cortical regions that contained information about the disparity-defined depth (cf. Preston et al, 2008, J Neurosci, 28, 11315-27). In particular, we trained an SVM to discriminate near/far depth for 100% correlated stereograms and then tested the SVM with fMRI responses evoked at lower coherence levels, thereby obtaining 'fMR-metric' functions. Comparing fMR-metric and psychometric functions indicated a close association between psychophysical judgments of depth and activity in higher dorsal areas V7 and VIPS. Consistent with recent findings, our results demonstrate an important role for higher dorsal areas in the perception of disparity-defined depth.

36.544 Visual Fusion and Binocular Rivalry in Cortical Visual Areas

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Correlates of visual fusion were studied independent from binocular rivalry by fMRI at various eccentricities in visual cortical areas V1 to V4 and MT+. Stimuli to elicit visual fusion (BF), binocular rivalry (BR), and simultaneous fusion and rivalry (BFR) were designed by superimposing fusable and non-fusable lattices. Responses to these were acquired in a group of ten subjects together with meridian-, eccentricity- and motion mapping in the same session. Retinotopic maximum probability maps on an average flat map for the group were calculated for dorsal and ventral visual areas V1 to V4 at five eccentricity intervals and motion area MT+, resulting in 41 ROIs for each hemisphere. To isolate either fusion- or rivalry-related activity within each ROI, 2×2 ANOVAs with factors eye and condition were performed where, for fusion, the condition levels were BFR and BR, and for rivalry BFR and BF, respectively. Resulting F values are reported as measure of activity. Visual fusion showed the highest activity within V3 and V4 at ROIs with increasing eccentricity, and further within Area MT+. Binocular rivalry, in contrast, mainly showed highest activities within V1 and V2, preferring lower eccentricities. In conclusion, fusion seems to be predominantly processed in the peripheral visual field representations in areas V3 and V4 as well as in MT+, playing a lower role within earlier visual areas.

36.545 Binocular coordination: Reading stereoscopic sentences in depth

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When we fixate objects that are close to us our eyes make disconjugate convergent movements (e.g., they move nasally), and when we fixate objects that are distant, our eyes make disconjugate divergent movements (Kirkby et al. 2008). We investigated how readers controlled their eyes binocularly as they read sentences presented stereoscopically such that they appeared to loom out from the screen towards the reader. To address this question, we had subjects read sentences as we monitored the movements of each eye simultaneously. Sentences were presented in three conditions: 1) a size-constant 2D condition in which sentence depth and character size were constant throughout the sentence; 2) an increasing-size 2D condition in which sentence depth was constant, but character size increased from left to right (a monocular cue used to infer depth); 3) a 3D looming condition where character size increased from left to right AND the text was presented stereoscopically such that the perceived sentence started at the screen and loomed toward the subject at an angle of 55° from the plane of the screen. To create the looming stimuli, the stereoscopic sentences were such that a letter from the left eye stimulus was displaced to the left of the corresponding letter in the right eye stimulus.

We predicted that binocular disparity would remain constant in the 2D conditions (1&2), but the eyes would become more converged as they progressed through the sentence in the looming 3D condition (3) if readers processed the text as they would in a real depth condition. Our results showed increased divergence as readers read further in the sentence, indicating that binocular eye coordination is driven by each eye's unique retinal signal rather than by depth cues associated with sentences that appear to loom towards the reader.

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36.546 Suppression in Intermittent Exotropia during fixation

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Intermittent exotropia (X(T)) is a common oculomotor anomaly where one eye intermittently deviates outwards. Patients with this type of strabismus are often not aware of the exodeviation and do not experience diplopia (Jampolsky 1954, American Orthoptic Journal, 4). The absence of diplopia during the divergent phase has been explained by suppression of the deviated eye. Since X(T) patients have stereopsis, it is widely believed that suppression occurs only during deviation. Here, we show that dichoptic images trigger suppression even during correct fixation. We studied 12 X(T) patients aged between 5 and 22 years. All had functional stereo vision with stereoacuity similar to that of 20 age-matched controls (0.2-3.7 arcmin).We measured suppression during fixation at 120cm. Each eye viewed an identical cartoon face (6x6 deg) dissociated by polarizing filters and presented for 400 msec. In one eye, the face was presented at the fovea; in the other, at different retinal positions along the horizontal axis. We also included catch-trials where two faces were presented in both eyes. The task was to indicate whether one or two faces were present. To ensure correct fixation, in between stimuli, subjects viewed a nonius image composed of a dissociated butterfly and a net on a binocularly-viewed forest background. All X(T) patients showed normal diplopia when the non-foveal face was presented in the nasal area of the retina. However 83% of X(T)s reported perceiving only one face when the non-foveal face was presented to temporal retina, indicating suppression during fixation. In a follow-up experiment, we examined which eye was suppressed. Some subjects suppressed the temporal stimulus regardless of which eye viewed it, so they always perceived the central stimulus; others always suppressed the same eye even when it viewed the central stimulus, so they then perceived the peripheral stimulus; others showed a mixture of both strategies.

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36.547 "What" constrains "where": Perceptual interactions between object shape and object location

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Object identification and object localization are processes that are thought to be mediated by two relatively segregated brain regions that are independent from each other (Mishkin, Ungerleider & Macko, 1983; Goodale & Milner, 1992). Much literature, however, argues that the two processes might not be as independent as previously assumed, given the evidence that, when both processes are engaged in a single task, the performance of one process interferes with the performance of the other (Creem & Proffitt, 2001). Most of the experiments that report this interference, however, rely on complex motor movements in reach-to-grasp tasks, and it remains possible that the interference arises from the fact that the two visual mechanisms, albeit independent in nature, both influence the motor component of the complex task (Milner & Goodale, 2008). In this study, in a series of perceptual tasks with minimal motor demands, we explore the extent to which object identification and object localization are truly independent. Participants are required to compare two pairs of objects, presented simultaneously on a computer screen, and to determine how many differences the pairs have between them using a numeric keypad. The pairs can differ by zero, one or two changes either in object shape or location. The results indicate that the two visual processes are not independent but, rather, that the shape processing mechanism recruits the location mechanism in, at least, some integral part of its function. This finding was confirmed in a second experiment in which, in separate blocks, participants made only a location change detection in which the objects either did or did not have a concurrent shape change, or made a shape change detection with location changes present or not. Importantly, any change in the orthogonal dimension was irrelevant to the participant's task. Whereas shape changes interfered with location judgments, the converse was not true.

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Temporal processing: Mechanisms and models

Vista Ballroom, Boards 548–556

Sunday, May 9, 2:45 - 6:45 pm

36.548 **Targets lurking behind a mask: Suppression of onset transient causes mislocalization of targets**

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We embedded masking in an apparent motion display that allowed us to inspect the targets independently of the masks. A set of masks and targets is presented alternating in adjacent locations around a circular path (e.g., MTMTMTM). The entire set steps forward repetitively so that masks fall where targets had been and vice versa. At each location there is an alternation of targets and masks but across locations the display is seen as a moving train of masks and targets. This display allows observers to attentively track one target as it steps from location to location and avoid the masks that precede and follow it at each location. At high contrasts the target can be seen at its actual location in the moving train, whereas at low contrasts it vanishes and the space between the masks appears to be empty. Surprisingly, we find that in the middle range of contrasts the target is visible again but mislocalized, appearing to lurk behind the subsequent mask as if the two were presented together rather than sequentially. We propose that the suppression of the target's onset transient delays its visible appearance until the next onset transient, the one triggered by the subsequent mask at the target's location. These results support the proposal (Motoyoshi, VSS 2007) that a suprathreshold onset transient is required for a target to reach awareness even for high levels of target contrast.

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36.549 **Apparent contrast peaks, rather than plateaus, as a function of stimulus duration**

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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. Above this critical duration, apparent contrast plateaus. Contrary to Bloch Law'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. Contradictory results have been published; some support Bloch's Law and some support the Broca-Sulzer effect. 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. previous studies used the authors as subjects), and that no previous study properly controlled for subject criterion. To address these concerns, we designed a 2-AFC task that counterbalanced stimulus dynamics and controlled for subject criterion. Nine human 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 show that when the stimulus duration had a value between 67-100 ms, subjects experienced significantly higher apparent contrast, peaking at approximately 7% greater perceived contrast than very long durations of the same stimulus. This result more-or-less matches the Broca-Sulzer finding, but provides the appropriate controls for the first time. The existence of this peak has important implications for the design of power-efficient lighting and visual display equipment.

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36.550 **The temporal profile of visual information sampling and integration**

Caroline Blais[1](caroline.blais@umontreal.ca), Martin Arguin[1], Frédéric Gosselin[1]; [1]Department of Psychology, University of Montreal

While intuition suggests that visual information sampling through time is continuous, some have argued instead that sampling occurs in temporally discrete moments (VanRullen, & Koch, 2003). Of related interest is the question of how visual information is integrated through time. For example, is the information simply summed? We attempted to clarify the nature of visual information sampling and integration through time using a temporal response classification approach. Five subjects were asked to decide which of two movies, presented successively at the center of the screen, was the brightest. Each movie consisted in a sequence of 30 Gaussian blobs (200 ms) of different contrasts and subtending one degree of visual angle. A patch of spatial bit noise displayed through a Gaussian aperture was presented for 200 ms at the movies' location immediately before and after each movie. The contrast of the Gaussian blobs varied randomly through time. Specifically, on each trial, both movies had the same average and maximum contrast values across their temporal extent, but they differed in the temporal distribution of the contrasts. Thus, the brightness decision could only be influenced by the interaction between the participant's sampling/integration profile and the temporal sequence of contrasts in the stimuli. The sequence of contrasts that "optimally" led to a bright percept was computed for each participant by performing multiple regressions on the contrast temporal sequences and the participant's decisions. Three participants out of five showed a clear oscillation in their information sampling function (ranging between 5 and 15 Hz), and a linear decrease of information intake through time; the other participants reported being incapable of performing the task. Our results support the hypothesis that the visual system samples information in a discrete manner. They also indicate that the weight given to the information sampled decreases as information accumulates.

36.551 **Temporal extinction in hemi-neglect patients**

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Recent neuroimaging and neuropsychological studies have suggested that the right temporo-parietal junction has a dominant role in visual time estimation, suggesting that it forms a core structure of a when pathway. Most of the time, neurological patients with right brain damage present extinction (i.e. when two brief near-simultaneous stimuli are presented they only report the ipsilesional item). In this experiment, we were interested in how hemi-neglect patients with visual extinction deal with the duration estimation of two simultaneous events. For this purpose, we asked participants to compare the duration of two stimuli, a standard and a test (a blue and a red circle) presented in their central visual field at different time durations (test/standard duration: 0.3 to 3.0 sec). We compared the performance of normal observers and left hemi-neglect patients who had a right temporo-parietal stroke or a hematoma and who presented visual extinction. Stimuli were shown diametrically opposed on a virtual circle (radius = 2.6 deg. of visual angle). Simultaneous events were obtained by setting the half duration of the second stimulus at the end of the first stimulus. We found that control participants were almost not impaired to estimate the duration of these two simultaneous events in comparison to sequentially presented stimuli (drop of 3.0% in their duration threshold). In contrast, hemi-neglect patients were significantly more impaired in the simultaneous versus sequential presentation (drop of 7.0% at minimum in their duration threshold). This result is in accordance with previous studies showing the crucial role of the parietal lobe for time estimation. Furthermore, our results show that hemi-neglect is probably not simply a bias in orienting attention to one side of space but a more profound deficit to process simultaneously two objects.

36.552 Reaction time and event-related potentials to visual, auditory and vestibular stimuli

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Involuntary physical responses to vestibular stimulation are very fast. The vestibulo-ocular reflex, for example, occurs approximately 20ms after the onset of vestibular stimulation (Lorente de No, 1933, Nature). Despite these fast responses, reaction time (RT) to the perceived onset of vestibular stimulation occurs as late as 438ms after galvanic vestibular stimulation, which is approximately 220ms later than RTs to visual, somatosensory and auditory stimuli (Barnett-Cowan & Harris, 2009, Exp Brain Res). To determine whether RTs to natural vestibular stimulation are also slow, participants in the present study were passively moved forwards by .1178m (single cycle sinusoidal acceleration; 0.75m/s/s peak acceleration) using a Stewart motion platform and were asked to press a button relative to the onset of physical motion. RTs to auditory and visual stimuli were also collected. RTs to physical motion occurred significantly later (>100ms) than RTs to auditory and visual stimuli. Event related potentials (ERPs) were simultaneously recorded where the onset of the vestibular-ERP in both RT and non-RT trials occurred about 200ms or more after stimulus onset while the onset of the auditory- and visual-ERPs occurred less than 100ms after stimulus onset. All stimuli ERPs occurred approximately 135ms prior to RTs. These results provide further evidence that vestibular perception is slow compared to the other senses and that this perceptual latency may be related to latent cortical responses to physical motion.

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36.553 The effects of aging on surround modulation of backward contrast masking

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Saarela and Herzog (J Vis, 2008, 8(3):23, 1-10) measured backward masking for a centrally-viewed Gabor target that was produced by a small central mask that overlapped the target, a surround annulus mask, and a large combination mask (i.e., centre plus surround). Interestingly, they found that significantly less masking was produced by the combined mask than the central mask, even though the surround mask produced little masking on its own. One interpretation of this result is that the surround reduced the effectiveness of the central mask. The current study examined whether this non-linear interaction between centre and surround masks is affected by aging. Detection thresholds were measured for a Gabor target (duration=80 ms) in five younger (~25 years) and older (~69 years) subjects. The target was preceded or followed by surround, central, or combination masks. Thresholds were measured using surround, central, and combination masks that were displayed for 200 ms at five SOAs relative to target onset. The target and masks were 4 cpd and had a horizontal orientation. Mask contrast was 0.4; a baseline, no-mask condition also was included. Significant masking was obtained in both age groups, and the combined mask produced less masking than the central mask. However, the temporal pattern of masking across target-mask SOA differed noticeably between groups. Our results suggest strong centre-surround interactions exist in older subjects, but that the temporal properties of these interactions change with age.

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36.554 Temporal and spatial grouping: questions derived from studies in patients with schizophrenia

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Patients with schizophrenia are known to have an impaired sense of continuity, which, according to Husserl, involves the integration of past, present and future moments. The experience of present time is thus not a point but a period in time. It can be evaluated by means of simple psychophysics experiments, in which two bars appear simultaneously or asynchronously, and then stay on the screen until subjects decide whether the bars appeared synchronously or not. Healthy volunteers typically judge bars as synchronous for SOAs up to 30 to 50 ms, in contrast with patients, who require a longer SOA to detect that bars are asynchronous. However in these studies, bars were systematically presented in different hemi-fields, and a qualitative and quantitative impairment of inter-hemispheric transfer has been suggested to exist in patients with schizophrenia. This impairment could explain why time windows are larger in patients when bars appear in two different hemi-fields. We checked this hypothesis by manipulating the location of the squares, displayed in either the same or across hemi-fields. Continuous eye tracking ensured that subjects looked at a central fixation point. SOAs varied between 0 and 96 ms, and subjects decided if squares appeared synchronously or not. Results showed an enlarged time window in patients but no location effect (intra versus inter-hemispheric presentation). Furthermore the analysis of the Simon effect showed that patients are sensitive to very short duration stimuli (8.3 ms). This suggests that the enlargement of the time window is not associated with a fusion of events in time, but rather to a difficult comparison between stimuli onsets. As the two stimuli are clearly separated in space, this leads to the question of the relationship between spatial and temporal event-coding. We will especially discuss the possibility that comparing time-onsets requires mental grouping of the compared stimuli.

36.555 Oppel-Kundt illusion weakens with shortening of the time presentations

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The magnitude of the Oppel-Kundt illusion was measured at various durations of presentation followed by the masking stimulus. The referential part of the Oppel-Kundt figure was of 70 arc min length and comprised 7 stripes, height of which was 28 arc min and width 1 arc min. The empty test part of the stimulus was terminated by a single stripe. The figure luminance was 52cd/m2 and background luminance was 0 cd/m2. The masking stimulus 130×200 arc min in size consisted of randomly distributed stripes equivalent to illusory figure elements but brighter twice (100 cd/m2). The stimulus display duration varied from 60 ms to 1.3 s. Each presentation consisted of three parts: the blank fixation point exposed for 700 ms on the screen, the Oppel-Kundt figure itself, and the masking stimulus appearing immediately after the figure offset and lasting 2s. Two alternative forced choice constant stimulus procedures were used to measure illusion strength. Psychometric functions were obtained for all display durations of the stimulus. Six subjects participated in the experiments. The Oppel-Kundt illusion weakened gradually from the maximum strength (of about 20% overestimation) within the 700 – 1300 ms interval to 2 – 3 times less strength at about 100 ms and showed tendency to decrease further at shorter times. The results suggest that an extra time is required to establish the spatial misperception of the Oppel-Kundt type compared to the time used in the length estimation procedure. The results obtained also denote that the Oppel-Kundt and Müller-Lyer illusions may be of different origin, as previous experiments with the Müller-Lyer illusory figure didn't show substantial strength variations with duration of presentations.

36.556 Controlling the timing of oscillations in neural activity and consciousness with rhythmic visual stimulation

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What is the underlying nature of conscious awareness? William James observed introspectively that consciousness, "… does not appear to itself chopped into bits…A 'river' or a 'stream' are the metaphors by which it is most naturally described." (James, 1890). Since this time, however, evidence has accumulated supporting an alternative, discrete nature of perception

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(Efron 1970; VanRullen & Koch 2003). Recently, we have found evidence that perception fluctuates on a fine temporal scale, as a function of the phase of ongoing neural oscillations. Visual targets presented in the peak of ongoing 10 Hz neural oscillations (alpha rhythm) are visible, while identical stimuli presented in the trough are less likely to reach consciousness (Mathewson et al., 2009). Furthermore, we have shown that rhythmic visual stimulation at similar frequencies can control the timing of oscillations in consciousness (Mathewson et al., in press). Here we show that it is possible to control ongoing neural oscillations with this rhythmic visual stimulation, thus eliciting predictable concomitant oscillations in brain activity and consciousness. After the offset of periodic visual stimulation, masked visual targets were presented at multiple lags, sampling various phases with respect to the induced oscillations. Targets presented in phase with the preceding rhythmic stimulation were more likely to be detected than those out of phase. This induced oscillation in visual sensitivity was strongly correlated with an induced oscillation in the EEG. These effects were markedly smaller for randomly spaced preceding stimulation. These data provide the first evidence of a causal link between ongoing neural oscillations and fine grained temporal variations in consciousness, and reveal a method to experimentally control these discrete perceptual snapshots.

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Monday Morning Talks

Binocular vision: Models and mechanisms

Monday, May 10, 8:15 - 10:00 am
Talk Session, Royal Ballroom 1-3
Moderator: Zhong-Lin Lu

41.11, *8:15 am*

Evidence that disparities defined by luminance and contrast are sensed by independent mechanisms

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We recorded the initial vergence eye movements that were elicited by 1-D sinusoidal gratings differing in phase at the two eyes by ¼ wavelength (binocular disparity) and created by luminance modulation (LM) or contrast modulation (CM) of dynamic binary noise that was uncorrelated at the two eyes. Whether horizontal or vertical, gratings defined by either LM or CM elicited vergence responses that were always compensatory, working to reduce the ¼-wavength disparity. When LM was added to the CM, vergence responses showed a U-shaped dependence on the magnitude of the LM, reaching a minimum with in-phase LM of 3.0-5.5%, consistent with the nulling of 1st-order distortion products due to compressive nonlinearities early in the visual pathway. The minimum vergence responses here were robust, had longer latencies than the responses evoked by the LM component of the stimulus (differences ranging from 15.5 to 31.2 ms), and were attributed to cortical mechanisms that can sense disparities defined solely by contrast. In a second experiment, we found that disparities defined by LM in one eye and CM in the other eye ("LM+CM stimulus") generated only weak vergence responses and these were always in the "wrong" direction, i.e., opposite to the imposed ¼-wavelength disparity, consistent with mediation entirely by 1st-order distortion products associated with the CM stimulus. Thus, these (reversed) vergence responses could be eliminated entirely by adding a small amount of LM to the CM stimulus (in phase), and the greater the depth of the CM, the greater the added LM required for nulling. Controls indicated that the failure of the LM+CM stimulus to elicit vergence responses (after nulling the distortion products) was not due to differences in the amplitude or timing of the inputs from the two eyes. These data suggest that disparities defined by LM and CM are sensed by independent mechanisms.

Acknowledgement: NEI Intramural Program

41.12, *8:30 am*

Local and non-local effects on surface-mediated stereoscopic depth

Barbara Gillam[1](b.gillam@unsw.edu.au), Harold Sedgwick[2], Phillip Marlow[1]; [1]School of Psychology University of New South Wales Australia, [2]SUNY College of Optometry

The magnitude and precision of stereoscopic depth between two probes can be mediated by the disparity of each relative to a common background surface (e.g. Glennerster & McKee, VR 1999). For example, the common underestimation of background surface slant produces a bias in relative probe depth. Gillam & Sedgwick (ARVO 2000) have shown that this bias is reduced when flanking surfaces in the frontal plane reduce underestimation of background surface slant. Here we manipulate the relations between flanking surfaces, background surface, and probes to explore the propagation of slant across surfaces and from surfaces to isolated objects. In our first experiment observers set two disc probes to apparent equidistance when viewed naturally against a horizontally slanted rectangular random dot surface whose height was varied. Frontal plane random dot rectangles abutted this surface above and below. The bias in the probes increased as surface height/flanker distance increased but even with flankers 4.4 deg from the probes, bias was less when flankers were present. In a second similar experiment the flankers were slanted and a central background surface, when present, was in the frontal plane. For flankers alone probe bias did not diminish up to a 4.4 deg.separation of flankers and probes. The addition of a central frontal plane background surface strongly reduced this bias as the separation of the flankers increased regardless of whether the central surface filled the gap between flankers or was of constant height in the centre. These results may be related to changes in contrast effects from flankers to background. Stereoscopic depth between probes is thus influenced by a common background surface, by neighboring surfaces acting (contiguously or non-contiguously) on the background surface, and by distant surfaces acting directly on the probes. These local and non-local effects are determined by the overall configuration of probes and surfaces.

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41.13, *8:45 am*

Biases and thresholds for depth perception from monocular regions of binocular scenes

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Monocular regions in binocularly viewed scenes are usually found near a step-change in depth, between a foreground object and the background scene. They occur because one eye can see a portion of the background that is occluded in the other eye's view by the foreground object itself. That such regions have a role in the perception of depth is clear, but what is less well understood is the nature of the visual mechanisms that deliver the perceived depth. For example, for most configurations, viewing geometry predicts that monocular regions do not specify a unique depth. Instead, the possible depth interpretations can be expressed in terms of a 'depth constraint region'. This specifies the minimum possible depth, and sometimes a maximum. Previous research has shown that perceived depth is often close to the minimum possible depth. Here we used a depth discrimination experiment to directly compare thresholds and perceived depth, for both conventional binocular disparity and depth from monocular occlusions. Forced-choice psychophysical methods were used, where observers were shown a target and comparison stimulus, and asked which contained the greater depth step. Targets contained either conventional binocular disparity, or depth from monocular regions. Comparison stimuli contained conventional binocular disparity. Depth discrimination thresholds were considerably elevated for depth from monocular regions compared with conventional binocular disparity. Depth biases were also found. There were large individual differences, but some biases were consistent with observers perceiving less depth from monocular occlusions than the depth constraint region would predict. Our experiments suggest that a different, less precise, mechanism is at work in the perception of depth from monocular occlusions, than that available for the perception of depth from conventional binocular disparity.

41.14, *9:00 am*

Depth magnitude and binocular disparity: a closer look at patent vs. qualitative stereopsis

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Ogle (1952; 1953) used measurements of perceived depth as a function of disparity to divide human stereopsis into patent (quantitative) and qualitative categories. Patent depth percepts result from a range of disparities within and outside Panum's fusional zone, while qualitative percepts result only from very large disparities well beyond the fusional limit. While this dichotomy is widely recognized, it is not clear if it is merely descriptive, or if it reflects an underlying neural dichotomy. If the latter is true, then patent and qualitative depth percepts should be associated with other distinguishing properties. In this series of experiments we evaluate the possibility that the 1st /2nd –order dichotomy proposed by Hess & Wilcox (1994) maps onto Ogle's patent/qualitative distinction. We used a magnitude estimation technique to evaluate the amount of depth perceived from test disparities within and beyond the fusable range. In separate blocks of trials we used stimuli designed to activate either the luminance-based 1st-order or the contrast-based 2nd-order system. The stimuli were windowed, 1D luminance noise patches that were presented either as correlated or uncorrelated stereopairs which activated 1st and 2nd-order stereopsis respectively. As anticipated, we find that at small disparities our 1st-order stimuli

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provide patent depth percepts that follow geometric predictions. However, our data also reveal that quantitative depth percepts are provided by 2nd-order stereopsis at small disparities, but the amount of depth is less than predicted by viewing geometry. Further, depth percepts become qualitative as the stimuli become diplopic and are mediated by solely 2nd-order mechanisms. Our results show that Ogle's qualitative stereopsis reflects the operation of a distinct neural mechanism designed to provide crude depth estimates for diplopic stimuli. The situation for stimuli within Panum's area is not as straightforward, as both 1st and 2nd-order mechanisms provide quantitative depth information in this range.

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41.15, *9:15 am*

Shape aftereffects require awareness

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High-level face identity aftereffects require awareness (e.g., Moradi et al., 2005), whereas low-level tilt aftereffects occur without awareness (e.g., He et al., 2001). Here we demonstrate that intermediate-level aspect-ratio aftereffects require awareness. During adaptation, we presented an ellipse with a tall or flat aspect ratio to one eye. In the unaware condition, a dynamic-masking pattern was dichoptically presented to prevent awareness of the adaptor ellipse. In the aware (control) condition, the dynamic-masking pattern was monoptically superimposed over the adaptor ellipse so that both were visible. This control condition allowed us to determine the degree to which preventing awareness reduced aspect-ratio aftereffects over and above local masking effects. During adaptation (2000 ms), participants reported the aspect ratio of the adaptor ellipse (if it was visible) so that we could verify the awareness manipulation. After adaptation, participants reported the aspect ratio of a briefly-flashed (73 ms and backward-masked) test ellipse using the method of adjustment. In the aware condition, the aspect ratio of the flashed ellipse appeared distorted away from that of the adaptor (e.g., adaptation to a flat ellipse made a circle appear tall). No aftereffect occurred in the unaware condition. Lack of awareness rather than low-level local masking is likely to be the crucial factor because local inhibitory interactions in V1 would have been stronger in the monoptic-masking than dichoptic masking condition (at least for neural spike rates; Macknik & Martinez-Conde, 2004). Furthermore, these aftereffects arise from adaptation in global aspect-ratio coding and not local curvature coding, because they showed substantial binocular transfer, and no aftereffects occurred for the component curved segments using the same paradigm. These results suggest that adaptation of aspect-ratio coding requires high-level and/or recurrent processes that generate conscious awareness, similar to face identity coding and different from local orientation coding.

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41.16, *9:30 am*

Phase-Independent Contrast Combination in Binocular Vision

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How the visual system combines information from the two eyes to form a unitary binocular representation of the external world is a fundamental question in vision science that has been the focus of many psychophysical and physiological investigations. Ding and Sperling (2006) measured the perceived phase of the cyclopean image as a function of the contrast ratio between two monocular sinewave gratings of the same spatial frequency but different phases, and developed a binocular combination model in which each eye exerts gain control on the other eye's signal and over the other eye's gain control. Critically, the relative phase of the two sinewaves plays a central role. We used the Ding-Sperling paradigm but measured both the perceived contrast and phase of cyclopean images in seventy-two combinations of base contrast, interocular contrast ratios, eye origin of the probe, and relative phase. We found that the perceived contrast of cyclopean images was independent of the relative phase of the monocular sinewave gratings, although the perceived phase of cyclopean images depended on the relative phase and contrast ratio of the monocular images. We modified the Ding-Sperling binocular combination model in two ways: (1) phase and contrast of the cyclopean images are computed in separate pathways, although with shared cross-eye contrast-gain control; and (2) phase-independent local energy from the two monocular images are used in contrast combination, after additional within-eye contrast gain-control. With five free parameters, the model yielded an excellent account of data from all the experimental conditions.

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41.17, *9:45 am*

Perisaccadic Stereopsis from Zero Retinal Disparity

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A stimulus flashed immediately before a saccade is perceived as mislocalized in the direction of the eye movement. This perisaccadic-positional shift varies with the time from the flash to the saccade onset (TSO:). We have shown that this shift is also strongly affected by the stimulus luminance for a single flash: the shift is larger with low than high luminance. We also found an interaction between flashes presented asynchronously to the same eye in which a flash with a longer TSO is shifted more than a second flash with a shorter TSO. The results suggest a low-level mechanism in which the visual system combines eye position information with a persistent neural representation of the retinal image (temporal impulse response) to estimate the visual direction during saccadic eye movements. These results also provided the foundation for studies of a head-centric disparity mechanism in which asynchronous dichoptic foveal flashes presented before a saccade produced different amounts of perisaccadic shift in each eye and resulted in the depth percept from the head-centric disparity of the zero retinal disparity stimulus. This head-centric disparity also cancelled a retinal disparity of opposite sign, illustrating an interaction between the retinal and headcentric disparity estimates. This is the first experimental evidence that demonstrates a head-centric disparity mechanism for stereopsis in human.

Acknowledgement: NSF-BCS-0715076

Attention: Time

Monday, May 10, 8:15 - 10:00 am
Talk Session, Royal Ballroom 4-5
Moderator: Khena Swallow

41.21, *8:15 am*

Do We Experience Events in Terms of Time or Time in Terms of Events?

Brandon M. Liverence[1](brandon.liverence@yale.edu), Brian J. Scholl[1]; [1]Perception & Cognition Lab, Department of Psychology, Yale University

In visual images, we perceive both space (as a continuous visual medium) and objects (that inhabit space). Similarly, in dynamic visual experience, we perceive both continuous time and discrete events. What is the relationship between these units of experience? The most intuitive answer is similar to the spatial case: time is perceived as an underlying medium, which is later segmented into discrete event representations. Here we explore the opposite possibility -- that events are perceptually primitive, and that our subjective experience of temporal durations is constructed out of events. In particular, we explore one direct implication of this possibility: if we perceive time in terms of events, then temporal judgments should be influenced by how an object's motion is segmented into discrete perceptual events, independent of other factors. We observed such effects with several types of event segmentation. For example, the subjective duration of an object's motion along a visible path is longer with a smooth trajectory than when the same trajectory is split into shorter independent pieces, played back in a shuffled order (a path shuffling manipulation). Path shuffling apparently disrupts object continuity -- resulting in new event representations, and flushing detailed memories of the previous segments. In contrast, segmentation cues that preserve event continuity (e.g. a continuous path but with segments separated by sharp turns) shorten subjective durations relative to the same stimuli without any segmentation (e.g. when the segments are bound into a single smoothly-curving path, in trajectory inflection manipulations). In all cases, event segmentation was manipulated independently of psychophysical factors previously implicated in time perception, including overall stimulus energy, attention and predictability. These and other results suggest a new way to think about the fundamental relationship between time and events, and imply that time may be less primitive in the mind than it seems to be.

41.22, *8:30 am*

The Attentional Boost Effect and Temporal Synchrony

Khena Swallow[1,2](swall011@umn.edu), Yuhong Jiang[1,2]; [1]Department of Psychology, University of Minnesota, [2]Center for Cognitive Science, University of Minnesota

Increasing attention to one task typically impairs performance in a second task. However, the opposite can also occur: Encoding is facilitated for images that are presented at the same time that attention to an unrelated target detection task increases ("the attentional boost effect"; ABE). One potential explanation for the ABE is that the appearance of a target orients attention to the moment in time that the target appeared, facilitating perceptual processing of concurrently presented information (temporal orienting hypothesis). Accordingly, an image whose presentation overlaps in time with the presentation of the target will receive additional attention and processing resources. Alternatively, the ABE may result from temporal grouping (temporal grouping hypothesis). In previous experiments the images and targets always onset at the same time. Because common onset is a strong cue for temporal grouping, participants may have grouped the image and target into a single temporal entity. If this is the case, then increasing attention to the target should lead to enhanced processing of the entire temporal group, resulting in the ABE. To address these two hypotheses common onset and temporal overlap were manipulated. Experiment 1 demonstrated that the ABE occurs even when the target appears 100 ms later than the image. Experiments 2 and 3 showed that even though common onset is not necessary for the ABE, temporal overlap is. In these experiments the target could overlap with the image in time or it could appear over a mask 100 ms before or 100 ms after the image. Consistent with the temporal orienting hypothesis, the ABE was eliminated when the target did not overlap with the image in time. Based on these data, we suggest that perceptual processing of images presented with targets is enhanced because attention is oriented to the moment in time that the target appeared.

Acknowledgement: NIH and the University of Minnesota Institute for Marketing Research

41.23, *8:45 am*

Attentional modulation of the temporal contrast sensitivity

Isamu Motoyoshi[1](motoyosi@apollo3.brl.ntt.co.jp); [1]NTT Communication Science Labs, NTT

Recent psychophysical studies show that attention not only raises the sensitivity for visual targets, but also enhances the spatial resolution. On the other hand, little is known about the effect of attention on the temporal property. A few studies suggest that attention rather declines the temporal resolution for suprathreshold stimuli (e.g., Yeshurun & Levy, 2003), but it is unclear if this reflects changes in the general properties of the visual system. In the present study we examined the effect of attention on the contrast sensitivity over a range of temporal frequencies. Eight observers were asked to detect a drifting grating (2.2 c/deg, 0 to 40 Hz,) presented gradually at one of eight possible locations (4.6 deg eccentricity) on a uniform background while performing a letter recognition task in the central RSVP display (dual task). The results showed that the removal of attention by the central task largely declined the contrast sensitivity, particularly to low temporal frequencies, resulting in the band-pass shaped CSF. The sensitivity ratio (90% correct response) between the single and dual task modes was 7.2 for the static grating, far greater than those obtained with flashed gratings (~1.5; e.g., Carrasco, Talgar & Eckstein, 2000), but was 1.2 for the drifting grating of 40 Hz. A system analysis revealed that the removal of attention reduced the overall gain and increased the transient factor of the CSF, but little affected the cut-off temporal frequency. These results support the notion that attention extensively modulates the sensitivities for sustained, but not transient, visual inputs.

41.24, *9:00 am*

Silent updating: cross-dimensional change suppression

Jordan Suchow[1](suchow@fas.harvard.edu), George Alvarez[1]; [1]Harvard University

A vivid, color-changing display was created by continuously cycling 300 randomly-colored dots through the color wheel. Surprisingly, when this display was rotated about its center, the color-change appeared to halt. In one experiment, the display alternated between rotating and remaining still, and observers were asked to adjust the rate of color-change when the annulus was still to match the apparent rate of color-change when the annulus moved. We found that, as the angular velocity of the annulus increased, the matched rate of color-change decreased. At high angular velocities (180 deg/s), observers reported a nearly-complete halt in color-change. We suggest that the transients produced by the dots' motion cause transients produced by color-change to go unnoticed, updating silently. Next, we examined how transients produced by continuous changes in two dimensions, position (motion) and luminance (twinkle), interacted when one was dominant. Twelve dots appeared in a ring, centered about fixation (dot radius = 0.5 deg, ring radius = 10 deg). In a blocked design, observers were asked to report which one of the 12 dots moved or twinkled, while simultaneously, all of the dots changed along the other dimension. We measured thresholds for detecting the specified change, and found that they rose by as much as a factor of four when the amplitude of change along the irrelevant dimension was increased. The reported interference suggests that transient signals produced by one dimension can suppress transient signals produced by other dimensions; this may play an important role in controlling which changes in the visual field capture attention, and which will fail to capture attention, updating silently.

41.25, *9:15 am*

Competing for consciousness: Reduced object substitution masking with prolonged mask exposure

Stephanie Goodhew[1](s.goodhew@psy.uq.edu.au), Troy Visser[1], Ottmar Lipp[1], Paul Dux[1]; [1]School of Psychology, University of Queensland

In object substitution masking (OSM) a sparse, temporally-trailing four-dot mask impairs target identification, even though it has different contours from and does not spatially overlap with the target (Di Lollo, Enns, & Rensink, 2000; Enns & Di Lollo, 1997). OSM is thought to reflect "perceptual hypothesis testing" whereby iterative re-entrant processing loops are initiated from higher cortical areas to lower ones in an effort to confirm the identity of coarsely coded visual stimulation. Because the target is presented only briefly while the mask remains on the display, this hypothesis testing results in the mask being confirmed as the identity of the stimulus, thus excluding the target from consciousness. Here, we demonstrate a previously unknown characteristic of OSM: at prolonged (e.g., ~ 600 ms) mask durations, observers show reduced masking relative to intermediate mask durations (e.g., ~ 250 ms). In our experiments, observers identified the location of the gap (left versus right) in a Landolt C target, which was trailed by a four-dot mask for various durations (Supplementary Figure 1A). Target identification accuracy decreased up to mask durations of 240 ms, but then improved at longer durations (Supplementary Figure 1B). This recovery was obtained across a range of stimulus presentation conditions using both trained and naïve observers. Our findings demonstrate that although initially only one of two spatiotemporally adjacent stimuli presented to the visual system may gain access to consciousness, the "losing" stimulus is not irreversibly lost to awareness.

41.26, *9:30 am*

Delayed reentrant processing impairs visual awareness: An object substitution masking study

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In object substitution masking (OSM) a sparse, common-onsetting, mask impairs conscious target perception if it temporally trails the target and spatial attention is dispersed. Di Lollo et al.'s (2000) Reentrant Processing Model explains OSM as reflecting the interaction of feedforward and feedback processes in the brain. Specifically, upon presentation of a target and mask a coarsely coded representation of both stimuli progresses from V1 to anterior brain regions (feedforward sweep). Due to the low resolution of this information feedback/reentrant processing is employed to confirm the identity of the visual stimulation. According to this model, dispersing spatial attention delays feedforward processing, increasing the likelihood that only the mask remains visible once reentrant processing is initiated. Therefore, the mask will substitute the target in consciousness. Notably, the Reentrant Processing framework predicts that OSM will be elicited when either feedforward or feedback processing is delayed/impaired as both will increase the probability that only the mask remains visible once reentrant analysis begins. Thus, it should be possible to observe OSM for spatially attended stimuli if feedback processing from anterior regions is delayed. We presented subjects with a standard OSM paradigm (Landolt C target, four-dot mask) while they performed a difficult arithmetic task known to engage brain areas involved in reentrant processing (prefrontal and parietal cortex). All stimuli appeared in the same spatial location and, employing a standard dual-task protocol, the arithmetic and OSM tasks had either a short (100ms) or long (800ms) stimulus onset asynchrony (SOA). Increased OSM was observed at the short relative to the long SOA and this was more pronounced when subjects performed, rather than ignored, the arithmetic task. The results support a key prediction of Di Lollo et al.'s Reentrant Processing Model: if feedback processing is delayed then OSM can be observed for spatially attended objects.

41.27, *9:45 am*

Explicit Auditory Discrimination Improves During the Visual Attentional Blink

Keren Haroush[1](kharoush@gmail.com), Shaul Hochstein[1,2]; [1]Department of Neurobiology, Silberman institute of Life sciences, Hebrew University, Jerusalem,Israel, [2]Interdiciplinary Center for Neural Computation, Hebrew University, Jerusalem,Israel

Gating of sensory information is an elementary function, necessary for survival. In a series of studies, we investigated how sensory modalities interact in this process. We previously probed implicit allocation of multisensory attention during the Attentional Blink (AB), a failure to report a second target closely following first target detection (Haroush et al., ECVP 2007). In that study, we examined AB effects on the event-related Mismatch Negativity (MMN), which is 'automatically' elicited upon appearance of a deviant within a sequence of sounds. We found that MMN amplitude surprisingly increased during the AB, presumably underlying enhanced implicit auditory change detection processes. Here, we examined whether and how this effect translates into behavior, testing explicit auditory discrimination during a visual AB. Subjects were asked to identify two visual targets (T1&T2) embedded within a rapid distractor stimulus stream, and simultaneously perform an auditory discrimination task in a two-alternative-forced-choice, 2down-1up staircase paradigm. The first sound appeared at the beginning of the trial, (before visual T1), and the second simultaneously with visual T2, at variable SOAs. Three auditory protocol blocks were used with/without fixed reference tones to distinguish sensory classification from working-memory (WM) dependent discrimination (Nahum et al., 2009). When auditory discrimination was WM dependent, auditory performance during visual attentional blink trials significantly improved compared to trials where both visual targets were correctly reported. In contrast, sensory classification alone did not benefit from the visual AB, presumably because of its independence of WM. We conclude that attention-controlled WM resources that could not be used by the visual system during the AB are freed to be employed by the auditory system. Notably, this attention allocation is evident despite the additional resources taxed by task-switching. These results have implications for current theories of multiple information processing bottlenecks.

Acknowledgement: Supported by a grant from the Israel Science Foundation

Perception and action: Pointing, reaching, and grasping

Monday, May 10, 11:00 - 12:30 pm
Talk Session, Royal Ballroom 1-3
Moderator: Eli Brenner

42.11, *11:00 am*

Why we need continuous visual control to intercept a moving target

Eli Brenner[1](e.brenner@fbw.vu.nl), Jeroen BJ Smeets[1]; [1]Human Movement Sciences, VU University Amsterdam

It is obviously advantageous to continuously adjust one's movements if a target that one wants to intercept moves in an unpredictable manner. We examined whether continuous visual control is also useful for intercepting targets that move predictably. We have previously argued that the accuracy with which people hit moving targets is close to what one would expect from the known limits of human vision. This argument obviously rests on our having chosen the correct measures for representing human vision. We therefore designed the present study to directly examine to what extent continuously controlling one's movements on the basis of updated visual information is beneficial when intercepting targets that move in a completely predictable manner. Subjects hit virtual targets as they passed a goal. Just before reaching the goal the target could briefly disappear from view. This was achieved by giving a section of the surface across which the target moved (just before it reached the gap) the same colour as the target. The advantage of making the target disappear in this manner is that subjects can anticipate from the beginning of each trial when the target will disappear, so they can plan their movements in accordance with the time that the information will be available. Both the accuracy and the precision with which the subjects hit the target were lower if the target briefly disappeared from view just before being hit. The extent to which the precision depended on the time for which the target was invisible is consistent with predictions based on continuous control and the limits of human vision. Thus we can conclude that it is advantageous to have accurate visual information throughout an interception movement, even if the target moves completely predictably, because the resolution of vision is a limiting factor when intercepting moving objects.

42.12, *11:15 am*

The 'automatic pilot' for the hand in patients with hemispatial neglect

Stephanie Rossit[1](srossit@uwo.ca), Robert McIntosh[2], Paresh Malhotra[3], Stephen Butler[4], Monika Harvey[5]; [1]Department of Psychology, University of Western Ontario, London, Canada, [2]Department of Psychology, University of Edinburgh, Edinburgh, UK, [3]Division of Neurosciences and Mental Health, Imperial College London, London, UK, [4]Department of Psychology, University of Strathclyde, Glasgow, UK, [5]Department of Psychology, University of Glasgow, UK

Left hemispatial neglect manifests itself in a rightward bias in perceptual tasks, yet the presence of this neglect-specific bias in visuomotor control remains a matter of debate. Here we investigated the ability of neglect patients (compared to patients without neglect and healthy controls) to rapidly adjust or interrupt (stop) their ongoing reach in response to a rightward or leftward target jump. Although neglect patients successfully corrected their reaches towards the left and right target shifts, these corrections were significantly slowed for leftward jumps. Interestingly though, in the stop condition neglect patients performed involuntary corrections towards the leftward target, similarly to those seen for the control groups. Furthermore, and unexpectedly, we found that neglect patients were impaired at stopping their movements in response to target jumps towards both sides of space. We argue that, in contrast to optic ataxic patients, who suffered from lesions in their dorsal visual stream, neglect patients show an 'automatic pilot' for reaching, yet that this 'pilot' is markedly slowed when the target jumps in a leftward direction. We also suggest that the inability to stop an ongoing reach might be related to non-lateralized deficits in response inhibition.

Acknowledgement: This work was supported by a grant (SFRH/BD/23230/2005) from the Foundation for Science and Technology (FCT, Portugal) to S. Rossit.

42.13, *11:30 am*

Neural substrates of target selection for reaching movements in superior colliculus

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The primate superior colliculus (SC) is important for the execution of saccadic eye movements, but recent evidence suggests that it also plays a role in the higher-level process of target selection for saccadic and pursuit eye movements, as well as in covert attention shifts. Thus, we speculated that SC activity may participate in a generalized salience map used for target selection for a variety of purposes. To test this hypothesis, we recorded the activity of isolated intermediate-layer SC neurons in monkeys trained to perform a reach target selection task. The monkeys were rewarded for maintaining fixation and reaching to touch an odd-colored target presented in an array of distractors. Even though no eye movements were made in this task, many neurons discriminated the target before the onset of the reach, and this activity typically persisted throughout the trial, consistent with SC involvement in target selection for reaching movements. To further determine if this SC activity plays a causal role in reach target selection, we tested the effects of temporary focal SC inactivation on monkeys' performance in two reach target selection tasks. In one task, a target was followed after a variable SOA by a distractor, and monkeys were rewarded for reaching to the target. In the second task, two potential targets were shown and a cue at the fovea indicated which was the target. Monkeys were required to maintain eye fixation throughout each trial. In both tasks, after SC inactivation, when the target appeared in the inactivated part of the visual field,

Monday AM

monkeys made more reaching errors to the distractor. In contrast, monkeys were unimpaired when the target was presented without distractors. These results establish that, in addition to its role in saccades, the SC plays a causal role in target selection for reaching movements.

Acknowledgement: National Eye Institute grant R01-EY014885, Core grant P30-EY006883, and R.C. Atkinson Fellowship Award

42.14, *11:45 am*

Developmental studies of visual-motor integration: A comparative approach

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Effortless, fluid integration of perception and action is ubiquitous during successful navigation of our ever-changing environment. How this integration plays out in real time is understudied, largely because visual perception and motor actions are often studied piecemeal by different investigators. We have taken a comparative, developmental approach to this problem. We used a dynamic reaching paradigm to track developmental changes in visually-guided motor control, investigating how infants calibrate and refine motor actions over development. We conducted parallel studies in human and macaque infants and found striking similarities across primate species. We tested visually-guided reaching in 50 human infants cross-sectionally (6–15 mos) and 2 macaque monkeys longitudinally (5–6 mos). We measured handedness and latency as a function of target location, and localization and grasp orientation errors. Infants were seated in a swivel chair that was rotated to face a vertical reaching board at the beginning of each trial. Target position was varied in a pseudo-random order trial-to-trial. All infants reached reliably for the targets. Human infants showed a slight bias for right hand reaches compared to left; they occasionally reached with both hands. Monkeys performed similarly, except they had a slight left bias. Importantly, however, both species' hand choices changed systematically with object position across the reaching space. The shortest reach latencies were to the right and left of midline, with longer latencies for midline and extreme lateral locations. Localization and grasp orientation errors were quickly corrected in human infants and declined with age; monkeys rarely mis-reached but grasp orientation errors declined over sessions. Human and monkey infants seamlessly used perceptual information to plan motor actions across visual space, to guide actions adaptively, and to correct slight errors in execution. Even the youngest infants were adept at perceptual-motor integration, and visually-guided actions only became more fluid over development.

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42.15, *12:00 pm*

Mapping Shape to Visuomotor Mapping: Generalization to Novel Shapes

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The accuracy of visually guided motor movements largely depends on the stability of the sensory environment that defines the required response mapping. Thus, as the environment keeps changing we constantly have to adapt our motor responses to stay accurate. The more sensory information we receive about the current state of the environment the more accurate we may be. Recruitment of additional cues that correlate with the environment can therefore aid in this adaptation process.

It has previously been shown that subjects recruit previously irrelevant cues to help them switch between 2 specific visuomotor mappings (e.g. Martin et al., 1996; van Dam et al., 2008). However, in rapidly changing environments additional cues will only be of real benefit if it is possible to learn a more continuous correlation between the cue and required visuomotor response. Here we investigate transfer of explicitly trained cue-element/response-mapping combinations to other cue elements from the same continuous scale (a shape morph).

In our experiment subjects performed a rapid pointing task to targets for which we manipulated the visuomotor mapping. During training subject simultaneously learned two mappings to two different target shapes. The target shapes were taken from a set of shape morphs (we morphed between spiky and circular shapes). After five sessions of 180 training trials, using catch trials, we tested subjects' performance on different target shape morphs that could either come from an interpolation or an extrapolation along the shape morph axis. Results show that for 7 out of the 12 subjects learning is not restricted to the trained shapes but interpolates and partially also extrapolates to other shapes along the morph axis. We conclude that participants learned implicitly the newly defined shape axis when trained with two distinct visuomotor mappings and they generalize their visuomotor mappings to this new dimension.

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42.16, *12:15 pm*

Divergent representations of manipulable and non-manipulable objects revealed with repetition blindness

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Neuroimaging and neuropsychological studies suggest that manipulable objects (i.e., objects associated with particular actions) have distributed representations that reflect not only their visual features but also the actions they afford. This study used rapid serial visual presentation (RSVP) to investigate the nature of the representations underlying identification of manipulable objects. When stimuli are presented at RSVP rates, items repeated within 500 msec of each other are frequently missed, a phenomenon known as repetition blindness (RB). RB is thought to occur because repeated stimuli activate the same abstract memory representation (type) but are not individuated into distinct visual episodes (tokens) due to the spatio-temporal constraints of RSVP. In two experiments that employed different stimulus sets (photographs vs line drawings), observers viewed RSVP streams containing three objects and six masks and attempted to identify the objects. The first and third objects in the stream were either the same object repeated, or distinct objects, and were either Action (i.e., manipulable) or Non-Action (non-manipulable) objects. There were two main findings. First, joint accuracy for reporting two distinct Action objects was considerably lower than for Non-Action objects, even when the two object classes were equated in terms of ease of identification. Second, whereas Non-Action objects induced RB independent of the objects' orientation, in keeping with previous findings (Harris & Dux, 2005; Hayward et al., in press), there was no RB at all for Action objects. Instead, significant priming was obtained when an Action object was repeated in the same orientation. Taken together, these findings implicate independent sources of visual and motor information, which require integration for successful identification. Under RSVP conditions, this renders Action objects vulnerable to interference from other objects associated with conflicting motor programs, but facilitates individuation of repeated objects associated with the same action.

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Object recognition: Categories

Monday, May 10, 11:00 - 12:30 pm
Talk Session, Royal Ballroom 4-5
Moderator: Sharon Gilaie-Dotan

42.21, *11:00 am*

Location information in category-selective areas: retinotopic or spatiotopic?

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Challenging the classic view that the ventral and dorsal visual streams correspond to "what" and "where" pathways, recent studies have reported the existence of location information, independent of object category, in traditionally object-selective regions of ventral visual cortex (e.g., Schwarzlose et al, 2008, PNAS). Does the location information in these higher-order visual areas reflect pure retinotopic position, or absolute location independent of eye position? To find out, we functionally localized several regions in the ventral visual stream, including the lateral occipital complex (LOC), fusiform face area (FFA), parahippocampal place area (PPA), and extrastriate body area (EBA). We then used multivariate pattern analysis to measure category and location information within these areas during the main task, in which subjects viewed blocks of three different kinds of stimuli (faces,

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scenes, bodies) in four different locations. The four locations varied in both eye position and stimulus position, generating pairs of conditions in which the stimuli occupied different retinotopic (eye-relative) positions but the same spatiotopic (absolute screen) position, the same retinotopic position but different spatiotopic positions, the same in both retinotopic and spatiotopic position, or different in both. In each of the object-selective regions, we found both location-invariant category information and category-invariant location information, replicating Schwarzlose et al. Moreover, the location information was specific to retinotopic coordinates. That is, the multi-voxel pattern of fMRI response was more similar (i.e., more highly correlated) across conditions that shared the same retinotopic position than across conditions that shared the same spatiotopic position. Furthermore, there was no evidence of any spatiotopic location information in any of the regions examined. In early visual cortex (identified using retinotopic mapping), no category information was apparent, and location information was again exclusively retinotopic. These results suggest that even higher-order category-selective visual areas code stimuli according to a retinotopic coordinate frame.

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42.22, *11:15 am*

The functional neuroanatomy of object agnosia: A case study

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Object agnosia is defined as an object recognition deficit and typically results from lesions of occipito-temporal cortex. However, little is known about the cortical (re-)organization of visual representations and, specifically, object representations in agnosia. We used fMRI to examine the cortical organization with respect to retinotopy and object-related activations in an agnostic patient and control subjects. Patient SM has a severe deficit in object and face recognition following damage of the right hemisphere sustained in a motor vehicle accident. Standard retinotopic mapping was performed to probe the organization of visual cortex in the lesioned and the non-lesioned hemisphere and to determine the lesion site relative to retinotopic cortex. Furthermore, we investigated object-selectivity in ventral visual cortex using fMRI-adaptation paradigms. Retinotopic mapping showed regular patterns of phase reversals in both hemispheres. Surface analysis revealed that the lesion is located in the posterior part of the medial fusiform gyrus anterior to V4 and dorsolateral to VO1/VO2. The contrast between object and blank presentations showed no significant difference in activated volume in SM, compared to healthy subjects. FMRI-adaptation induced by different types of objects, however, revealed differences in activation patterns. In healthy subjects, object-selective responses were found bilaterally in the anatomical location of the lesion site as well as posterior, dorsal, and ventral to the site. In SM's right hemisphere, voxels immediately surrounding the lesion lacked object-selectivity. Object-selective voxels were exclusively found approximately 5 mm posterior to the lesion. In SM's left hemisphere, no object-selective responses were found in mirror-symmetric locations. Our data suggest that the right medial fusiform gyrus is critically involved in causing object agnosia and, furthermore, in adversely affecting object processing in structurally intact areas of the ventral pathway in the non-lesioned hemisphere. Future studies will show the impact of this isolated lesion on object processing in the dorsal pathway.

42.23, *11:30 am*

Fast decoding of natural object categories from intracranial field potentials in monkey's visual cortex

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Object categorization involves very fast cognitive processes. Previous studies have demonstrated that both human and non-human primates can categorize natural scenes as containing animals very rapidly and accurately (Thorpe et al. 1996; Fabre-Thorpe et al. 1998). How such abstract categories could be accessed by visual processes remain an open question. Here two macaque monkeys were trained to perform such animal categorization using natural scenes. During task performance, we recorded intracranial EEG from intermediate areas of the ventral stream of the visual cortex. Unlike standard brain imagery techniques, electrocorticogram provides a good balance between time resolution and spatial coverage. Using multivariate pattern analyses, we quantified at millisecond resolution the amount of visual information conveyed by intracranial field potentials from 12 electrodes in one monkey and 16 in the other. As previously demonstrated in human epileptic patients (Liu et al. 2009) our analyses suggest that category information can be decoded as early as 100 ms post-stimulus. More importantly, we found that the readout performance of a linear classifier was significantly correlated with reaction times using single trial signals from V2 and V4. These results suggest that categorical decisions could be supported by the early information conveyed by relatively low-level visual areas.

42.24, *11:45 am*

Giving the brain a hand: Evidence for a hand selective visual area in the human left lateral occipito-temporal cortex

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There is accumulating evidence for a "map" of brain areas specialized to represent and process specific categories of stimuli. Evolution may have played a significant role in shaping such specializations for particular categories. For example, stimuli which have played a critical role in social adaptive behaviour such as bodies and faces have dedicated cortical representations in visual cortex: extrastriate body area (EBA) and fusiform face area (FFA), respectively. The human hand with its unique structure (e.g., finger-thumb opposition) has played a major role in human evolution, and is thus a prime candidate to be represented by a specialised brain area in the visual cortex. Using functional magnetic resonance imaging (fMRI), we provide the first evidence for a brain area selective for the human hand. In our study, 14 right handed participants looked at 8 different categories of stimuli (whole-bodies, body-parts, hands, fingers, feet, robotic-hands, tools and chairs) and performed the one-back task. The hand-selective area was found in all participants within the lateral occipital sulcus and so we name this area the Lateral Occipital Hand Area (LOHA). LOHA responds more to hands compared to body stimuli and it is anatomically separated from body selective areas (e.g., EBA). In addition, LOHA responds more to hands compared to i) hand parts (fingers), ii) other single body parts (feet) and iii) stimuli sharing functional traits with hands (robotic hands). These findings suggest that LOHA is specialized for representing and processing the shape of the human hand as a whole. Remarkably, in contrast with other body-selective sites, which are primarily lateralized in the right hemisphere (EBA and FFA), LOHA is localized in the left hemisphere. Overall, our study sheds further light on the functional organization of the human visual system and brings new evidence in support of the domain-specificity theory for visual object recognition.

42.25, *12:00 pm*

Top-down engagement modulates the neural expressions of visual expertise

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Perceptual expertise is traditionally associated with enhanced brain activity in response to objects of expertise in category-selective visual cortex, primarily face-selective regions. We reassessed this view asking (1) What are the neural manifestations of visual expertise and are they confined to category-selective cortex and (2) Is expertise-related activity an automatic process or does it depend on the top-down engagement of the experts with their objects of expertise? We conducted two fMRI studies comparing neural manifestations of car expertise in absence of task constraints (Experiment 1) and when the task-relevance of cars was explicitly manipulated (Experiment 2). We unveiled extensive expertise-related activity throughout the visual cortex, starting as early as V1, which extended into non-visual areas. However, when cars were task-irrelevant, the expertise-related activity drastically diminished, indeed, becoming similar to the activity elicited

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by cars in novices. We suggest that expertise entails voluntary top-down engagement of multiple neural networks in addition to stimulus-driven activation associated with perceptual mechanisms.

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42.26, *12:15 pm*

Trade-off between spatial resolution and gray-scale coding for letter recognition

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Letter recognition is usually thought to rely on the shape and arrangement of distinctive pattern features such as line segments and curves. In findings to be reported, we have found that high levels of letter-recognition accuracy are possible when low-pass filtering reduces the spatial bandwidths of letters to levels not expected to support adequate recognition of letter shape. We addressed this apparent discrepancy by testing the hypothesis that the human visual system relies increasingly on grayscale coding (contrast coding) for letter recognition when spatial resolution is severely limited. The hypothesis predicts that as spatial resolution for rendering letters decreases, subjects will rely more on grayscale variations, therefore requiring a larger gap between contrast thresholds for letter detection and letter recognition. We measured contrast thresholds for detecting and recognizing single letters (Courier, 1°) drawn at random from the 26 letters of the English alphabet. The letters were low-pass filtered (blurred) with a third-order Butterworth filter with bandwidths (defined as the frequency at half amplitude) of 0.9, 1.2, 2, and 3.5 cycles per letter. Threshoolds were also measured for unfiltered letters. Data from seven normally-sighted subjects showed that differences in contrast thresholds between detection and recognition increased substantially with decreasing bandwidth. The ratio of recognition to detection thresholds increased from 1.5 for the unfiltered letters to 8.8 for the most blurred letters (0.9 c/letter). These findings support the hypothesized increased reliance on grayscale information for letter recognition when spatial resolution is reduced.

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Eye movements: Selection and cognition

Royal Ballroom 6-8, Boards 301–315

Monday, May 10, 8:30 - 12:30 pm

43.301 Orientation statistics at fixation

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Eye movements are not random. When viewing images, human observers tend to fixate on regions that, on average, have higher contrast than randomly selected regions (Reinagel & Zador, 1999). We extend this analysis to the study of local orientation statistics via the “orientation tensor” (Granlund & Knutsson, 1994), computed as the 2x2 covariance matrix of local horizontal and vertical derivatives (i.e., the gradient vector) within an image patch. This may be converted into three natural parameters: energy, orientedness, and orientation. Energy is the total variance in the gradients, and is related to contrast; orientedness indicates the strength of the dominant orientation; orientation indicates the predominant orientation. We use an eye movement database (van der Linde et al., 2009) to measure the orientation tensor within local 1 deg image patches that are either fixated by human observers (n=29), or selected at random (by using fixations for a different, randomly chosen image). We then obtain image-specific log distributions of the three parameters of the orientation tensor. Averaged across all images and subjects, energy is higher in fixated patches, consistent with similar reports on contrast, but we do not observe such differences for orientation or orientedness. However, when we compare fixated and random distributions of these parameters on an image-by-image basis, we observe systematic differences. In particular, for the majority of images, the distribution of fixated patches, when compared to that of random patches from that image, is closer to the generic distribution averaged over all images. We use multi-variate techniques to characterize this effect across the database. We find that fixated distributions shift towards the generic distribution by about 10 to 20%, and the trend is significant for all three parameters. Our results suggest that when viewing a particular image, observers fixations are biased towards locations that reflect the typical orientation statistics of natural scenes.

43.302 Second-order saliency predicts observer eye movements when viewing natural images

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Humans move their eyes approximately three times per second while viewing natural images, between which they fixate on features within the image. What humans choose to fixate can be driven by features within the early stages of visual processing (salient features e.g. colour, luminance), top-down control (e.g. task, scene schemas), or a combination of both. Recent models based on bottom-up saliency have shown that it is possible to predict some of the locations that humans choose to fixate. However, none have considered the information contained within the second-order features (e.g. texture) that are present within natural scenes. Here we tested the hypothesis that a salience map incorporating second-order features can predict human fixation locations when viewing natural images. We collected eye movements of 20 human observers while they viewed 80 high-resolution calibrated photographs of natural textures and scenes. To maintain natural viewing behaviour but keep concentration, observers were asked to study the scene in order to recognize sections from it in a follow-up forced-choice test. Interestingly, human observer eye movement patterns when viewing natural textures do not show the same central bias as with natural scenes. Salience maps were constructed for each image using a Gabor-based filter-rectify-filter model that detects the second-order features. We find that the fixation location predicted by a model that incorporates second-order information does not differ from that of human observers when viewing natural textures. However, when the model is applied to natural scenes, we find that the ability of the model to predict human observer eye movements decreases, due to the failure in capturing the central bias. A further improvement to the model would be to incorporate a mixture of bottom-up salience and top-down input in the form of a central bias, which may increase the performance of the model in predicting human eye movements.

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43.303 What is the shape of the visual information that drives saccades in natural images? Evidence from a gaze-contingent display

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The decision of where to move the eyes in natural scenes is influenced by both image features and the task at hand. Here, we consider how the information at fixation affects some of the biases typically found in human saccades. In an encoding task, people tend to show a predominance of horizontal saccades. Fixations are often biased towards the centre of the image, and saccade amplitudes show a characteristic distribution. How do these patterns change when peripheral regions are masked or blurred in a gaze-contingent moving window paradigm? In two experiments we recorded eye movements while observers inspected natural scenes in preparation for a recognition test. We manipulated the shape of a window of preserved vision at fixation: features inside the window were intact; peripheral background was either completely masked (Experiment 1) or blurred (Experiment 2). The foveal window was square, or rectangular or elliptical, with more preserved information either horizontally or vertically. If saccades function to increase the new information gained on each fixation, a horizontal window should lead to more vertical saccades and vice versa. In fact, we found the opposite pattern: vertical windows led to more vertical saccades, and horizontal windows were more similar to normal, unconstrained viewing. The shape of the window also affected fixation and amplitude distributions. These results suggest that saccades are influenced by the features currently being processed, rather than by a desire to reveal new information, and that in normal vision these features are sampled from a horizontally elongated region. The eyes would rather continue to explore a partially seen region than launch into the unknown.

Acknowledgement: Commonwealth Postdoctoral Fellowship

43.304 Temporal scramble disrupts eye movements to naturalistic videos

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When viewing a scene, humans rapidly move their eyes to foveate visual features and objects of interest. In natural conditions, this process is temporally complex, yet little is known about how the temporal structure of naturalistic stimuli affects the dynamics of eye movements under free viewing. We tracked eye position while observers watched a 6-minute scene from a feature film that was shot as a continuous sequence (with no cuts). Consistent with previous reports (Hasson et al., J Neurosci, 2008), eye movements were highly reliable, both across repeated presentations and across observers. We then divided the scene into clips of various durations (ranging from 500 ms to 30 s) and scrambled the temporal order of the clips, thereby introducing cuts. Eye-movement reliability, quantified as the covariance between eye positions to the scrambled clips and those during the corresponding portions of the full-length scene, was found to increase as a power-law function of clip duration, from ~0 for the 500 ms clips to an asymptote for clips >30 s in duration. We developed a model that assumed that observers searched randomly following each cut, fixating at arbitrary locations until finding a target of interest and then tracking it faithfully. We fit the model to the data by analytically deriving the model’s prediction for the relationship between clip duration and eye movement reliability (covariance). While simple, this model fit the data well with only two free parameters (number of possible target locations, asymptotic covariance). However, the model fits exhibited a systematic bias at the shortest scramble

durations. We conclude that exploratory fixations depend critically on the temporal continuity of stimuli, and that human observers might utilize a random search strategy when viewing naturalistic, time-varying stimuli.

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43.305 **Suboptimal Choice of Saccade Endpoint in Search with Unequal Payoffs**

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Purpose. Observers' choice of saccade endpoint in searching for a target embedded in noise is well modeled by an ideal observer (Najemnik & Geisler, Nature, 2005). In this study we ask whether observers' choices of saccade endpoint optimally take rewards into account.

Method. Observers searched for a target in noise. On each trial, the observer fixated the center of a display. Eight Gaussian-white-noise disks (1.5 deg diam, 10 deg eccentricity) appeared, equally spaced around fixation, to one of which was added a low-contrast Gabor-patch target. Correct detections in most locations resulted in a 100-point reward, and either the top (90 deg) or bottom (270 deg) position had a reward of 500 points (indicated in advance). There was no reward for incorrect responses. The contrast of the Gabor patch was adjusted so that d' = 1 at 10 deg eccentricity. The observer had 250 ms to initiate a saccade. The target remained visible for 200 ms following the end of the saccade, thus affording a second look at the stimulus. Subjects judged which patch contained the target. A full visibility map was obtained and used to model saccadic choices of an ideal observer that maximizes expected gain.

Results and Conclusions. There were significant differences between actual and ideal distributions of saccade location in all conditions (8 target positions x 2 reward positions). The ideal observer tends to make short saccades halfway between the initial fixation position and the target or high-reward position. Human observers make longer saccades, landing on or near the 8 patches. Most saccades land on or near the target or the high-reward position. For each condition, efficiency was calculated as the ratio of the human observer's actual gain to that expected of the ideal observer. Efficiencies were near optimal for targets adjacent to the high-reward location.

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43.306 **Eye movements during picture exploration and natural action**

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Much of the work on fixation patterns in complex scenes has been performed with 2D images. However, in natural behaviour fixation patterns are highly task dependent. 2D images differ from the natural world in several ways, including the nature of the task demands and the dimensionality of the display. To investigate the role of these factors in gaze patterns, we monitored eye movements in both normal and schizophrenic participants. Schizophrenic patients have previously been shown to exhibit prolonged fixations and reduced spatial exploration in free viewing of 2D images. Participants started with two free viewing tasks. They were asked to (1) look at a scene on a computer screen (2D passive exploration) and (2) look at a real scene on a table (3D passive exploration). Then, participants performed two other "active viewing" tasks: (1) picturing themselves making a sandwich in front of a computer screen (2D active exploration) and (2) making a sandwich (3D active exploration). The scenes contained both task- relevant and irrelevant objects. Temporal and spatial characteristics of gaze were compared for each task. The primary factor in determining gaze location and duration was the task demands. Fixation durations were longer for the active than the passive task for both 2D and 3D images. Normal participants did not show any difference between 2D and 3D images in passive viewing condition, although 2D and 3D active viewing conditions differed. Moreover, allocation of gaze between relevant and irrelevant objects differed in active viewing but not in passive viewing. Participants looked more at relevant objects during the real task. For patients with schizophrenia, the introduction of a task essentially eliminated differences from normal controls that are observed in passive viewing. Thus real versus 2D images had little effect on viewing patterns, but the task constraints were critical.

43.307 **Eye movement preparation affects target selection for manual reaching**

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During many daily tasks we typically look at an object first and then we reach towards it. It has been shown in monkeys that areas related to hand movement planning integrate information about the current eye and hand position. Similar interactions have been observed using psychophysical studies in humans. In a series of experiments we measured how reaching preferences are updated when eye position is changing. In the first experiment participants were asked to reach to one of two locations in a free choice task, while fixating at different locations on the screen. In accordance with previous studies, we demonstrated that selection of the reaching target is influenced by the current eye position: Participants were more likely to choose targets closer to the current gaze direction. In the second experiment we asked participants to make a saccade to a cued location, and during saccade preparation we briefly flashed two possible reaching targets. The results showed that reaching goal preferences were influenced by the future eye position for targets flashed 100 ms before the eye movement onset, suggesting that reaching target selection takes into account the future eye position before saccade onset. This extends physiological and behavioural findings on eye - hand position interactions by demonstrating updating of reaching preferences before the eye movements.

43.308 **Eye-hand coordination in finding and touching a target among distractors**

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We asked observers to find and touch a target among distractors. Observers earned money by touching the target. Earnings decrease linearly with movement time. If observers did not initiate hand movement until the target was found they would earn much less than if they attempted to integrate visual search and reach. Two clusters of objects were located to left and right of the midline of the display, one cluster containing four objects, the other two. Each object was equally likely to be the target. Initially the observer did not know which object was the target but could gain information by searching. The observer could potentially update his movement trajectory based on information from visual search. Optimal initial movement strategy was to move toward the larger cluster while optimal visual search strategy was to first search the smaller, thereby quickly learning which cluster contained the target. We compare observers' initial search/reach to the performance leading to maximum expected gain (MEG). Methods: Objects for the search/reach task were presented on a 32" ELO touchscreen located on a virtual arc around a starting position. Eye movements were tracked with an Eyelink II tracker. Before the search/reach task, observers were trained in moving on the touchscreen and in visual search with keypress response. Five naïve observers participated. Results: For each trial we recorded the direction of initial movement and the cluster initially search. Two observers correctly searched the cluster with fewer objects first ($p < .001$) while moving toward the other ($p < .01$). These observers earned within 9% of MEG. The remaining observers failed to search/reach optimally ($p > .05$). These observers received on average 62% of MEG.. As observers searched objects, they eliminated possible targets. We will discuss how information accrued in visual search affected the movement trajectory.

43.309 **Eye movement transition depends on tasks and stored information in 3-D object recognition**

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In the 3-D object recognition task, the patterns of eye movements during the learning phase were different depending on tasks, suggesting that eye movement patterns may reflect different encoding strategies depending on the prespecified task. When the same object is presented repeatedly, information to encode objects exquisitely would be different depending on information that has already been stored. In this study, we measured eye movements during learning of 3-D objects to reveal the effects of stored information on spatiotemporal eye movement patterns, and investigate the 3-D object encoding processes. An unfamiliar 3-D object was presented for 10 seconds at the study phase, during which participants' eye movements were recorded. It was followed by a recognition test in which the test stimulus was presented 500 milliseconds from either the same viewpoint as they learned (non-rotation condition) or a various viewpoint (rotation condition). The task was to respond as to whether or not it was the same object which had been presented earlier regardless of their rotation, and the same learning objects were presented repetitively. In the beginning of experiment, participants fixated on the center of components of objects more frequently in the rotation condition, suggesting that objects were encoded more categorically. The proportions of large saccades were the same at first, but, after a few trials, they changed depending on the test condition: At the beginning of trials, the arising proportion of large saccades was significantly higher in the rotation condition than in the non-rotation condition, and immediately after the large saccade longer durations arose more often in the rotation condition. These results suggest that participants may encode 3-D objects more categorically in the rotation condition, and after a few trials they obtain the global shape of object first based on their categorical stored information.

43.310 **Saccade target selection in subjects cued to remember single or multiple visual features**

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Most visuomotor experiments use dots or simple shapes as targets, but in the real world we act on complex objects with many visual features. Here we tested the limitation of memory in a feature detection paradigm for saccades. 6 Head-fixed subjects were shown a 'probe' template with a conjunction of two features (shape and texture) at central fixation for 500 ms, and instructed to remember either the shape, texture, or both features before each trial. After a delay, subjects were presented with a mask followed by stimuli at four radial locations at an eccentricity of 5° for 1 second. After stimuli were extinguished, subjects were required to saccade to the stimuli that matched the probe. In trials where only one feature was to be remembered, the three other stimuli differed from the probe only in the given feature. In trials where both features were to be remembered, the other stimuli differed in one or both features. We analysed the data with a 2(number of features)x4(locations)x6(subjects) mixed-model ANOVA, with subjects as a random factor. Results indicate that subjects performed significantly better if they only had to remember only one feature. Interestingly, a main effect of probe location was also found. Post hoc tests revealed that subjects responded significantly better if the probe was shown left of center rather than to the top right, and if shown at the top left rather than bottom right. There were also significant interactions between probe location and both number of features and subject. We are currently analyzing probability distributions of correct and incorrect saccades to one or both features within each task, and compared across both tasks. Future experiments will repeat this paradigm with transcranial magnetic stimulation over parietal cortex to examine its causal role in the integration of visual features into the motor plan.

Acknowledgement: Ontario Graduate Scholarship Program, CIHR, Canada Research Chairs Program

43.311 **Dynamic interactions between visual working memory and saccade planning**

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In a recent line of psychophysical experiments, we found that working memory for a surface feature (color) interacts dynamically with saccadic motor planning, even if subjects are instructed to make saccades based only on spatial cues. A match between the remembered color and the color of either the designated target or a distractor influences saccade target selection, metrics of averaging saccades, and saccade latency in a systematic fashion. We give a theoretical account for these effects using the framework of dynamic neural fields, in which neural processes are modeled through the evolution of continuous activity distributions over metric feature spaces. In an architecture that is consistent with visual processing pathways in the primate cortex, we use separate multi-layer representations for spatial and surface feature information, which are both coupled bidirectionally to a combined perceptual representation of visual input. Peaks of activity in the top layer of the spatial representation indicate the metrics of saccadic motor plans. In the feature representation, the contents of working memory are represented by activity peaks that are self-sustained by means of lateral interactions. Although these memory peaks do not evoke any overt activity in the earlier perceptual representations by themselves, they influence the evolution of activity in response to a visual stimulus. They can thereby exert a biasing effect on the formation of a motor plan. With this model, we simulated the complete experimental time course, including formation of working memory from a visual cue, planning and execution of saccades under different stimulus conditions, and subsequent test of the memory performance. We were able to replicate the key experimental observations regarding saccade target selection, metrics, and latency. Our work shows how neural processes supporting perception, memory, and motor planning can interact even if they are localized in distinct representational structures.

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43.312 **Visual information extraction for static and dynamic facial expression of emotions: an eye-tracking experiment**

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Human faces convey a great deal of information for human social interactions. In this wealth of information, rapid and exact inferences about what others think or feel play a crucial role in tuning our behaviors. Most studies aimed at identifying the visual processes and strategies subtending facial emotion recognition have used static stimuli. However, there is a growing body of evidence that recognizing facial emotion in the real-world involves motion (e.g., Kamachi et al., 2001; Ambadar, Schooler, & Cohn, 2005). The goal of the present study was to compare eye movements during the recognition of facial expression of emotions in static and dynamic stimuli. We used the stimuli from the STOIC database (Roy et al., submitted; the database includes static and dynamic facial expression of emotion of the six basic categories—fear, happiness, sadness, disgust, anger, and surprise—plus pain and neutral). Twenty participants each completed 320 trials (4 blocks of 80 stimuli, containing either static of dynamic stimuli). After each 500-ms stimulus, participants had to recognize the displayed emotion. Participants wore the EyeLink II head-mounted eye-tracking device while looking at the photos or videos showing different emotions. Participants were more accurate with dynamic than with static stimuli (83% vs. 78%). Average fixation maps were computed for each emotion and stimulus condition using the correct answers only. Eye movements clearly differed for the static and dynamic stimuli: For the dynamic faces, the gaze of participants remained close to the center of the face, whereas, for the static faces, their gaze rapidly spread outward. This was true for all the facial expressions tested. We will argue that the ampler eye movements observed with static faces result from a ventral-stream compensation strategy due to the relative lack of information useful to the dorsal-stream.

Acknowledgement: NSERC

43.313 **Differences in Own- and Other-race Face Scanning in Infants**

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The other-race effect has been found to exist in both adults (Meissner & Brigham, 2001) and infants (Kelly et al., 2007). It is most often described in terms of discrimination abilities and manifests itself as an own-race recognition advantage. While recognition advantages for own-race faces have been found as early as 3 months (Sangrigoli & de Schonen, 2004), what remains unclear is whether different attentional patterns can be detected during the scanning of own- versus other-race faces in infancy. The present study investigated whether infants viewing own- and other-race faces displayed differential scanning and fixation patterns that may contribute to the previously reported own-race recognition advantage.

Participants were Caucasian infants (n =22) aged 6 to 10 months (M = 8.5 months). Infants were presented with two videos on a Tobii Eye-Tracking screen while their fixations and scanning patterns were recorded. Each

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video contained the face of an adult female talking directly into the camera against a neutral background for a duration of 30 seconds. The identity of the face and the order of the presentations were counterbalanced and randomized across participants. Data was analyzed by comparing the proportion of infants' fixations to the different facial features across conditions (races).

An analysis of variance (with results to date) revealed a significant interaction between race and feature, in that infants looked significantly longer at the eyes of the own-race faces as compared to the other-race faces, p <0.5. A significant 3- way interaction of race by feature by age was also found, in that older infants looked significantly more at other-race mouths compared to own-race mouths, p <0.001. The present results contribute to the understanding of the underlying perceptual processes that may influence recognition differences for the processing of own- and other-race faces.

43.314 Are letters the correct unit to measure eye behaviour in reading? Testing the effect of character size on the launch site effect

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In reading, the metrical properties of saccadic eye movements are traditionally measured in letters. This approach, supported by several empirical findings showing that the mean length of saccades, when measured in letters, does not vary as a function of viewing distance and character size, may however bias our interpretation of basic eye-movement patterns along the lines of text. In the present study, we investigated the contribution of character size to one of these rather robust phenomena, the launch site effect; this reveals that the eyes land further into a word as the distance of the eyes to the beginning of the word decreases. The eye movements of five participants were recorded while they read lines of words in an animal-name search task. Words were presented in two different font sizes (.2° and .4°) and the eccentricity of the first target word (or launch site) was manipulated. As in previous studies, the launch site was defined in number of character spaces (1 to 9) from the beginning of the target word. Results confirmed a launch site effect in both font sizes, but the effect tended to be stronger for small-printed target words; as the launch-site distance became smaller, the eyes tended to land closer to the end of small- compared to large-printed words. As revealed in further analyses, this trend extended beyond the word boundaries as the likelihood of skipping the target word was greater for small- compared to large-printed words in the close launch site conditions. Inconsistent with classical accounts of the launch site effect, the present findings provide new benchmark data for models of eye-movement control in reading. They also suggest that we may need to reconsider the use of letters as a metric to measure eye behaviour in reading.

43.315 Line bisection in simulated homonymous hemianopia

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Homonymous hemianopia is a frequent visual field defect after injury of the postchiasmatic visual pathway. It has long been known that hemianopic patients make systematic errors during line bisection, placing bisection markers not in the centre of the line but biased instead toward their visual field defect. The cause for this contralesional bisection error is unknown. Various hypotheses attribute the error to the visual field defect, long-term strategic adaptation to the defect, or, more recently suggested, a consequence of extrastriate brain injury. To determine if bisection error can occur without the contribution of the latter two factors, we studied line bisection in healthy subjects with simulated homonymous hemianopia using a gaze-contingent display paradigm, with different line lengths and the presence or absence of line-end markers. We found that simulated homonymous hemianopia induced a line bisection error towards the simulated hemianopia, that this was associated with a significant bias of fixations toward the blind field, and that the effect was present with all line lengths but accentuated when line-end markers were present. In a second experiment we showed that the eccentric fixation alone, without a simulated hemianopia, is sufficient to produce a similar bisection error, with or without line-end markers. Our results indicate that a homonymous visual field defect alone is sufficient to induce a line bisection error and previously described alterations in fixation distribution, and does not require long-term adaptation or extrastriate pathology.

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Memory: Brain mechanisms of working and short-term memory

Royal Ballroom 6-8, Boards 316–330

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43.316 Electrophysiological evidence of interhemispheric resource recruitment during visual working memory

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Recent neuroimaging work has shown that resources involved in the storage of information in visual working memory can be shared between cerebral hemispheres (Serences et al., in press). We examined whether similar sharing occurred during a lateralized visual working memory task using contralateral delay activity (CDA), an electrophysiological component that is sensitive to the number of items being currently held in WM. We show that ipsilateral activity increases and contralateral activity decreases during the maintenance period of the WM task, leading to a decreased CDA and suggesting that the information may be being shared. This apparent resource recruitment only occurs when no competing visual information is present: CDA amplitude did not decrease when participants had to inhibit competing information during the maintenance period. We explored the specificity of this effect by placing task irrelevant motion in attended or unattended location in space. We found evidence for resource sharing when irrelevant motion was present in unattended location, but this effect disappeared when the motion was in attended locations. In Experiment 3, we explored the time course of interhemispheric resource sharing by manipulating the onset of irrelevant motion. We found that even when the irrelevant motion onset 1500ms after the onset of the memory information, there was a rapid increase in CDA amplitude in response to the motion. This suggests that the decrease in CDA amplitude observed in the absence of competing information in related to the active maintenance of visual information rather than the initial selection or consolidation of this information.

43.317 In and out of consciousness - the role of visual short-term memory

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What is involved in holding a visual object in conscious awareness? We approached this question by using a typical shape-from-motion (SFM) display, in which fragmented line-drawings of an object move relative to a background of randomly oriented lines. When static, the fragmented line-drawings are indistinguishable from the line background, but when motion is added observers can readily distinguish the figure from the ground. The resulting percept of the object persists briefly even after the motion has stopped. During this persistence period, the object fades out of consciousness as it disintegrates and blends into the background. We wanted to examine whether visual short-term memory (VSTM) is involved in sustaining the percept during the persistence period. Participants observed SFM displays that were presented bilaterally and were asked to indicate with a button press for how long the object persisted after the motion stopped. While participants performed this task, we measured their brain activity using electroencephalography (EEG). Specifically, we examined the contralateral delay activity (CDA) which is a negative ERP waveform computed as the difference between contralateral and ipsilateral activity and whose amplitude correlates with VSTM capacity. In other words, we used a neural index of VSTM to test for its involvement. We observed a greater negativity (larger CDA amplitude) for conditions that induced perceptual persistence compared to a control condition. This suggests that VSTM is involved in holding a visual object in conscious awareness.

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43.318 **Working memory, feature-based attention, and their interaction modulate the perception of motion direction in human observers**

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Attending to a visual stimulus feature modulates the perception of that feature. Here, we used moving stimuli to investigate whether maintaining the representation of a visual feature in working memory (WM) produces a similar effect, and whether such effect interacts with the effect of feature-based attention (FBA). Seven subjects identified the direction of a brief pulse of coherent motion occurring in a 0% coherence random dot pattern (RDP). Concurrently, they performed a second task consisting of either a) attending to four sequentially presented moving RDPs and detecting whether they changed direction (Experiment 1), or b) remembering the direction of a moving RDP (sample) and, after a delay, determining how many of four sequentially presented RDPs (tests) matched the sample's direction (Experiments 2&3). In Experiment 1, the pulse co-occurred with one test, while subjects attended to it. In Experiment 2, the pulse occurred during an inter-test interval, while subjects remembered the sample. In Experiment 3, the pulse co-occurred with one of the tests, while subjects remembered the sample and attended to the test. Pulse identification performance was significantly higher when the pulse direction was the same as the concurrently attended RDP (FBA, Experiment 1) or the remembered sample (WM, Experiment 2), than when it was opposite. In Experiment 3, performance was highest when both the remembered sample and the attended test directions (WM+FBA) were the same as the pulse direction, intermediate when one was the same and the other opposite, and lowest when both were opposite. When subjects performed the pulse identification task but ignored the sample and tests, performance was unaffected by the sample and test directions, demonstrating that mere exposure to these stimuli did not influence pulse identification. Our results show that WM and FBA can individually and simultaneously modulate the perception of motion direction in human subjects.

43.319 **The Role of Selective Attention in Visual Working Memory Capacity: An ERP study**

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Visual working memory (VWM) capacity has been consistently measured both behaviorally and electrophysiologically using change detection tasks (See, e.g., Luck & Vogel, 1997; Vogel & Machizawa 2004). Many studies have estimated that the average healthy adult can hold 3-4 items in VWM. Recent research suggests that selective attention influences storage capacity. Therefore, the present study sought to determine if sensory processing is enhanced at the locations of objects being encoded into VWM, just as in studies that directly manipulate spatial attention. Observers performed a lateralized change detection task, in which a cue indicates that subjects should encode the colors of the items on one side of fixation, ignoring the items on the other side. While subjects were encoding the items on one side, a high-contrast dartboard probe stimulus was sometimes presented on either the attended or unattended side. We examined neural activity during the maintenance interval when no probe was presented, along with the sensory response elicited by the probe stimulus. As in previous studies, the amplitude of the delay activity increased monotonically as the memory load increased, up to the storage capacity limit. We also found that the P1 sensory response elicited by the probe stimulus was enhanced when the probe appeared on the attended side of the display, indicating that encoding information into VWM involves a modulation of sensory transmission in the spatial region of the items being encoded. Moreover, the magnitude of this P1 sensory modulation was largest when the number of items being encoded was near the capacity limit (3-4 items) and was much smaller when the number of items being encoded was either well below capacity (1-2 items) or well above capacity (5-6). These results suggest that visuospatial attention plays a role in VWM encoding, especially when capacity is being challenged.

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43.320 **What are the differences between comparing visual working memory representations with perceptual inputs and comparing two perceptual representations?**

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We reported that the speed of judging presence or absence of any difference between memory and test items (any-difference task) stays relatively constant as the number of difference increases. Contrarily, we also found that the speed of judging that of any sameness between memory and test items (any-sameness task) accelerates as the number of sameness increases. To assess the nature of this contrasting difference, the present study let subjects directly compare two sets of four colored boxes that are simultaneously presented across fixation under any-difference and any-sameness manipulation. The RT results showed that increasing the number of difference or sameness between sample and test moderately accelerated speed of subjects' responses in both conditions. These RT patterns were also observed when position matching between the boxes was made easier. There was however a robust pattern of faster RTs in any-different trials with every item being the same across two sets than any-sameness trials with every item being different. The pattern virtually replicates the 'Fast-same' effect reported in our previous study. The present results indicate that comparing two perceptual representations may undergo a matching process that is in part similar to the process for comparing VWM representations with perceptual inputs.

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43.321 **Role of LIP persistent activity in visual working memory**

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Parietal cortical areas have been implicated as a critical neural substrate for visual working memory. Human fMRI and ERP studies have revealed persistent parietal activation during delay periods of visual working memory tasks and shown that such activation scales with the capacity limit of visual working memory. A second line of evidence has been provided by neural recordings in primates performing memory-guided saccades. Neurons in parietal cortical areas, such as the lateral intraparietal area (LIP), have been shown to exhibit persistent activity during the memory delay of this task, but the contribution of LIP persistent activity to mnemonic processes remains poorly understood. Specifically, it is unclear whether persistent activity carries a retrospective visual or prospective saccade-related representation, or how it could be related to the capacity limit of visual working memory. To address this, we recorded the activity of single LIP neurons in three monkeys while they performed memory-guided saccades and carried out two sets of analyses. We first compared the visual and motor responses of each neuron with persistent delay period activity. LIP neurons exhibited a pattern of activity consistent with a noisy retrospective code: most neurons had greater visual than saccade-related activity, and persistent activity was most strongly linked with the preferred direction of each neuron, but highly variable. We then investigated how persistent activity could relate to visual working memory capacity. We derived estimates of baseline and persistent activity from our sample of LIP neurons, and used these values to compute the theoretical number of discriminable representations that could be carried over a range of realistic simulated activity distributions using an ROC analysis. This number ranged from one to approximately four. These data show that LIP persistent activity is visually biased and suggest a neural basis for the capacity limit of visual working memory.

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43.322 **A biased-competition account of VSTM capacity limits as revealed by fMRI**

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The capacity of visual short-term memory can be increased significantly when the to-be-remembered objects are presented sequentially across two displays, rather than simultaneously in one display (Ihssen, Linden, & Shapiro, VSS, 2009). Interestingly, a similar performance increase is observed when the (simultaneous) display is repeated. The present study sought to elucidate brain mechanisms underlying the sequential and repetition benefit. We used functional magnetic resonance imaging during a change detection task where participants had to maintain 8 different objects (colours and white shapes). Objects were presented either simultaneously (baseline condition), split into two temporally separated 4-object arrays (sequential condition), or presented twice (repetition condition). Importantly, conditions were matched for perceptual load and visual onset by filling the sequential 4-object arrays with placeholders and presenting a second "empty" placeholder array in the baseline condition. Whole-brain BOLD analyses revealed two main results: Relative to the baseline condition, both sequential and repeated conditions evoked stronger brain responses in extrastriate visual areas. Mirroring memory performance, BOLD amplification in these areas may relate to the higher number of object representations that are activated along the ventral pathway. In contrast to the occipital effects, two key regions of the frontoparietal attention/working memory network dissociated the sequential and repetition conditions. In the inferior parietal lobe and the frontal eye fields, sequential displays elicited reduced brain activation, relative to BOLD responses in the repetition and baseline conditions, which showed no difference. Implications of these findings are discussed within the framework of biased competition.

Acknowledgement: Wales Institute of Cognitive Neuroscience

43.323 **α-oscillations and the fidelity of visual memory**

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Low amplitude of α-oscillations in EEG is associated with selective attention, and has been taken as a sign of enhanced neuronal processing in task-relevant cortical areas (W. Klimesch). As fidelity of encoding is a prerequisite for visual memory, we hypothesized that α-amplitude would be inversely related to the fidelity with which a visual stimulus is encoded and later recalled. We tested this hypothesis by recording scalp EEG while subjects attended to lateralized Gabors whose spatial frequency they would have to reproduce from memory. On each trial, two Gabors were presented simultaneously for 300 msec, one to the left of fixation, the other an equal distance to the right. Either before stimulus presentation or after, subjects were cued which Gabor's frequency they would have to reproduce from memory; subjects were to ignore the non-cued stimulus. Each trial's reproduced spatial frequency showed a strong influence from information that is not relevant to the task, that is, reproductions were attracted toward the average spatial frequency of Gabors seen on preceding trials. This effect was greatly reduced when the cue preceded the stimulus pair rather than followed it. This improved suppression of task-irrelevant information was accompanied by a consistent change in the contralateral α amplitude. At various, widely-distributed electrode sites, we saw a lateralized, attention-driven reduction in α amplitude, implying enhanced processing of the cued Gabor. However, occipito-parietal electrode sites showed lateralized α amplitude only during early visual encoding (0-200 msec after stimulus onset). Moreover, this reduced α amplitude at contralateral occipito-parietal locations to the cued Gabor was associated with a reduction in the influence of task-irrelevant information from preceding trials. These results suggest that neural enhancement of relevant information is a determinant of optimal memory performance, and that it protects remembered stimulus from intrusion of irrelevant information.

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43.324 **An electrophysiological measure of visual short-term memory capacity within and across hemifields**

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Recent ERPs studies have identified a specific electrophysiological correlate of the contents of visual short-term memory (VSTM) (McCollough et al., 2007; Vogel & Machizawa, 2004). A sustained posterior negative wave was observed throughout the memory retention period, which was larger over the contralateral side of the brain (with respect to the position of the memory items in the visual field) relative to the ipsilateral side. Importantly, the amplitude of this contralateral delay activity (CDA) increased progressively with the number of items to be remembered, reaching an asymptotic limit at around 3-4 objects. This contralateral organization of visual memories raises the possibility that each hemisphere has its own capacity of storage: more items could be held in memory when they are split between the left and right hemifields as when they are all presented within a single hemifield. In the present study, we measured CDA amplitude in 15 participants while they remembered colored squares from either one hemifield or both hemifields. We found that the amplitude of the CDA was modulated by the total number of items held in memory, independently of their spatial distribution in the visual field. When individuals had to remember one side of the memory array, the CDA activity increased for arrays of one, two, and three items, but ceased to get larger for arrays of four items. However, when individuals had to memorize the items from both sides of the memory array, this contralateral activity reached its asymptotic limit for arrays of two items per side. These results suggest that despite being contralaterally organized, VSTM is limited by the number of objects from both hemifields. VSTM may consist of a pool of resources that can be allocated flexibly to one or both hemifields and allow a maximum of 3-4 objects to be maintained simultaneously.

Acknowledgement: This work was supported by the Experimental Psychology Society, UK

43.325 **A contribution of persistent FEF activity to object-based working memory?**

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We examine delay period activity in the FEF during the performance of an object-based working memory task. In the task, the monkey is briefly presented a single image (sample) in the periphery. Following the sample presentation, the monkey must remember the sample throughout a 1-second blank delay period. Following the delay, one target (a repeat of the sample image) and one distractor object appear in the periphery and the monkey must saccade to the matching target to receive a reward. We compare FEF neuronal activity during blocks in which target and distractor images always appear at locations that include the sample location (overlapping condition) with blocks in which the target/distractor always appear at positions rotated 90 degrees from the sample position (orthogonal condition). Thus we can examine the degree to which spatially selective delay period activity of FEF neurons contributes to object-based working memory. We also use a memory-guided saccade task to identify the functional classes of FEF neurons that might contribute to the persistence of purely object-based information. We observe persistent, spatially selective delay period activity in the FEF consistent with the use of spatial signals in maintaining object information.

Acknowledgement: NIH grant EY014924, NSF grant IOB-0546891, and the McKnight Foundation

43.326 **Using Multi-Voxel Pattern Analysis to explore the role of retinotopic visual cortex in visual short-term memory: mapped memories or plain prospective attention?**

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Introduction: There are two long-standing debates regarding the nature of visual short-term memory (VSTM) representations and their neural underpinnings. One question is whether VSTM depends on the same neural circuitry as vision or whether it functions separately. The second question is whether VSTM and attention use overlapping mechanisms. Methods: To evaluate these questions, two experiments evaluated retinotopic activation during attention and VSTM maintenance. Participants attended to and remembered the contents of two (out of four) visually presented sectors. After this they were tested for change detection on the sectors: in the first experiment change detection was performed in the same location (prospective attention encouraged), while in the second the change detection was performed centrally regardless of the sectors' location (prospective attention discouraged). Results: During the VSTM maintenance period, both univariate methods and Multi-Voxel Pattern Analysis showed evidence of spatial encoding in visual cortex only where prospective attention to the sector locations was encouraged, but no evidence when it was not required. However, spatial encoding was evident during attention in both experiments, ruling out an explanation based on power. This spatial selectivity was equivalent to that obtained from purely sensory stimulation. Conclusion: We conclude that VSTM does not use the same low-level visual circuitry as typical visual processing or attention, suggesting it is underpinned by different mechanisms than either of these. Visual processing and attention, on the other hand, appear to have similar neural correlates. We suggest that previous findings of VSTM activating visual cortex are due to residual attentional activation.

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43.327 **Dissociating feature complexity from number of objects in VSTM storage using the contralateral delay activity**

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Many recent studies have examined the neural correlates of visual short-term memory (VSTM) maintenance using an ERP component known as the contralateral delay activity (CDA), whose amplitude corresponds to memory load within individuals and to memory capacity across individuals. The parietal distribution of the CDA makes it a particularly compelling locus of capacity-limited VSTM storage given that it overlaps with fMRI findings of feature- and location-based VSTM systems located in the superior and inferior intra-parietal sulcus. An under-explored question, however, is the extent to which the CDA indexes the feature complexity of items to be remembered or the number of objects/locations to be remembered, or both. We employed a lateralized change detection task in which the feature complexity and number of items to be remembered were independently manipulated. Items to be remembered were either simple features (shape, color, or orientation) or conjunctions of these features, and they were presented either at one location or at three locations. Behavioural results demonstrated that individuals performed comparably for simple features and conjunctions presented one at a time, while performance for simple features declined when three were presented at different locations relative to when they were conjoined in one object. We found that ERP amplitudes at the lateral, posterior sites that are typically measured in the CDA reflected the number of objects to be remembered, while more central, anterior sites indexed the complexity of the objects to be remembered. Thus, feature- and location-based systems in the parietal cortex can be dissociated even at the course spatial resolution of ERP.

43.328 **Accessing a working memory representation delays updating that representation**

Judith Fan[1](jefan@fas.harvard.edu), George Alvarez[1]; [1]Department of Psychology, Harvard University

Recent research into probabilistic models of mental representation have profited from requiring participants to give multiple responses on a given trial (Vul et al., 2009). This method assumes that accessing a mental representation leaves it intact for subsequent sampling. Here we tested the consequences of sampling (memory access) on the mental representation of an object's velocity. On each trial, observers saw an object move at a constant velocity and were instructed to continue mentally tracking the object's position as it moved behind a virtual occluder. Either one or three visual markers were posted at a range of distances (early, middle, late) along the length of the occluded path. Observers responded by pressing a key when the object was imagined to have reached each marker. The results demonstrate that the accuracy of the velocity representation depends on whether previous responses were given. When three responses were given, the object's velocity was reliably underestimated (even on the first response), and the degree of underestimation increased with position. Velocity was also underestimated in the single-click condition, but the degree of underestimation did not increase as a function of position [the interaction between number-of-responses and position was highly reliable, $F(2,30) = 10.779$, $p<0.001$]. In the three-response condition, the increase in underestimation with each response was amplified at higher speeds. A model with a single free parameter (a temporal delay to updating object position information when a response is given) accurately predicts the mean velocity estimate for the middle and late marker position at 3 different speeds (best fit temporal delay = 40 ms per response). These findings suggest that accessing a mental representation to generate a report briefly delays updating of that mental representation, and more generally that the architecture of working memory may prevent simultaneous reading and writing from memory.

43.329 **Visual Short-Term Memory Load Induced Blindness**

Nikos Konstantinou[1](nkonstantinou@gmail.com), Bahador Bahrami[1,2], Geraint Rees[1,2], Nilli Lavie[1]; [1]Institute of Cognitive Neuroscience, University College London, [2]Wellcome Trust Centre for Neuroimaging, Institute of Neurology, University College London

We present imaging and behavioral experiments, establishing that visual short-term memory (VSTM) load, similar to perceptual load (e.g. Macdonald and Lavie (2008), but opposite to task-unrelated verbal working memory load (see Konstantinou & Lavie, 2010), can reduce both detection sensitivity (d') and the related signal in V1 for peripheral stimuli presented during the memory delay. Participants in the fMRI scanner were required to maintain the color and position of a memory set (consisting of colored squares) and detect a contrast increment (CI) presented in one of the four quadrants during the delay. VSTM load was varied through the memory set size. Both the CI related stimulus-induced retinotopic V1 response and detection sensitivity were significantly reduced under the high (vs. low) load condition demonstrating "VSTM load-induced blindness". Moreover, a significant negative correlation between the magnitude of VSTM load effects on memory capacity (i.e. Cowan's K) and on detection sensitivity showed that the impact of VSTM load on detection sensitivity was reliably predicted by the extent to which VSTM was occupied. This trade-off between the estimated number of items held in VSTM and detection sensitivity further demonstrates shared resources between VSTM and conscious perception.

Acknowledgement: Wellcome Trust grant (WT080568MA)

43.330 **Comparing Working Memory for Visual Item versus Relational Information**

Christopher Ackerman[1](ackerman@jhu.edu), Susan Courtney[1,2]; [1]Department of Neuroscience, Johns Hopkins University, [2]Department of Psychological and Brain Sciences, Johns Hopkins University

Past research has probed the working memory representations of visual object features, but less is known about how visual relational information is stored in working memory. To investigate this, we employed a delayed recognition behavioral paradigm using visual object features that also afford relational comparisons between objects: specifically, the magnitude dimensions of size and luminance. In a series of experiments, we examined whether the working memory capacity for relations is similar to the capacity for objects and their features, whether memory for relational information is decomposed into magnitude and direction components, and whether relative magnitudes (eg, "X much bigger than") are encoded similarly to absolute magnitudes (eg, "X big"). Results for object features reproduce earlier findings for nonscalar visual dimensions. Accuracy was equally high when subjects had to encode either size or luminance as when they had to encode both size and luminance, indicating that multiple features of an item can be remembered as well as a single feature of an item. Relational magnitude, however behaved differently. When subjects had to encode both the size differential and the luminance differential of two pairs of objects, accuracy was significantly lower than when they had to encode only the size or luminance differential of two pairs of objects. This suggests that visual comparative relations are not maintained in separate feature stores, nor are they automatically bound into an integrated "object-like" multidimensional relational representation. Rather, size and luminance relational representations compete with each other for a limited shared memory resource, and the capacity of this resource is similar to that found for objects. These behavioral results are consistent with fMRI results from our lab comparing the neural representations of item-specific and relational information along the dimensions of size and luminance.

Attention: Deciding where we look

Orchid Ballroom, Boards 401–412

Monday, May 10, 8:30 - 12:30 pm

43.401 **Role of different salient features in guiding gaze of monkeys with unilateral lesion of primary visual cortex**

Laurent Itti[1,2](itti@usc.edu), Masatoshi Yoshida[3,4], David Berg[2], Takuro Ikeda[3,4], Rikako Kato[3,4], Kana Takaura[3,4], Tadashi Isa[3,4]; [1]Computer Science Department, University of Southern California (Los Angeles, California), [2]Neuroscience Graduate Program, University of Southern California (Los Angeles, California), [3]Deptartment of Developmental Physiology, National Institute for Physiological Sciences (Okazaki, Japan), [4]CREST, JST (Japan)

In this and the companion paper (Yoshida et al.), we evaluate the role of different low-level visual features in guiding monkey gaze after unilateral ablation of primary visual cortex (area V1). Here we analyze eye movements (108,458 saccades) of six macaques (three normals, three with unilateral V1 ablation) watching 54 minutes of natural videos. A computational model of saliency-based visual attention quantifies the monkeys' propensity to attend to salient targets in their normal vs. lesioned hemifields. The model combines five low-level feature channels: Luminance contrast; L-M (red-green) chromatic contrast; S-(L+M) (blue-yellow) chromatic contrast;

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oriented edges (V1-like Gabor filters); and motion. All monkeys are significantly attracted towards salient stimuli, with salience computed as the sum of the five features, for saccades both into normal and lesioned hemifields (t-tests, p<0.0001 or better). We conduct an optimization to evaluate the strength by which each feature contributes to gaze, in two steps: (1) find the best set of relative feature weights, for each of three groups: horizontal saccades of control monkeys, horizontal saccades into the affected, and into the intact, hemifields of lesioned monkeys; (2) re-optimize after removing one of the five features (leave-one-out). Comparing (1) with (2) quantifies the non-redundant contribution of each feature to gaze. In all three groups, every feature provides significant non-redundant contribution, with motion the strongest. Significant differences between control and lesioned hemifields are: decreased contribution of Gabor-like oriented edges; increased contribution of luminance contrast; and (surprisingly) increased contribution of S-(L+M) chromatic contrast (Bonferroni-corrected t-tests, p<0.05). The increased contribution of S-(L+M) is further evaluated in the accompanying paper of Yoshida et al. Our results suggest that unilateral ablation of V1 does not abolish the monkeys' natural tendency to gaze towards salient targets during natural vision, but significantly affects the relative strength by which different low-level features contribute to attention.

Acknowledgement: Supported by NSF and HFSP

43.402 **The effects of 2nd-order feature interactions in predicting human gaze**

Farhan Baluch[1](fbaluch@usc.edu), Laurent Itti[1,2]; [1]Neuroscience Graduate Program, University of Southern California, [2]Dept. of Computer Science, University of Southern California

How do features interact to guide human gaze? Models of human attention have assumed a linear combination of features to construct a final saliency map that drives human overt/covert attention. We asked what role, if any, do second order feature interactions play in attracting attention.

We examined the eye movements of 8 subjects while they watched videos containing natural and synthetic scenes. A set of five low-level feature channels including Color (C), Intensity (I), Orientation (O), Flicker (F) and Motion (M) using center-surround differences were computed for each of 46,489 video frames shown to the subjects. A total of 11,430 saccades were analyzed. We compared 4 models including i) simple unweighted sum of 1st-order terms, i.e., C, I, O, F, M; ii) a weighted linear sum of 1st-order terms; iii) unweighted sum of 1st-order and all 2nd-order multiplicative feature interaction terms (e.g., CC, CI, CO, CF, CM, etc.); and iv) a weighted linear combination of 1st and 2nd order terms. For the weighted combinations, the weights were learned using a genetic algorithm (GA) that optimizes a cost function defined as the difference between the distribution of human saccade end points and salient locations as computed by the respective models. The optimal solution was found from a large search space of size 2^20 for the model incorporating 1st order terms and 2^80 for the model incorporating both 1st and 2nd order terms respectively.

We found that the optimized 1st order model performed significantly better than all other models (p<0.05). Further we found that models using 2nd-order interactions did not improve the predicitive power of a model in explaining eye movements of human subjects.

43.403 **Explaining visual fixation durations in scene perception: Are there indeed two distinct groups of fixations?**

Sebastian Pannasch[1,2](pannasch@psychomail.tu-dresden.de), Johannes Schulz[2], Boris Velichkovsky[2]; [1]Low Temperature Lab, Helsinki University of Technology, Finland, [2]Applied Cognitive Research Unit, Dresden Technical University, Germany

Everyday oculomotor behavior reveals a substantial variation in the duration of visual fixations. This variance can be generally explained by direct and indirect control mechanisms. Recent experiments using a scene onset delay paradigm demonstrated a prolongation of a part of the fixations which lasted until the reappearance of the scene (Henderson & Pierce, 2008; Henderson & Smith, 2009). This has been considered as evidence for two distinct 'subpopulations of fixations', one under direct and another under indirect control. However, a similar prolongation can be obtained in as much as all fixations when distractors are presented during free visual exploration of a scene (e.g. Graupner, Velichkovsky, Pannasch, & Marx, 2007; Pannasch, Dornhoefer, Unema, & Velichkovsky, 2001; Reingold & Stampe, 2000). Since the behavior of fixations is similar in both paradigms, we argue that the findings by Henderson et al. (2008, 2009) can be explained in terms of the distractor effect from the scene onset together with artifacts produced by a variable delay in the scene changes. We provide new data from two experiments with a variable delay of distractor application that allow to numerically simulate the Henderson et al. (2008, 2009) results from the scene onset delay paradigm. Based on these findings, we question the particular version of the mixed control model. We also discuss the issue of control mechanisms for visual fixation duration. Instead of suggesting two distinct groups of fixations our results demonstrate that each fixation can be under shifting control of several brain mechanisms (see Pannasch & Velichkovsky, 2009). Most prominent among them seem to be mechanisms of ambient and focal mode of processing or, respectively, that of dorsal and ventral streams (pathways) within the visual system.

Acknowledgement: This research was supported by the Deutsche Forschungsgemeinschaft (DFG: PA 1232/1) and the Russian Foundation for Basic Research (Interdisciplinary oriented research 09-06-12003).

43.404 **The role of "rescue saccades" in tracking objects through occlusions**

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We hypothesize that our ability to track objects through occlusions (and near occlusion events; NOEs) is mediated by timely assistance from gaze in the form of "rescue saccades"—eye movements to tracked objects that are in danger of being lost due to impending occlusion. Subjects tracked 2-4 target sharks (out of 9) for 20 seconds as they swam through a rendered 3D underwater scene. One of the sharks was then probed, and the task was to indicate whether the probed shark was one of the targets. Tracking accuracy with 2-3 targets was >95%, but dropped to 74% with four targets. This tracking performance was mirrored in the frequency of rescue saccades. For trials in which the probed object was correctly identified as a target, the probabilities of a saccade accompanying an occlusion were .52 and .51 in the Track 2 and 3 conditions, but only .34 in the Track 4 condition (p<.001). This low Track 4 frequency of rescue saccades did not differ from the rescue saccade rate on incorrect Track 4 trials (.29), although rescue saccades in all target conditions occurred far more frequently than saccades to targets during non-occlusion tracking (≤.18). Analyses of the distances between targets and the nearest other object also revealed the expected increase in occlusions and NOEs with the number of targets (creating more opportunities for object confusions), as well as an inverse correlation between rescue saccades and this nearest-object distance. We interpret these data as evidence for a tracking system that monitors tracked objects for events that might result in track loss (e.g., occlusions and NOEs), and requests help from the oculomotor system to resolve these momentary crises. Because rescue saccades are inherently serial, as the number of these crises increase with targets, some requests for help go unsatisfied, resulting in degraded tracking.

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43.405 **Overt and Covert attention interact with curvature-based perceptual singularities**

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The presence of significant contrast in a texture's dominant feature (i.e., orientation) is the foundation of many texture segregation models. Nevertheless, texture patterns consisting of slowly varying orientations were shown to preattentively segregate into perceptually coherent regions. Without an abrupt feature gradient, the striking perceptual singularities of these orientation-defined textures (ODTs) are not detected by the standard texture segregation models, and instead were recently predicted by a new theory based on multiple texture curvatures. To further investigate the role of perceptual singularities in vision, here we explore their interaction with attentional processes. Indeed, we show that perceptual singularities interact and affect both covert and overt attention similar to classical findings whereby attentional selection is influenced by strong feature gradients or higher level visual objects. A series of experiments using divided attention and saccadic programming are described and analyzed.

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43.406 **Can't Take My Eyes Off of You: Delayed Attentional Disengagement Based on Attention Set**

Walter Boot[1](boot@psy.fsu.edu), James Brockmole[2]; [1]Department of Psychology, Florida State University, [2]Department of Psychology, University of Notre Dame

The attentional consequences of task-irrelevant properties of objects outside the focus of attention have been studied extensively (attention capture). However, the extent to which task-irrelevant properties influence attentional deployment when they are already within the focus of attention has generally been ignored. This is an important oversight because attention capture effects should be thought of as being composed of both the pull of attention to a location, and the holding of attention once it gets there. We present the results of a series of experiments examining the ability of task-relevant and irrelevant properties of the currently fixated item to hold attention (as measured by dwell times). The attentional disengagement paradigm has participants start each search trial fixating an object that could never be the search target. Surprisingly, completely irrelevant properties of this object determined how long attention dwelled and where attention went next. Task-relevant properties at this irrelevant location also increased dwell times. We present evidence that contingent disengagement effects are not restricted to simple target features. In one experiment participants viewed displays containing many circles and each trial began with participants fixating a circle that was never the target circle (the sole red circle). The task was to indicate the presence or absent of a target letter (e.g., p) within the red target circle as quickly as possible, and participants were told to ignore the initially fixated circle. However, when this initially fixated, always irrelevant item contained the target letter disengagement was significantly delayed. Additionally, when this item contained a letter similar to the target (e.g., q), disengagement was delayed compared to a dissimilar letter (e.g., i). In this series of experiments we found stimulus-driven and contingent capture effects on disengagement, and we present the disengagement paradigm as a promising means to study complex attention sets.

43.407 **Fatal attraction or reluctance to part: Is oculomotor disengagement independent of the initial capture of the eyes?**

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Highly salient distractor stimuli may prolong reaction times to a target stimulus. This distraction effect is largely due to the fact that our eyes are sometimes captured by the distractor. To respond to the target, the eyes need to be redirected from the distractor to the target which is time-consuming. Distractors that are similar to the target cause a stronger distraction effect than dissimilar distractors. On the one hand, this can be explained by the finding that the eyes go more often to a distractor that looks like the target than to a distractor that does not look like it. On the other hand, the larger interference caused by the similar distractors is due to more difficulty disengaging the eyes from an object that looks like the target than from an object that looks quite different. The goal of the present study was to test whether these two processes (oculomotor capture and disengagement) are independent. We used a variant of the oculomotor capture paradigm. Participants were asked to make an eye movement to a gray target. Simultaneously with the target, we presented a green onset distractor. After a short delay (30-40 ms), the distractor changed either to gray (target-similar color) or to red (dissimilar color). Results show a clear dissociation between oculomotor capture and disengagement. Whereas there were only small differences in the percentage of capture, dwell times on the distractor were substantially longer when the distractor changed to the target-similar color. If, however, the color change occurred later in time (60-80 ms), this similarity effect in dwell times was gone as well. The latter finding is discussed in terms of rapid disengagement of covert attention from the distractor site and a critical time window for the influence of distractor characteristics on gaze dwell times.

43.408 **Fixations on Low Resolution Images**

Tilke Judd[1](tjudd@mit.edu), Frédo Durand[1], Antonio Torralba[1]; [1]Massachusetts Institute of Technology

When an observer looks at an image, his eyes fixate on a few select points that correspond to interesting image locations. However, how this process is affected by image resolution is not well understood. Here we investigate how image resolution affects human fixations through an eye tracking experiment. We showed 100 images at different resolutions to 30 observers. Each image was shown at one of seven resolutions (width of 4, 8, 16, 32, 64, 256, 1024 pixels) and upsampled to the original size of 1024x768 pixels for display. We found that: 1) As image resolution decreases, users fixate in fewer locations and fixations get more concentrated near the center. 2) Fixations from lower resolution images can predict fixations on higher resolution images. We measure how well one observer's fixations predict another observer's fixations on the same image at different resolutions using the area under the ROC curves as a metric. Fixations on an image at full resolution are predicted better by fixations on the same image as the resolution increases, but the rate of improvement declines after a resolution of 64px. 3) Fixations are most consistent across users on images at a resolution of 32 and 64px. More specifically, the fixations on 32 and 64 resolution images predict fixations on the same image better than fixations from any other resolution predict fixations of that resolution. The fixations on the lowest and highest resolution images are harder to predict. These findings suggest that working with fixations at an image resolution of 32-64px could be both perceptually adequate and computationally attractive.

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43.409 **Eye movements while viewing captioned and narrated videos**

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Research on visual attention has been mainly limited to static images, but in everyday life we often rely on a narrative to guide us through dynamically changing scenes. Sometimes the narrative is presented via audio and in special cases as a caption. Narratives can help guide attention, but may require additional processing that increases task demands, or distracts attention from relevant locations when presented as a caption. This study examined how narrative and video interact to drive attention while viewing documentary clips. Video clips (~120 s each) were cut from 4 documentaries such that no talking heads were present in any frame. Videos were accompanied by narration in the form of either audio or captions. Videos with both audio and captions, or neither, were also tested. In order to motivate viewing, multiple choice tests on content were given after each clip. Captions were strong attractors of gaze. 56% of saccades were devoted to reading captions when no audio was present, and 41% when audio was present (surprisingly large, given that audio made reading of captions unnecessary). Durations of fixations were shorter for reading captions (~260 ms) than inspecting the video (~420 ms), regardless of the presence of audio. Fixations made to inspect the video clustered near the scene center when narration was present. In the absence of narration, eye movements were more exploratory; the 2D scatter of saccadic endpoint locations increased by up to 70%. These changes to the spatial distribution of saccades, as well as the adoption of the time-consuming strategy of reading captions even when redundant with audio narration, show that eye movements while inspecting videos are motivated mainly by a cognitive strategy of searching for clues that facilitate the interpretation of viewed events.

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43.410 **Modeling gaze priorities in driving**

Brian Sullivan[1](brians@mail.utexas.edu), Constantin Rothkopf[2], Mary Hayhoe[1], Dana Ballard[1]; [1]Center for Perceptual Systems, University of Texas at Austin, [2]Frankfurt Institute for Advanced Studies, Goethe University

Gaze behavior in complex tasks (e.g. navigation) has been studied[1,2] but it is still unknown in detail how humans allocate gaze within complex scenes especially in temporally demanding contexts. We have previously studied gaze allocation in a virtual walking environment and modeled human behavior using a reinforcement-learning model[2]. We adapted this approach to the study of visuomotor behavior in virtual driving, allowing for controlled visual stimuli (e.g. other car paths) and monitoring of human motor control (e.g. steering). The model chooses amongst a set of visuomotor behaviors for following and avoiding other cars and successfully directs the car through an urban environment. Performance of the model was compared to that of human subjects. Eye movements were tracked while driving in a virtual environment presented in a head mounted display. Subjects were seated in a car interior mounted on a 6 degree-of-freedom hydraulic platform that allows the simulation of vehicle movements.

Monday AM

Subjects were instructed to follow a 'leader' car and to avoid other traffic present. Our analysis assumes that subjects gaze strategies are a direct measure of task priorities. These priorities can be derived from subject behavior using inverse reinforcement learning to extract individual reward values. The majority of fixations were devoted to keeping gaze on the leader car and a smaller proportion on objects of avoidance, with relatively few fixations on other objects unless no traffic was present. We discuss the detailed measures underlying gaze and motor behavior in these experiments and their relationship to the reinforcement-learning model. Additionally, we will discuss future refinements of the model and techniques using inverse reinforcement learning that allow for better fitting of human data. [1] Jovancevic J, Sullivan B, Hayhoe M.; J Vis. 2006 Dec 15. [2] Rothkopf CA. Modular models of task based visually guided behavior; Ph. D. Thesis

43.411 **The Dynamics of Gaze When Viewing Dynamic Faces**

Melissa Vo[1](mlvo@search.bwh.harvard.edu), Tim Smith[2], John Henderson[2]; [1]Harvard Medical School, Brigham & Women's Hospital, [2]University of Edinburgh

How do we attend to faces in realistic encounters? Is it, for example, true that we tend to look at somebody's eyes? Most of the work on face perception has come from static face presentations raising the question whether previous findings actually scale to reality. An intermediate step towards real-world face perception is to use dynamic displays of faces. Here we monitored participants' eye movements while they watched videos featuring close-ups of pedestrians engaged in interviews. Dynamic interest areas were used to measure fixation distributions on moving face regions including eyes, nose, and mouth. Additionally, fixation distributions were analyzed as a function of events such as speech, head movement, or gaze direction. Contrary to previous findings using static displays, we observed no general preference to fixate the eyes. Rather, gaze was dynamically adjusted to the dynamics of faces: When a depicted face was speaking, participants showed increased gaze towards the mouth, while the eyes were preferably fixated when the face engaged with the viewers by looking straight into the camera. Further, when two faces were present and one face looked at the other, viewers followed the observed gaze from one face to the other. Thus, especially in dynamic displays, observed gaze direction seems to promote gaze following. Interestingly, when a face moved quickly, participants tended to look more at the nose than at any other face region. We interpret this "nose tracking" as a strategy to use a centered viewing position to optimally track and monitor moving faces. All in all, these findings provide evidence for the wealth of moment-to-moment adjustments of gaze control that become necessary when viewing dynamic faces. Since human interaction heavily relies on the understanding of information conveyed by facial movements, it is of key interest to learn more about gaze dynamics while viewing dynamic faces.

43.412 **An Eye for Art: Effects of Art Expertise on the Visual Exploration of Drawings**

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When presented with a complex new visual stimulus, viewers unfold an information sampling strategy which through a series of fixations and saccades provides them with the information they require given the task at hand. When that task is only loosely structured, as is the case when one is asked for an aesthetic appreciation of an unknown work of art, there is no single "best" location to send the eye to next. Under these conditions, scanpaths may be shaped by featural saliency, by systematic oculomotor biases, by image composition or by an active search for elements that allow aesthetic judgment. In the present study, we have attempted to assess the relative impact of these various determinants by asking art novices and art experts to evaluate a series of drawings ("Kalligrafie" by Anne-Mie Van Kerckhoven). During their inspection, eye movements were registered and afterwards measures of appreciation and evaluation were collected. Repeated stimulus exposure and presence vs. absence of an explanation of the artist's modus operandi were used to assess the effects of episodic and semantic experience with the viewed drawings. Scan paths were analyzed by means of fixation dispersion, fixation duration and fixation sequence measures. The obtained profiles were related to aesthetic judgments in order to determine whether different ways of looking at a work of art explain differences in judging it. In addition, the observed scan paths were compared to predictions made on the basis of featural saliency models, oculomotor bias models, and artist-defined region-of-interest models. Results indicated that art expertise mediates the predictive validity of these models of eye guidance when viewing art, and that parameters of scan paths allow predictive inferences about the aesthetic judgments that follow them.

Acknowledgement: METH/08/02

Attention: Mechanisms and models

Orchid Ballroom, Boards 413–424

Monday, May 10, 8:30 - 12:30 pm

43.413 **Comparing signal detection models of perceptual decision confidence**

Brian Maniscalco[1](brian@psych.columbia.edu), Hakwan Lau[1]; [1]Department of Psychology, Columbia University

Introduction: We investigated the mechanisms underlying reports of perceptual confidence. In particular, is all the information used for perceptual decisions available to confidence reporting? Some models of perception suggest that there are multiple channels of information, and subjective reports such as confidence ratings can only tap into one of the channels (e.g. cortical, but not subcortical channels). Is this intuitive view correct? We capitalize on an original psychophysical finding (Lau & Passingham 2006 PNAS) that subjective reports of perceptual confidence and perceptual performance (d') can dissociate, and apply formal model comparison techniques to identify the mechanism underlying confidence reporting.

Methods and Results: We considered several signal detection theory models, including: A simple SDT model where confidence is determined by setting criteria on the primary decision axis; a late noise model where the noisy perceptual signal becomes even noisier when making confidence judgments; and a two-channel model where only one channel contributes to confidence judgments. We compared models by evaluating the likelihood of each model, given the metacontrast masking data, using the Akaike information criterion. All models could account for perceptual performance, but the late noise model provided the best fit to the observed performance-confidence dissociation.

Discussion: Our results suggest that simple SDT models may not adequately characterize the relationship between perceptual decisions and confidence, because they do not provide a process that allows for the kind of performance-confidence dissociation observed in the metacontrast masking paradigm. However, this extra process need not be an extra information processing channel. Our best-fitting model was a hierarchical, single-channel model where noisy perceptual signals accrue further noise when used for rating confidence. This suggests that confidence decisions may be made by mechanisms downstream from perceptual decision mechanisms.

43.414 **The Attentional Attraction Field: Modeling spatial and temporal effects of spatial attention**

Orit Baruch[1](oritb@research.haifa.ac.il), Yaffa Yeshurun[1]; [1]Psychology Departement, University of Haifa

Attentional effects were found for both neuronal and behavioral responses. Most of the studies considered spatial aspects of perception, but some revealed attentional effects in the temporal domain. Here we propose a model that is based on the conception of attention as an attraction field: The allocation of attention to a location attracts (shifts) the centers of receptive fields towards this location. We show that this attentional attraction of receptive fields can serve as a simple unifying framework to explain a diverse range of attentional effects including gain enhancement, enhanced contrast sensitivity, enhanced spatial resolution, prolonged temporal integration, prolonged perceived duration, prior onset and degraded temporal resolution. Additionally, the model successfully simulates multiplicative and non-multiplicative modulations of neuronal response and suppressed response surrounding the focus of attention. Thus, this model offers a novel way of looking at attentional effects. Instead of assuming that the fundamental impact of attention is enhancing neuronal response, we suggest that enhanced response and other seemingly unrelated attentional effects may all be a consequence of this attentional attraction field. Notably, this model links physiological measurements at the unit level with psychophysical observations of both the spatial and temporal domains of perception.

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43.415 Pre-Stimulus EEG Oscillations Reveal Periodic Sampling Of Visual Attention

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Our senses are constantly confronted with an excess of information. One mechanism that limits this input to a manageable amount is selective attention. An important effect of sustained attention is the facilitation of perception through enhanced contrast sensitivity. While the term `sustained' suggests that this facilitative effect endures continuously as long as something is attended, we present electrophysiological evidence that perception at attended locations is actually modulated periodically.

Subjects had to detect brief flashes of light that were presented peripherally at the individual contrast threshold such that subjects detected approximately half of the flashes (hits) and entirely missed the other half (misses). Additionally, a central cue instructed subjects where to focus their attention, so that stimuli could be presented either at the attended or the unattended location. EEG was recorded concurrently.

As expected, the contrast threshold was lower for attended than for unattended stimuli. Analysis of the EEG data revealed that event-related potentials (ERPs) were of much larger amplitude for hits than for misses. Moreover, the single-trial amplitude of the ERP was correlated with the single-trial phase of spontaneous EEG oscillations in the theta (~7Hz) frequency-band just before stimulus onset. In fact, the single-trial phase in this time-frequency range was significantly predictive of detection performance for attended stimuli - but not for unattended ones.

Spontaneous EEG oscillations correspond to ongoing periodic fluctuations of the local electrical field and the excitability of neuronal populations. The present results extend our recent finding that visual detection performance fluctuates over time along with the phase of such oscillations in the theta (4-8Hz) and alpha (8-13Hz) range. By demonstrating that this effect exists only for attended stimuli, the data suggest that sustained attention in fact operates in a periodic fashion.

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43.416 The role of salience-driven control in visual selection

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Salient objects in the visual field tend to attract attention and the eyes. However, recent evidence has shown that salience affects visual selection only during the short time interval immediately following the onset of a visual scene (Donk & van Zoest, 2008). The aim of the present study was to further examine the short-lived nature of salience effects. In a series of experiments, we investigated how the salience of different orientation singletons affected probe reaction time as a function of Stimulus Onset Asynchrony (SOA) between the presentation of a singleton display and a probe display. It was tested whether the transient nature of salience effects could be explained by (1) people using a specific attentional set acting against the maintenance of salience, (2) response priming, or (3) eye movements. The results demonstrated that these factors could not explain the short-lived nature of salience effects. The results were discussed in terms of current models on visual selection.

Donk, M. & van Zoest, W. (2008). Effects of salience are short-lived. Psychological Science, 19(7), 733-739.

43.417 Unifying two theories of local versus global perception: Attention to relative spatial frequency is the medium for shape-level integration

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Hemispheric asymmetries in the perception of hierarchically arranged visual stimuli (i.e., "hierarchical perception") have long been established, and a myriad of studies have demonstrated that the left hemisphere (LH) is biased towards local processing and that the right hemisphere (RH) is biased towards global processing. However, the mechanisms that produce these asymmetric biases are still debated. Hubner and Volberg (2005) recently proposed that the identities of shapes in hierarchical displays are initially represented separately from their hierarchical level (local/global), and that the LH is more involved in binding shapes to the local level while the RH is more involved in binding shapes to the global level ("integration theory"). This is in contrast to previous models implicating the importance of attentional selection of spatial scale in hierarchical perception (e.g., Double Filtering by Frequency (DFF) theory, Ivry & Robertson, 1998), which proposes that asymmetric biases towards relatively high (by the LH) and relatively low (by the RH) SFs underlie the hemispheric asymmetry in local versus global processing, respectively. Rather than considering these two theories as mutually exclusive, we unify them into a single framework and provide evidence that selective attention of SF is the medium for hierarchical integration. Attention to the higher or lower SFs in a previously presented compound grating modulated shape-level binding errors in a subsequently presented hierarchical display. Specifically, attentional selection of higher SFs facilitated binding by the LH of shapes to the local level and attentional selection of lower SFs facilitated binding by the RH of shapes to the global level.

43.418 How objects and spatial attention interact: Prefrontal-parietal interactions determine attention switching costs and their individual differences

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How are spatial and object attention coordinated to achieve rapid 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. Our model explains psychological data about covert attention switching and multifocal attention without eye movements. The model predicts that '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 prefrontal cortex (PFC) while shrouds compete among themselves for dominance. Winning shrouds support view invariant object category learning and active surface-shroud resonances support conscious surface perception. In the present model, visual inputs are transformed by simulated cortical magnification and then separated into left and right hemifield representations, consistent with both anatomical and behavioral evidence of independent attention resources in the left and right visual hemifields (Alvarez and Cavanagh, 2005). Activity levels of filled-in surface representations are modulated by attention from shroud representations in PPC and PFC, consistent with V4 neuronal data (Reynolds and Desimone, 2004). Attentive competition between multiple objects is simulated in variations of the two-object cueing paradigm of Egly, Driver and Rafael (1994).

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43.419 Re-thinking the active-passive distinction in attention from a philosophical viewpoint

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Whether active and passive, top-down and bottom-up, or endogenous and exogenous, attention is typically divided into two types. To show the relationship between attention and other functions (sleep, memory, learning), one needs to show whether the type of attention in question is of the active or passive variety. However, the division between active and passive is not sharp in any area of consciousness research. In phenomenology, the experience of voluntariness is taken to indicate activity, but this experience is often confused with others. In psychology, task-dependent behavior is taken to indicate activity, but is often conflated with complex automatic behavior. In neuroscience, top-down processes are taken to exclusively

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indicate activity despite the fact that both top-down and bottom-up activations are always present in the brain. Moreover, work in attention has shown that the results of so-called passive and active processes are sometimes inseparable. Carrasco, et al. (2004), for example, show that active attention results in the same change in perceptual contrast that is enacted by bottom-up mechanisms. Likewise, Reynolds and Desimone (2003) show that top-down and bottom-up attention effect neural contrast in the same way. Thus, the passive-active distinction does not seem to neatly separate two types of attention. Perhaps a more convincing model of attention combines active and passive processing into a single mechanism of control. One such potential model is what we call the Unitary Saliency Map Model, first suggested by Koch and Ullman (1985) and developed by Treue (2003). In such a model, top-down and bottom-up processes each feed into the same saliency map, from which attention is controlled. We argue that this makes sense of the phenomenological, psychological, and neuroscientific data. Finally, the acceptance of such a model will force us to review some of our previous findings on attention and its relation to consciousness.

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43.420 Application of a Bottom-Up Visual Surprise Model for Event Detection in Dynamic Natural Scenes

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We present an application of a neuromorphic visual attention model to the field of large-scale video surveillance and show that it outperforms a state-of-the-art method at the task of event detection. Our work extends Itti and Baldi's Surprise framework as described by "A Principled Approach to Detecting Surprising Events in Video" in CVPR 2005. The Surprise framework is a biologically plausible and validated model of primate visual attention which uses a new Bayesian model of information to detect unexpected changes in feature detectors modeled after those in the mammalian primary visual cortex. We extend this model to cover extremely large fields of view, and present methods for processing and aggregating such large amounts of visual data. Our system is tested on real-world data in which events containing both pedestrians and vehicles are staged in an outdoor environment and are shot on a 16 mega-pixel camera at 3 frames per second. In these tests, we show that our system is able to provide a greater than 12.5% gain in an ROC AUC analysis over a reference (OpenCV) algorithm ("Foreground Object Detection from Videos Containing Complex Background," Li, et al, 2003). Furthermore, our system is rigorously tested and compared against the same algorithm on artificially generated target events in which image noise and target size is independently controlled. In these tests, we show an approximately 27% improvement in noise invariance, and an approximately 10% improvement in scale invariance over the comparison algorithm. The results from these tests suggest the importance of strong collaboration between the neuroscience and computer science communities in developing the next generation of vision algorithms.

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43.421 Perception of simultaneity is impaired in correspondence to the amount of allocated attention: Evidence from a visual prior entry study

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Studies on visual prior entry show that two stimuli presented simultaneously, or with short temporal delay, are only rarely perceived as simultaneous if one of these stimuli is attended to. If the same two stimuli are equally unattended, simultaneity is frequently perceived. The temporal profile model (Stelmach & Herdman, 1991, Journal of Experimental Psychology: Human Perception and Performance, Vol. 17(2), pp. 539-550) predicts such an impairment of simultaneity perception by attention and allows to quantify this impairment. The higher the amount of attention selectively allocated towards one of two stimuli, the less often these stimuli should be perceived as simultaneous. We tested this hypothesis in a visual prior-entry paradigm, using masked and non-masked peripheral cues for orienting attention. The amount of attentional allocation was manipulated by varying the temporal delay between cue and cued target (34 ms, 68 ms and 102 ms). Since in larger cue-target delays the cue has more time to shift attention towards its location, a higher amount of attention should be allocated towards the respective cued target. Observers judged simultaneity of two visual stimuli presented with varying temporal delays either with a temporal-order or a simultaneity-judgment task. Results supported the hypothesis that perception of simultaneity depends on the amount of attentional allocation: The larger the cue-target delay, the less frequent were the simultaneous judgments. Visibility of the cue and the judgment task had no influence on this effect. These results provide a challenge for theories on temporal (order) perception because they contradict an (implicit) assumption of most models, viz. that simultaneity should be perceived if temporal order cannot be detected and vice versa.

43.422 fMRI evidence for top-down influences on perceptual distraction

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Studies of visuospatial attention have demonstrated that the extent to which task-irrelevant information is processed depends on the perceptual demands of processing task-relevant information (e.g., Lavie, 1995). This result has been explained by the load theory of attention that assumes that perceptual resources are allocated automatically and exhaustively (e.g., Lavie et al., 2004). Here, we tested the extent to which the automatic allocation of perceptual resources can be influenced by top-down attentional control systems using behavioral and neural measures. Fourteen observers searched for a target letter (X or N) amongst a homogeneous (low-load) or heterogeneous (high-load) array of distractors. Prior to the search array, a color change at fixation cued the display load (84% valid; 16% invalid). Processing of task-irrelevant information was assessed behaviorally by measuring the interference caused by a task-irrelevant flanker letter. fMRI methods were used to record BOLD responses during the task. The cue+target trials were randomly intermixed with trials in which there was a cue, but no target (cue-only) and trials in which there were no stimuli. The results indicated that behavioral interference was modulated by cue validity, such that on valid trials, there was little interference, but on invalid trials there was greater interference under low than high load. fMRI analyses of the cue-only trials revealed regions of the dorsal frontoparietal network. BOLD responses in subregions of this network (bilateral IPL; left MFG) on cue+target trials were correlated with individual differences in behavioral interference. In visual cortex, areas that represented the task-irrelevant locations (identified by a separate localizer scan) showed larger cue-only responses on low-load trials than on high-load trials. In contrast, areas that represented the task-relevant locations showed larger cue-only responses on high-load trials. These results suggest that top-down expectations influence the allocation of perceptual resources to compensate for anticipated levels of perceptual load.

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43.423 Modulation of attention decision thresholds is responsible for inter-trial biases of attention in the distractor previewing effect

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The distractor previewing effect (DPE) is observed in oddball search tasks and refers to delayed responses to targets that have been associated with distractor status on an immediately preceding target-absent trial. A recent eye-movement study of the DPE (Caddigan & Lleras, 2008) showed that when participants were asked to make a saccade to a color-oddball target, saccade latency was slower and saccades were less accurate when the target color in the current trial was the same as the color of the distractors in the preceding target-absent trial. These changes in eye-movement behavior can be due to changes in bottom-up signals or to top-down modulations about what to do with those signals (or to both). In terms of bottom-up changes, attention may be less likely to be attracted to the target because its salience has decreased, thereby slowing the rate of evidence accumulation towards an attention movement in its direction. Alternatively, top-down modulations may also be at play: heightening attentional decision thresholds would require longer accumulation periods before an attention movement is executed. Here we modeled the eye-movement data using a computational model based on a leaky, competing accumulator in which both

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target and distractors have their own parameters of signal strengths and decision thresholds. Goodness-of-fit tests showed that changes to signal strengths alone (evidence accumulation) cannot account for the observed data. Only when changes to the decision thresholds were modeled (heightening thresholds to recently seen distractor colors and simultaneously lowering thresholds to other features) was the model able to accurately predict the saccade latency and landing accuracy data. Our results clearly support a top-down interpretation of the DPE (see Lleras et al., 2008) and further specifies how attentional biases are instantiated between trials: as modulations of decision thresholds responsible for triggering attention (and eye movements) toward specific features in the display.

43.424 **Visual attention related to difficulty in n-back tasks**

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Behavioral and fMRI techniques have been utilized to investigate the neuroanatomical correlates of goal directed visual attention. It was hypothesized that comparing target to non-target activation for each participant (Single subject event-related functional magnetic resonance imaging [ER-fMRI], on two visual 1-back working memory tasks, with three levels of difficulty, would reveal a network of frontal and parietal sites, similar to Corbetta's visual attention networks with a significant positive correlation between the accuracy level for each task and the strength of the signal contrast between target and non-target activation. One task used highly familiar cartoon faces of varying colour and emotional expression, expected to primarily activate the left hemisphere, while the second task was expected to activate the right hemisphere, using 3-D cubes with 0, 45 or 90 deg rotations. The 1-back design required manipulation, continuous updating and selective attention, with each task type requiring different button presses to differentiate repeat and non-repeat responses. The block designed and ER-FMRI results both demonstrated fronto-parietal networks of activation predominately in the left hemisphere for both tasks differing with respect to stimulus class and across individuals. No correlation was observed between the strength of activation and task accuracy. Increasing difficulty of the mental rotation 1-back task appeared to activate a bilateral network of areas with greater bilateral parietal than frontal activation, while the facial attributes tasks activated largely LH dominant frontal areas.

Attention: Inattention and attention blindness

Orchid Ballroom, Boards 425–438

Monday, May 10, 8:30 - 12:30 pm

43.425 **Attentional blink magnitude is predicted by the ability to keep irrelevant material out of working memory**

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Participants have difficulty reporting the second of two masked targets if this second target is presented within 500 ms of the first target -- an Attentional Blink (AB). Even unselected, healthy, young participants differ in the magnitude of their AB. Previous studies (Arnell, Stokes, MacLean & Gicante, 2010; Colzato, Spape, Pannebakker, & Hommel, 2007) have shown that individual differences in working memory performance using the OSPAN task can predict individual differences in AB magnitude where individuals with higher OSPAN scores show smaller ABs. Working memory performance also predicts AB magnitude over and above more capacity based memory measures which are unrelated to the AB (Arnell et al., 2010). Why might working memory performance predict the AB? One possibility is that individuals showing smaller ABs are better able to keep irrelevant information out of working memory. The present study employed an individual differences design, an AB task, and two visual working memory tasks to examine whether the ability to exclude irrelevant information from visual working memory (working memory filtering efficiency) could predict individual differences in the AB. Visual working memory capacity was positively related to filtering efficiency, but did not predict AB magnitude. However, the degree to which irrelevant stimuli were admitted into visual working memory (i.e., poor filtering efficiency) was positively correlated with AB magnitude over and above visual working memory capacity such that good filtering efficiency was associated with smaller ABs. Good filtering efficiency may benefit AB performance by not allowing irrelevant RSVP distractors to gain access to working memory.

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43.426 **Attentional Blink without Masking**

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The Attentional Blink (AB) is a well-known RSVP paradigm in which two visual targets (T1 and T2) are embedded in a stream a distractors. In this paradigm, performance on T2 is largely impaired when it appears briefly after T1 (i.e. within 200-500ms). This paradigm is thought to reveal the time course of attention. An important feature of the AB paradigm concerns the necessity of a light masking of the two targets. Thus, although the classical interpretation of the AB effect refers to the limited capacity of attentional resources, this interpretation is not straightforward since masking T2 also contributes to its impaired visibility. Here, by contrast, we demonstrate that while the masking of T2 is necessary in a standard AB task, such a condition is no longer necessary when T2 is a gabor patch at threshold. Indeed, we reasoned that having T2 at threshold would maximize the probability of an AB effect without masking. These results support a clear capacity limited account of the AB effect without relying on masking and call for more consideration of the role of temporal attention in theories of the AB.

43.427 **Word Superiority within the Attentional Blink**

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There is enough evidence of word superiority effects (WSE) on letter processing under various masked presentation conditions, including forward, backward, metacontrast and lateral masking. However, there are indications that without focused attention there might be no word superiority (e.g. Pantyushkov, Horowitz, & Falikman, 2008). The question remains whether the WSE would improve performance for stimuli lacking attention, e.g. due to the attentional blink (AB). Previously, we've observed a sort of the WSE on the AB (Falikman, 2002), but for words presented letter-by-letter, with at least some letters presumably safe from the AB. Here, we studied the influence of a simultaneously presented word context on the letter target processing within the AB. In a rapid serial visual presentation procedure, observers were presented with strings consisting of five identical digits, among which two strings of letters were embedded. After each trial, participants reported the central letter of each letter string using the 2AFC procedure for the 1st and for the 2nd letter in order. The 1st target was always flanked by identical letters, whereas the 2nd target (the probe) was embedded in the string of letters forming a 5-letter nonpronunceable nonword, a pronounceable pseudoword, or a Russian word, in which the middle letter could be replaced with another letter, as in the Reicher-Wheeler paradigm (e.g. river-rider). For probes embedded in nonwords, a standard AB was obtained. For probe letters embedded in words, there was no AB, the result that might be considered a word-superiority effect. For pseudowords, the probe performance within the AB was better than with nonwords, but in general still poorer than with words. Thus, word superiority shown might be partly, but not entirely explained by the closest familiar context set by letters flanking the probe. Supported by RFBR, grant #08-06-00171-a.

43.428 **T1 difficulty modulates the attentional blink only when T1 is unmasked**

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The attentional blink (AB) is consistently observed when people are required to identify or detect two consecutive targets (T1 and T2). T2 suffers in performance when it is presented less than 500 ms after T1. The two stage theory (Chun & Potter, 1995) proposes that the AB is caused by limited processing resources being occupied by T1 when T2 is presented. If so, it is expected that varying T1 difficulty should modulate the AB magnitude. Previous findings however are inconsistent: Christmann & Leuthold (2004) manipulated T1 difficulty by contrast and found that an easy T1 (high contrast) decreased the AB, but in a similar experiment Chua (2005) found the opposite. McLaughlin and colleagues (2001) varied T1 difficulty by target exposure and found no effect on the AB. In previous experiments (Nielsen, Petersen & Andersen, VSS 2009) we found no evidence of AB interference from varying T1 difficulty with contrast and exposure. We suggested that the use of pattern masks might have compromised ours, and similar studies. In a new set of experiments we test this hypothesis and vary T1 difficulty with contrast, only this time we omit T1's mask. We find significant AB interference from manipulating T1. In the easy condition (high contrast) we observe an increase in AB magnitude for SOA's of 200 ms. These findings supports the hypothesis that visual masking has an antagonistic influence on the AB effects of T1 difficulty. The result however, is the opposite of what we should expect from the two stage theory. We hypothesize that the rapid onset of T1 induces an attentional capture effect, which increases with contrast. This challenges the use of contrast to manipulate T1 in studies examining how an easy T1 affects the AB – any positive effects may be compromised by the increased capture effect.

43.429 **Boosting back to the future: Explaining order reversals in the attentional blink**

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The second of two targets (T2) is often missed when it follows the first (T1) within 500 ms in a rapid stream of distractors– a finding referred to as the attentional blink. No attentional blink occurs when T2 immediately follows T1, at lag 1. Intriguingly, T2 is then often reported before T1, even though it occurs 100 ms later. These order reversals have been attributed to limited-capacity episodic representations within which order is completely lost. We provide evidence that order reversals are instead due to prior entry: T1 causes an attentional enhancement that is beneficial to T2 and speeds up its processing. This predicts that order reversals should be reduced when T1 itself is enhanced, e.g. by a cue. Conversely, order reversals should increase when T2 is cued instead. These predictions are borne out by the results. Moreover, the observers that exhibited the greatest shift in performance between T1 and T2 also showed the greatest change in the number of order reversals. These results support the theory that an attentional boost rather than deficit underlies order reversals, lag-1 sparing, and the attentional blink.

43.430 **Specific Task Strategies Affect Repetition Blindness**

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Repetition Blindness (RB) refers to a cognitive phenomenon in which participants fail to report repeated items in a rapid serial visual presentation (RSVP) stream. Report and detection are two tasks commonly used to measure RB. Participants are required to report targets in the report tasks, while they are required to detect repetition in the detection task. However, it is unclear whether strategic differences between the two tasks affect RB. In Experiment 1, we measured RB with the two tasks by using two common types of stimuli, letters or words, as the targets, and with symbols as the distractors. A significant RB was found in the detection task, but not in the report task. This surprising result may be due to the order effect of the two tasks. Therefore, we manipulated the order of the two tasks sequentially in Experiment 2 and studied the lag interval between two targets as well. The result was consistent with Experiment 1 in that RB was found in the detection task across 4 lag intervals but priming was found in the report task. Thus, across the two experiments, RB was found more easily in our detection task than in our report task. Therefore, strategic processing in RB may be differentially involved across tasks, and may have stronger effects on report tasks than detection tasks.

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43.431 **High perceptual load does not induce inattentional blindness or early selection**

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Perceptual load theory has been one of the most influential theories of attentional selection during the past fifteen years, providing a resolution to the early versus late selection debate by arguing for a flexible, load-dependent mechanism of selection. A number of recent behavioral and neurophysiological studies have demonstrated that high perceptual load displays produce inattentional blindness, in which participants are "blind" to task-irrelevant flanking stimuli that appear in the display. Presumably, when the perceptual load of the primary task is high, early selection occurs and participants completely fail to process task-irrelevant information. Such an interpretation argues for a strong, load-dependent early-selection mechanism occurring very early during perceptual processing. However, because inattentional blindness phenomena might be attributed to memory failures, not perceptual failures, we hypothesized that more sensitive measures of flanker identification might provide evidence that participants processed the task-irrelevant flankers to a relatively late level. In the current experiments we measured distractor-related Simon effects and sequential effects to assay interference from flanking stimuli, instead of measuring traditional flanker effects. When distractor processing was measured using traditional flanker effects we replicated the basic load effect: Participants showed no flanker interference under high perceptual load. However, when examining the Simon effect and sequential effects, large interference effects were observed in high-load displays, indicating that the distractors' identities were processed and affected responses. These findings suggest that high perceptual load neither induces 'blindness' for task-irrelevant information nor involves early selection.

43.432 **Blind, Blinder, Blindest: Individual differences in change blindness and inattentional blindness**

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Research on change blindness and inattentional blindness has explored why and when failures of visual awareness occur, but few studies have examined who is most susceptible to failures of awareness. Although a few studies have shown group differences in the detection of changes and unexpected events, most have focused solely on how scene content influences detection for groups with special interests rather than on more global individual differences. Here we explored whether individual differences in perception, attention, cognitive style, and personality predict change blindness and inattentional blindness. Participants completed a battery of change blindness, inattentional blindness, perceptual, and personality measures, including both incidental and intentional tests of visual awareness. A variety of personality measures, including factors related to effort, amiability, intelligence, and speed covaried with performance on basic measures of attention and perception as well as with change detection performance. Most of these individual differences in personality appear to influence the strategies people are likely to use when performing the tasks. Interestingly, the pattern of predictors for intentional change detection tasks differed from that for unexpected changes in incidental change detection and for unexpected objects in an inattentional blindness task. For example, better functional field of view is associated with more efficient intentional search for change, but not with the detection of unexpected visual events. Performance on a flicker change detection task was unrelated to the likelihood of noticing unexpected objects or changes. These findings are consistent with the idea that individual differences in perceptual and attentional abilities do not predict detection of unexpected events. We consider how individual differences in personality interact with the task demands for intentional and incidental tasks to predict who will notice expected and unexpected visual events.

43.433 **Change Blindness: A Comparison of Selective Attention of Novice and Experienced Drivers**

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This study used a change blindness paradigm to investigate differences in selective attention between non-drivers (no driving experience), new drivers (one-year or less driving experience) and experienced drivers (three years or more driving experience). A modified flicker method used typical road scenes to test change blindness for stimuli of varying relevance to driving. Twelve photographs of common road scenes, which ranged in complexity from open rural roads to congested urban streets, were used to create 36 pairs of modified and unmodified road scenes. The changing elements were selected to include three levels of conspicuity and relevance to the driving task: relevant/conspicuous, relevant/inconspicuous and not relevant. The participants' task was to identify the manipulated element in each pair of road scenes within a 30 second time constraint. Analysis of variance showed a main effect in response time between experience groups, with non-drivers exhibiting significantly slower response times in detecting the element of modification compared to drivers with three years or more

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experience. The ANOVA also showed a significant main effect of salience category (relevance/conspicuity) on percent accuracy for correctly identified manipulated road scenes. There was no difference between experience groups in accuracy of identifications. These results indicate that non-drivers fixate different road elements compared to experienced drivers. These findings may provide preliminary insight as to why novice drivers are at a greater risk of causing a vehicular accident compared to experienced drivers.

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43.434 **Synchronous Motion-Induced Blindness and Disappearance of a Ring**

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Purpose: On the Motion-Induced Blindness (MIB), the target dots are invisible spontaneously or stochastically. We investigate, however, the mask or noise patterns that induce synchronous disappearance of the targets. With the new inducing masks we could find MIB where a fairly large target figure, rather than conventional dots, would slips away from our consciousness. A ring target of 5 degree size is tried.

Methods: Experiment1: At 5 degree eccentric position, the 3 white dots, 0.25 degree of size forming a triangle were displayed statically on the black background with the central fixation point. Surrounding the each target, one or two concentric blue rings were displayed. In the motion condition, the rings were expanding and shrinking at 2 degree/s velocity between 0.1 degree and 2 degree from the outer edge of the target. In the ON-OFF condition, one inducing ring simply turned on and off at 1 degree apart from the target at 1Hz which was far slower than conventional Flicker-Induced Blindness (FIB). Experiment2: the target was a white ring of 5 degree size whose thickness could vary from fairy thin to thick. The inducing mask is also the concentric blue rings which were at either inside of the target or outside or both. The motion condition and ON-OFF condition are the same as the Experiment1.

Results: Experiment1: In the motion condition, while inducing rings were expanding, the onset moment of the most inner ring, the 3 target dots were disappeared synchronously and they are visible again when the mask rings started shrinking. In the ON-OFF condition we observe less effective disappearances. Experiment2: The observers saw occasionally totally invisible ring.

Discussion: Relatively few accounts were published on the moment of disappearance. This is simply because the masks were generally random or at least independent of the target.

43.435 **Attention modulates perceptual rivalry within after-images**

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Visual afterimages were initially thought to be solely caused by bleaching of photochemical pigments or neural adaptation in the retina. A number of recent results, however, require a contribution of cortical processing to after-image perception. Here, evidence is reported that afterimages are modulated by attention after the stage of visual adaptation. Observers adapted to overlapping colored, transparent horizontal and vertical bars. Upon offset of the adapting pattern, observers experienced an after-image that spontaneously alternates between three possible perceptual states before completely fading: 1. Only the vertical component after-image of the vertical-horizontal bar adapting stimulus; 2. Only the horizontal component of the after-image; or 3. The after-image of both horizontal and vertical components. That 1 and 2 dominate and alternate, as in cases of monocular rivalry, suggests that the after-image itself undergoes perceptual rivalry. If, upon offset of the adapting stimulus, two overlapping outline rectangles are presented, corresponding to the boundaries of the vertical and horizontal components of the adapting stimulus, an endogenous attentional influence on the perception of after-images is observed. When observers attended to either the horizontal or vertical outline rectangle of an overlapping horizontal-vertical rectangle pair of the same size as the adapting stimulus, they tended to report seeing an afterimage of horizontal bars if they attended to the horizontal outline rectangle, and reported seeing an afterimage of vertical bars if they attended to the vertical outline rectangle. Flashing either the vertical or horizontal outline rectangle of an overlapping horizontal/vertical outline rectangle pair modulated the visibility of either the vertical or horizontal component of the after-image in an analogous manipulation of exogenous attention. Because attention is a cortical process, this provides further evidence that there is a cortical contribution to afterimage formation.

43.436 **Distractor Evaluation affects Awareness under High Load**

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Perceptual load plays a critical role in determining awareness. Awareness of a distractor was reduced under high-load (that requires more resources) compared to low-load conditions. The salience hypothesis argues that salience of distractors and not perceptual load per se determines selective attention and distractor processing. Meaningful stimuli may capture attention and hence may suffer less inattentional blindness (IB). In addition to conscious perception, attention also affects evaluation of stimuli. Given differences in emotion-attention interactions, the study investigated the awareness of distractor emotional faces under different conditions of attention (low-load and high-load) using the IB paradigm. Participants performed a low or high-load task with a letter string superimposed on an emotional or neutral face. Participants were presented two faces and asked to identify the face (happy or sad) that appeared in the critical inattentional blindness trial. Results contradict predictions from load theory and indicated that differences in attention do matter for awareness. Attention-emotion interactions have different effects on awareness. Happy faces were identified better in the high-load condition indicating facilitation of unattended happy faces. However, performance was worse than chance for sad faces indicating inhibition of unattended distractor faces with sad expression. Inhibition or facilitation is associated with the emotional content of the distractor stimuli as well as the availability of the attentional resources. Distractor evaluation was dependent on emotion and affected awareness only under the high-load condition indicating the automatic nature of such evaluations. The lack of such evaluation effects in the low load condition indicates that the extra resources might inhibit the automatic evaluation mechanisms. The results have implications for theories of attention as well as the role of emotions in awareness and open a new set of possibilities to explore the factors affecting distractor evaluation under different attentional conditions.

43.437 **Gist perception requires attention**

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In the past decade, studies have claimed that the gist of a scene is immune from inattentional blindness (IB) (Mack and Rock, 1998) and can be perceived without focused attention (Li et al., 2002; Rousselet et al., 2002). However, it seems possible that these studies did not use sufficiently difficult primary tasks and that more demanding tasks would show that gist perception requires attention. To test this possibility, we devised a novel form of the IB paradigm in which we employed the multiple object tracking task (MOT) and had participants track 4 of 8 identical black circles. While tracking these circles, a sequence of background images were rapidly presented (one every 65ms), consisting of grids of squares comprised of randomized colors. On the fifth trial, the second to last background image was unexpectedly a natural scene from one of five categories (beach, mountain, indoor, highway, city). Of the 10 subjects run, all showed inattentional blindness to the scene, failing to report its presence. Immediately following these 5 trials, participants completed 20 trials where they switched the focus of their attention from the tracking task to monitoring the background. When this was done, these same participants could correctly identify when a scene was present and classify that scene with 92% accuracy. In Experiment 2, participants tried to track objects and detect a scene simultaneously. While tracking 4 objects, participants' tracking and scene detection performance dropped significantly relative to when they completed each task individually ($p < .05$ for both tasks). However, when the tracking load was lessened to 3 objects, performance did not decrease ($p > .51$ and $p > .37$ respectively). Together, these two experiments show that contrary to what has been previously claimed, gist perception is not immune from inattentional blindness and requires attention.

43.438 The Attentional Cost of Feature-based Inhibition

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Visual search is improved when half of the distractors are presented, before the remaining distractors and the target are added to the display, (The Preview Benefit: Watson & Humphreys, 1997). However, when colour is shared between old irrelevant information (i.e., distractors) and new relevant information (i.e., a new target), observers show a degree of inattentional-blindness to the new target (The Negative Colour-based Carry-over Effect: Braithwaite et al., 2003). To account for these effects, the researchers argue for a multi-factor inhibitory model, in which locations and features are used to filter the old irrelevant items from attention. Here we present the first demonstration of colour-based carry-over effects under more ecologically valid dynamic visual search conditions. Furthermore, we show that the carry-over effect is greatly magnified under dynamic conditions (both common motion and random motion), relative to equivalent static search conditions. These findings support the notion of a flexible inhibitory mechanism of attentional guidance across time: when location-based information is abolished (i.e., under dynamic conditions) there is an increased weighting on the feature-based component to aid in tracking and successful filtering – however, the consequence of this is an increased degree of attentional-blindness for new target information carrying that feature. The results will be discussed in terms of their important contributions towards understanding the mechanisms that may be responsible for failures of awareness, such as instances of sustained inattentional blindness, in the real dynamic visual world.

Acknowledgement: ESRC 1+3 QUOTA Studentship

Perceptual organization: Grouping and segmentation

Orchid Ballroom, Boards 439–458

Monday, May 10, 8:30 - 12:30 pm

43.439 Target Discrimination Performance Reveals That Competition For Figural Status Entails Mutual Inhibition

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Studies show that figure-ground perception entails competition between shapes that might be seen on opposite sides of a border. We presented small, enclosed, symmetric novel silhouettes designed to favor the inside as figure, but to differ in the strength of competition from shapes that might be seen on the outside. In high-competition silhouettes, a portion of a familiar shape was suggested, but not perceived, on the outside of the figure's border. In low-competition silhouettes, the shape suggested on the outside was novel. We used a target orientation discrimination task in which tilted bar targets were presented on the inside or outside of high-competition and low-competition silhouettes to assess whether: (1) More attention was drawn to the inside to resolve the greater competition from the outside in high- than low-competition silhouettes; if so, RTs should be faster for targets on the inside of high-competition than low-competition silhouettes. (2) More inhibition was applied to the outside of the high-competition than low-competition silhouettes because of the greater competition from the outside in the former than the latter; if so, RTs should be longer for outside targets shown with high-competition than low-competition silhouettes. (3) Whether cross-border competition involves mutual inhibition; if so, RTs should be longer for both inside and outside targets shown with high-competition compared to low-competition silhouettes. For both inside and outside targets, accurate discrimination responses were significantly slower for targets shown with high-competition than low-competition silhouettes ($p < .05$). Thus, our results support the hypothesis that competition for figural status entails mutual inhibition of the competing shapes. We find no evidence that more attention is deployed to the inside to resolve the greater competition in high-competition than low-competition silhouettes. Nor do we find that inhibition is applied only to the outside of high-competition silhouettes, where the strong competitor lay.

43.440 Contour Shape Processing: Contrast Polarity and Perceived Aspect Ratio

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The visual system parses the visual scene into objects and their spatial locations by integrating local signals into global object representations. We have shown that spatial distribution of luminance polarities in an image plays an important role in the processes of perceptual unit formation (Spehar, 2000; Spehar & Clifford, 2003). For example, a pronounced degradation of perceived illusory shapes is observed in configurations with contrast polarity variations at the intersections of orthogonally oriented edges within inducing configurations, but not in configurations where contrast polarity variations did not coincide with points of highest orientation discontinuity. A similar effect of the distribution of contrast polarity reversals was demonstrated in perceptual closure: the presence of contrast polarity reversals impaired visual search for shapes with contrast polarity reversal positioned at points of high contour curvature of the bounding contour (Spehar, 2002). Here we report an analogous effect of the distribution of contrast polarity reversals on the computation of aspect ratio of centrally presented contour shapes. The perceived aspect ratios appear more vertically elongated when contrast polarity changes at points of intersection of differently oriented component lines (corners), compared to configurations with no contrast polarity variations and configurations where contrast polarity variations appear at the collinear line segments. These results suggest an important and different role of contrast polarity in combining smooth parts of object contours with those at points of high curvature. We believe that this pervasive sensitivity to the distribution of contrast polarity reversals along bounding contours is related to the processes that mediate grouping at intersections of lines of different orientation. If contrast polarity reverses at such junctions the probability that these segments will be grouped together is decreased which in turn influences the mechanisms involved in computation of shape area.

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43.441 One complex representation is more than two simple ones: Insight from schizophrenia

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We can effortlessly focus on and compare separate items, even when part of different objects. Here, we ask whether establishing new links between items is enough to consider such items, or whether it is also necessary to build a more complex representation that integrates these new links with groups issued from automatic grouping, thus helping to preserve the stability of background information. We explore this question by studying how such processes are disturbed in patients with schizophrenia (N=43) relative to controls (N=43). In a perceptual task (derived from Beck & Palmer, JEP:HPP 2002), subjects have to find two identical and adjacent figures displayed among six different objects arranged on a circle. Targets are either connected by a line (within-group pairs), or are unconnected but belong to different groups (between-group pairs). It is easier to find targets when they belong to the same rather than to different groups, but this advantage is reduced when between-group trials are more frequent. In contrast with controls, patients with schizophrenia show an advantage for between-group trials, and an impairment in finding within-group targets when incited to prioritize between-group trials (i.e. when those trials are more frequent). Else they show a preserved advantage for within-group pairs. A similar result is observed when the task is adapted to explore memory. The results show that patients are able to establish links between separate, between-group figures when forced to do so. Automatic grouping also seems preserved in usual conditions, and even if such grouping is fragile, it could explain a loss but not a reversal of the advantage for within-group pairs. It is thus rather the integration of the two types of pairs in a single representation that seems to be impaired in patients, showing that establishing links between separate items is not enough to flexibly explore the environment.

 See page 3 for Abstract Numbering System

43.442 Grouping of orientation but not position cues in the absence of awareness

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How the brain constructs a coherent representation of the environment from noisy and discrete visual input remains poorly understood. Here we explored whether awareness of the stimulus plays a role in the integration of local features into a representation of global shape. Participants were primed with a shape defined either by position or orientation cues, and performed a shape discrimination task on a subsequently presented probe shape. Crucially, the probe could either be defined by the same or different cues as the prime, which allowed us to distinguish the effect of priming by local features and global shape. We found a robust priming benefit for visible primes with response times being faster when the probe and prime were the same shape, regardless of the defining cue. However, rendering the prime invisible uncovered a dissociation: while there was only local priming for position-defined primes, we found only global priming for orientation-defined primes. This suggests that the brain extrapolates global shape from orientation cues in the absence of awareness of a stimulus, but it does not integrate invisible position information. In further control experiments we tested the effects of invisible priming on processing of local elements without a global interpretation.

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43.443 Finding the egg in the snow: The effects of spatial proximity and collinearity on contour integration in adults and children

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We tested adults and children aged 7 and 14 on the ability to integrate contour elements across variations in the collinearity of the target elements and in their spatial proximity. Participants were asked to find the 14 Gabors forming an egg-shaped contour among randomly positioned background Gabors. Across trials, the density of background noise Gabors was varied according to a staircase procedure to determine a threshold for each combination of collinearity and spatial proximity. Thresholds were expressed as the relative density of the background noise elements to target elements (Δ).

When the collinearity of the target Gabors was high, the thresholds of adults (n = 24 in each of Experiments 1 and 2) were largely independent of spatial proximity and varied only with Δ. It was only when collinearity was less reliable because the orientation of the elements was randomly jittered that spatial proximity began to influence adults' thresholds. These patterns correspond well to the probability that real-world contours compose a single object: collinear elements are more likely to reflect parts of a real object and adults integrate them easily regardless of the proximity among those collinear elements. The results from 7- and 14-year-olds (n=24 per age group) demonstrate a gradual improvement of contour integration throughout childhood and the slow development of sensitivity to the statistics of natural scenes. Unlike adults, integration in children at both ages was limited by spatial proximity regardless of collinearity and one strong cue did not compensate for the other. Only after age 14 did collinearity, the most reliable cue, come to compensate efficiently for spatial proximity.

43.444 The role of grouping in shape formation: New effects due to the directional symmetry

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The problem of perceptual organization was studied by Wertheimer in terms of grouping by showing how elements in the visual field 'go together' to form an integrated, holistic percept according to some general well-known principles. Grouping per se does not make any prediction about shape. The role of the gestalt principles is to define the rules of "what is or stay with what" i.e. the grouping and not the shape. The notion of 'whole' due to grouping is phenomenally different from the one due to shape. The form of grouping represents the groups of elements that assume the role of "parts" within a holistic percept. The form of shape is instead the result of a global perceptual process emerging parallel to or after the form of grouping and giving to the whole a unitary form mostly along the boundary contours. This suggests that grouping and shape formation can be considered as two complementary integrated processes of perceptual organization. The main purposes of this work are (i) to study the relationship between grouping and shape perception, (ii) to demonstrate that the form of grouping can influence the form of shape, and (iii) to demonstrate that the directional symmetry is a second order organization that polarizes the perception of the shape and that represents the basic principle of shape formation. Psychophysical experiments under motion conditions revealed several new shape illusions due to grouping and depending on the directional symmetry.

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43.445 Visual grouping in Gabor lattices: a psychophysical and computational study

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In this study we examined the relative contribution of two perceptual grouping principles, namely proximity and collinearity, to the perception of a global orientation. For this purpose, we used Gabor lattices, two-dimensional patterns of regularly placed Gabor patches aligned in a sheared grid with two different principal directions (its axes). The distance between Gabor elements along each axis of the grid and the local orientation of the Gabor elements with respect to the grid were manipulated, in order to examine the effects of proximity and collinearity, respectively. We also examined whether the presentation time of the Gabor lattice had an influence on which grouping principle dominated the participants' percept. We found that proximity and collinearity interacted with each other to determine which axis was seen to be the global orientation. We found a relative preference for grouping based on collinearity for Gabor lattices in the short duration condition, whereas there was a relative preference for grouping based on proximity for Gabor lattices in the long duration condition. We will explain the pattern of results in terms of first- and second-order filters tuned to different orientations and scales.

Acknowledgement: Erasmus

43.446 Creating links in empty space: an fMRI study of perceptual organization

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When faced to the need of comparing two objects at the same time, information selection can be modulated by the presence of grouping factors. Automatically processed grouping cues enable effortless selection of groups of objects. On the other hand, selecting non-automatically grouped objects implies the creation of mental links between them through top-down processes. To explore the neural basis of bottom-up grouping versus top-down grouping, 16 participants were tested in a variant of the Repetition Discrimination Task (Beck & Palmer, JEP:HPP 2002) in a fMRI experiment. Circles and squares were presented in spatial alternation except for two figures, the target pair (i.e., two contiguous figures that were identical, either two squares or two circles), around a central fixation point. Contiguous figures could be linked by a connector (within-group pair) or not (between-group pair), and located within the same or in separate hemifields. Participants had to determine the identity of the target pair (i.e., circles or squares). Two blocks incited subjects to prioritize either target type, by manipulating the proportion of within-group and between-group trials. Each block was followed by a series of trials with equivalent proportion of within- and between-group trials, with an event-related design. Continuous eye movements recording in the scanner ensured to check correct central fixation. The behavioural data show a cost of RT for between-group compared to within-group, and reproduce earlier results (Van Assche, Gos, Giersch, Vis Cogn 2008). Frontal and parieto-occipital areas were more recruited to identify between-group compared to within-group targets, especially when in separate hemifields. For between-group pairs, supplementary internal temporal activations were observed after inciting to prioritize between-group compared to within-group pairs. The results are discussed in terms of the building of a hierarchical representation superimposing between-group on within-group pairs.

43.447 Perceptual Organization based on Gestalts: Emergent Features in Two-Line Space

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What exactly are the "parts" that make up a whole object, and how and when do parts group? The answer we propose hinges on Emergent Features (EFs), defined as features that (1) are possessed by no individual part but that materialize only from the configuration; and that (2) make the object more salient than its parts. The Configural Superiority Effect (CSE) was used to diagnose EFs in an odd-quadrant visual discrimination task. The CSE is obtained when discrimination between two parts (e.g., a vertical line segment in one quadrant vs. a horizontal in each of the other three) is made faster by adding the same context element to each quadrant (e.g., another vertical). Such a result suggests that adding a second line segment creates EFs that are processed more quickly than are isolated segments. Previous work looking for CSEs with dot and three-line patterns has demonstrated several EFs, including orientation, proximity, and linearity. This experiment focuses on two-line configurations. A portion of the infinite, 8-dimensional space of all possible configurations of two line segments was systematically sampled by varying the x and y coordinates of the second segment, thus sweeping out a 2-dimensional plane through that space. The displays were coded to determine what EF differences arose between the odd quadrant and the other three. RTs were then mapped across this plane and were compared with RTs predicted from the number of EF differences between the odd quadrant and the other three and on the direction of those differences (present vs. absent in odd quadrant). The results show large differences in performance depending on the location of the context segment and demonstrate salient EFs including Parallelism, Connectivity, Intersections, and others.

43.448 Classification of seismic images depends on perceptual skill more than geological expertise

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Expert interpreters inspect seismic images to identify relevant features and diagnose the possible presence of interesting subsoil structures. Typically, a 2D seismic image is a set of adjoining seismic traces referring to variations of acoustic impedance that, taken together, compose a non mimetic representation of the subsoil. Seismic interpreters must rely on both domain-specific knowledge in the field of structural geology and general-purpose visual abilities involved in texture segregation and feature matching.

We studied three groups of observers with different degrees of expertise with seismic images (researchers of the National Institute of Oceanography and Experimental Geophysics; geology students; psychology students) and compared their performance in a task in which they should classify a target fragment as belonging or not belonging to a large seismic image. As expected, more experienced observers performed better than less experienced observers; furthermore, observers of all groups classified meaningful targets (those with clear geologically relevant features) more efficiently than non-meaningful targets (those with uncertain features). Against our expectations, however, the superiority of meaningful over non-meaningful targets did not increase at increasing expertise; rather, it appeared to depend on the level of individual perceptual skill, which was broadly distributed over the three groups. We argue that performance in the classification of seismic image fragments - which is a possible component of a seismic interpreter's work – reflects general-purpose visual abilities more than geological expertise.

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43.449 Representing grating-texture surface begins with spreading of grating-texture from the surface boundary contour

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Research on color filling-in suggests the visual system represents a homogeneous surface by first coding the surface boundary contours and then filling-in the interior with the surface feature (color). Here, we investigated if texture surfaces are similarly represented. A trial began with the presentation of a vertical grating display (4 cpd, 4.14 x 4.14 deg). After 200 msec, a rectangular region (length = 2.67 deg) with horizontal grating (4 cpd) was added onto the central area of the vertical grating display. The upper and lower boundary contours of the rectangular region were blurred with a Gaussian kernel (FWHM = 0.6 deg), leaving only the right and left boundary contours with sharp edges. This rectangular region was presented for 30, 50, 100, 150, 200, 250, or 500 msec. Observers were instructed to judge the proportion of the central area of the rectangular region not filled with the horizontal grating, and report the proportion based on a rating scale from 0 to 6. A scale of "0" indicates the entire length of the rectangular region being filled with horizontal grating, whereas "6" indicates no horizontal grating being seen in the entire rectangular region. It is predicted if the representation of the rectangular region begins with the horizontal grating spreading from the boundary contours, the rated number (proportion of the central area not filled with horizontal grating) will decrease with increasing stimulus duration. Confirming the prediction, we found the area of the rectangular region represented by horizontal grating texture increased with stimulus duration. We further fitted our data according to the cortical magnification factors in areas V1 and V2, and found the average grating spreading speeds were relatively constant at 49.5 and 78.3 cm/s, respectively. Thus, our study underscores the important role of boundary contours in representing texture surfaces.

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43.450 Contribution of motion parallax to depth ordering, depth magnitude and segmentation

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Motion parallax, i.e. differential retinal image motion resulting from movement of the observer, provides an important visual cue to segmentation and depth perception. Previously we examined its role in segmentation (VSS 2009), and here we additionally explore its contribution to depth perception.

Subjects performed lateral head translation while an electromagnetic tracker recorded head position. Stimuli consisted of random dots on a black background, whose horizontal displacements were synchronized proportionately to head motion by a scale factor (gain), and were modulated using square or sinewave envelopes to generate shearing motion.

Subjects performed three tasks: depth ordering, depth magnitude and segmentation. In depth ordering they performed a 2AFC task, reporting whether the half-cycle above vs below the centre of the screen appeared nearer. Depth magnitude estimates were obtained by matching the perceived depth to that of a texture-mapped 3d surface of similar shape which was rendered in a perspective view. 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 motions of the stimuli were "played-back".

For square wave modulation, good depth ordering performance was obtained only at low gain values; however sinewave modulation yielded unambiguous depth across a broader range of gains. In the depth magnitude task, subjects matched proportionately greater depths for larger gain values. In the segmentation task, orientation discrimination showed surprisingly similar thresholds for head motion and playback.

These results suggest that the ecological range of depths in which motion parallax gives good segmentation is very wide, whereas for good depth perception it is quite limited. The dependence of depth ordering on modulation waveform suggests that motion parallax is more useful for depth differences within one object than between occluding objects.

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43.451 Local propagation of border-ownership

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Most studies of figure/ground have used methods that presume a single global figural assignment, such as asking subjects which entire region appears in front. In our study, we used the motion-probe method introduced in Kim and Feldman (2009) designed to assess figure/ground locally at arbitrary points along a boundary, seeking evidence of local propagation of border-ownership (figure/ground assignment) along the boundary. In the motion-probe method, a small spatially circumscribed motion signal is created at a point on the boundary between two coloured regions, and

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the subject is asked which colour appeared to move; because the figural region "owns" the boundary, the response reflects border-ownership. In our study, subjects were shown semicircular shapes, to which a bar was added in such a way that in some configurations the T-junctions induced a clear local change in figure/ground assignment (example display at http://ruccs.rutgers.edu/~jacob/Demos/figure_ground.html). We then assessed figure/ground at various other points along the border, ranging from relatively near the inducing bar to relatively far, giving us the opportunity to capture the propagation of the figural status induced by the junction cue. We found a systematic effect of probe position, with probes closer to the inducer showing an increasingly strong tendency to receive figure/ground assignment consistent with the inducer---that is, as if the figural status propagated spatially from the point of the inducer. A computational model of the propagation mechanism based on Bayesian belief networks suggests intriguing parallels to known properties of neural coding of border ownership in visual cortex.

43.452 **Neural adaptation reveals cultural tuning in local/global processing**

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Cultural differences in the way adults from East Asian and Western Caucasian societies perceive and attend to visual stimuli have been consistently demonstrated in recent years. Westerners display an analytical processing style, attending to focal objects and their features. By contrast, Easterners show interest in context and relationships between objects, which is indicative of holistic processing. Although much behavioural evidence supports the existence of these cultural processing styles, the neural mechanisms underlying such perceptual biases are poorly understood. The combination of Navon figures, which contain both global and local elements, and the measurement of neural adaptation constitute an ideal way to probe this issue. Here we exploited a novel neural adaptation single-trial EEG method and recorded electrophysiological signals from British and Chinese observers while viewing two sequentially presented Navon Shapes. To control for potential confounds related to Westerners' familiarity with letters from the Roman alphabet, we constructed Navon figures made from geometric shapes. Additionally, to control for potential attentional biases and eye movements, observers performed a colour change detection task on a central fixation. In each trial, participants sequentially viewed a Navon shape followed a further shape from one of four categories: the same, local changes, global changes, local and global changes. Both groups displayed most adaptation at P1 and N170 when neither element was changed and most when both were altered. However, the critical results come from the local or global change conditions. By contrast to Westerners, Easterners showed no sensitivity to local changes, with as much adaptation occurring as when no elements were changed. This suggests that default neural coding of local and global properties occurs very early in visual processing and differs markedly between cultures, with inefficient coding of local elements in Easterners. Such visual tuning could underlie more complex behavioural differences observed across human populations.

Acknowledgement: ESRC

43.453 **Detection of Closure Reverses Unilateral Field Advantage for Repetition Detection**

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Previous research suggests that subjects are faster and more accurate detecting repeated elements presented unilaterally (both items in the same visual field) versus bilaterally (one item in each visual field). This finding has been explained in terms of an efficient within-field organization process for groups defined by similarity and proximity (Butcher & Cavanagh, 2008). But what about other grouping cues? Here, we examine the cue of closure. On each trial, subjects were presented with four items, each occupying one of four positions defined by left/right x up/down around central fixation. The participants' task was to report whether any two out of four items were the same or whether all four were unique. The repeated target stimuli were square brackets. The distractors were composed by rearranging the line segments of the targets. The repeated brackets occurred in either the same orientation("[[" no-closure) or mirror reversed orientation ("[ ]" closure). We found a significant unilateral field advantage in the no-closure condition (12 ms, $t(18) = 2.0$, $p = 0.05$), replicating previous work on detecting repetitions presented in the same orientation. However, in the closure condition, we found bilateral repetitions were detected significantly faster than unilateral repetitions (28 ms, $t(19)= 3.83$ $p = 001$). These results suggest that closure is more efficiently detected across visual fields versus within a hemifield.

43.454 **The visual attractor illusion**

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The perception of an object's features can often be biased by the object's immediate surroundings, leading to many perceptual illusions. In contrast, the presence of nearby, static objects often enhances the perceived spatial location of another object. Here we present a new type of visual illusion in which the presence of a static object (the attractor) alters another object's perceived location. Participants localized the edge of a briefly presented and masked target object (e.g., an outline square or a centrally presented line). Localization was accurate when the masked target was presented in isolation. However, when another nearby object (e.g., a face) was presented at the same time as the target, localization deviated toward the nearby object. This "visual attractor illusion" (VAI) was found across different attractor types and across different colors of targets and masks. The VAI is a relatively unique phenomenon that can be distinguished from other mislocalization effects such as foveal bias, the flash-lag effect or the landmark effect. Furthermore, the VAI is a relatively high-level effect that appears to be modulated by attention: It was stronger when the attractor object was task-relevant rather than task-irrelevant, and diminished as the experiment progressed. Visual transients also play an important role in the illusion, which depends on the sudden onset of the attractor object and backward masking of the target. We discuss two possible mechanisms: 1) the distortion of perceptual space by the brief appearance of an object, which draws in the perceived location of a neighboring object; 2) localization of a masked target may be weighted towards the position of a concurrently presented visual transient. The VAI may provide a unique example of a grouping-and-assimilation effect in the spatial domain.

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43.455 **Collinear Facilitation Is Recovered Across Disparities by Embedding in a Slanted Surface**

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The detection threshold of a Gabor target can be reduced by the presence of collinear flanking Gabors. Such collinear facilitation is disrupted when the target and the flanker have different disparity (Huang et al, 2006, Vision Research). Here, we further investigated whether it is the depth or surface difference between the target and the flanker that causes the abolition of collinear facilitation. The target and the flankers were 2 cy/deg vertical Gabor patches. The distance between the target and the flankers was three wavelengths. There were three viewing conditions: target and flankers were set (1) in the same frontoparallel plane; (2) at different disparities in different frontoparallel planes; and (3) at different disparities but embedded in the same slanted plane as defined by the orientation difference in stimuli between the left and right eye images. The Zero disparity was maintained by reference squares presented at the edge of the display. We measured the target contrast detection threshold with and without the flankers present with a temporal 2AFC paradigm and the Psi staircase method. Strong collinear facilitation was observed when the target and the flankers were either in the same frontoparallel plane or embedded in the same slanted surface even though the target and the flankers were at different disparities. The facilitation disappeared when the stimuli at this disparity difference were in different frontoparallel planes. Noticed that, for all viewing conditions, the target and the flankers were always collinear when monocularly viewed and thus produced collinear facilitation. Even if the collinear facilitation was operating at the monocular level, once the target and flankers occupied different disparities, the collinear facilitatory

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effect was disrupted. Our results suggest that it is the difference in surface assignment, not the difference in disparity per se, that causes the disruption of collinear facilitation.

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43.456 The effect of background grouping on central task in patients with parietal lobe lesions

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We investigated the effects of grouping between irrelevant background stimuli on a central task. We compared performance between non-lesioned control participants and patients with visual neglect and extinction. Our patient group included right and left visual neglect patients. On each trial participants reported the presence or absence of a central target (a single digit) presented on (0.5 contrast) random noise patch (duration =100ms). The visibility of the central target was matched between participants such that performance on a pretest was always 80% correct. In addition to the central stimulus a pattern of black and white dots was presented on either side of fixation on a gray background. Those dots were either arranged in alternating rows of black and white dots or randomly placed in the same matrix (intermixed in a single block). Patients were faster (p=0.03) on the central task when the background dots were in rows compared to when they were in random positions. However, the main effects of the field, patient group (left vs right hemisphere lesion) and their interactions were not significant. We did not find this effect of grouping in the non-lesioned control participants (Fs<1). These effects were not due to explicit recognition of the background pattern since no patient was able to report the presence of the grouping; only 3 patients mentioned the dots and out of them only two patients reported them being black and white. We found facilitation of a central detection task by grouping within the background pattern, even though this background pattern could not be explicitly reported. This implies that simple forms of grouping can occur without attention.

43.457 A new approach to modeling Figure-Ground Organization

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Figure-Ground Organization (FGO) refers to finding regions and contours in a 2D image that correspond to 3D objects in a visual scene. Establishing FGO is difficult because there is not enough information in a 2D image to prevent ambiguity. The visual system (and any model) must use a priori simplicity constraints (aka priors) to eliminate these ambiguities. Doing this requires solving two problems, specifically: (i) discovering the nature of the priors, and (ii) developing operations to combine these priors with the image data. Most prior researchers assumed that because FGO was a 2-dimensional problem, 2D priors and 2D computations should be used. But, 2D priors can never convert an ill-posed problem into a well-posed problem because multiple 2D groupings and segmentations exist for any given 2D image. Not surprisingly, this approach has never worked. We treated FGO as a 3D problem and have made progress by looking for 3D symmetrical objects in the 2D image. Images of a room, containing several pieces of furniture, were used as stimuli. The model begins by selecting several starting points from which regions are grown. The growth of each region is based on a color, or color variance, similarity. Next, each region is approximated by an alpha-hull, a generalization of a convex hull. These alpha-hulls are compared to edges detected by a modified Canny edge detector. Edge detection is then performed inside each of the resulting regions. Edges are then grouped, and the cycles of edges are detected by closing the branches of a Minimum Spanning Tree produced by the edges. This produces the internal contours that are essential for detecting 3D skewed symmetry. Regions without internal contours are unlikely to correspond to 3D objects. The regions and contours found by our model are similar to those seen by the authors.

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43.458 On the relative dominance of global and local shape features in generalization: Moderating variables and general principles

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There is a long-standing debate concerning the holistic or analytic nature of perceptual processing and whether the representation builds up from global to local or from local to global. Despite many fruitful contributions demonstrating the global and local levels in object recognition, little systematic attention has been directed at the local-global dominance in generalization and categorization. We investigated the global and local dominance of visual cues in a name generalization task. Two obvious features, one on a global scale and one on a more local scale, were implemented in the stimulus set. Stimuli were always 2-D shapes, generated by Boundary Descriptors. Participants were asked to infer new members of a category and could freely choose new instances in the stimulus set. By evaluating the inferred exemplars, the global-local dominance in generalization was studied. The results demonstrate that general conclusions are hard to draw based on the theoretically presumed allocation of the visual cues to the local or the global level of processing. However, by a thorough evaluation of the visual cues in terms of their regularities in the stimulus set, we were able to draw a general conclusion: Participants derive category membership by relying on regularities on the most global scale. Regularities on a more global scale are conceived as less coincidental features in the stimulus set, and therefore, they are preferred as a basis to infer new instances. Additionally, we tested the moderating influence of particular context variables like superordinate category ownership, planar rotations, and complexity on participants' reliance on global or local scale shape properties in generalization. Superordinate category ownership had no influence but more complex shapes and arbitrary planar rotations of the stimuli led to huge differences in participants' reliance on visual cues. We will discuss the results in light of some contemporary models of object recognition.

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Motion: Mechanisms and models

Vista Ballroom, Boards 501–512

Monday, May 10, 8:30 - 12:30 pm

43.501 Role of form cues in second-order motion pooling

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Previous research has shown that form cues can affect how first-order (FO) motion signals are pooled. We investigated whether form cues can also affect the pooling of second-order (SO) signals. Global-Gabor stimuli (JoV, 2009, 9, 1-25) were used. These consist of multiple Gabors that define a global-motion vector by having their carriers all move in a manner that is consistent with a single Intersection-of-Constraints (IOC) defined solution. It has been shown that FO stimuli are pooled in this manner. Form cues were introduced by adding orientation information to the apertures that were either consistent (aligned with) or inconsistent (orthogonal to) with the global-solution. With FO stimuli, inconsistent form cues resulted in the loss of the IOC solution, with observers instead perceiving motion along the axis defined by the orientation cue. No such effect was observed for the SO stimuli. These results will be discussed in light of a related study (see companion abstract; this meeting) that has shown form cues affect the pooling of 1-dimensional motion signals (i.e. signals for which the aperture problem hasn't been solved) but they do not affect the pooling of 2-dimensional signals (signals for which the aperture problem has been solved).

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43.502 The role of form cues in the pooling of 1D and 2D motion signals

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Local-motion information can provide either 1-dimensional (1D) or 2-dimensional (2D) solutions. 1D signals occur when the aperture problem hasn't been solved, so each signal is an estimate of the local-orthogonal component of the object's motion. 2D signals occur when the aperture problem has been solved, so each signal is an estimate of the object's motion. Previous research (JoV, 2009, 9, 1-25) has shown that 1D and 2D signals are pooled differently, via intersection-of-constraints (IOC) and vector-average processes, respectively. Previous research (e.g. VisRes, 2003, 2290-2301) has also indicated that form cues can influence how motion signals are perceived. We investigated whether forms cues can affect the pooling of motion signals and whether they differentially affect the pooling of 1D and 2D signals. Global-Gabor (GG) and global-plaid (GP) stimuli were used. These stimuli consist of multiple apertures that contain either Gabors or plaids, respectively. In the GG stimulus the global solution is defined by having the Gabor carriers move (1D signals) such that they are consistent with a single IOC-defined solution. In the GP stimuli the plaid motion (2D signals) are consistent with a single VA solution. Form cues can be introduced by adding orientation information to the apertures that is either consistent (aligned with) or inconsistent (orthogonal to) with the global-solution. With the 1D stimuli, inconsistent form cues resulted in a loss of the IOC solution; observers instead perceived motion along the axis defined by the orientation cue. With the 2D signals, form cues had minimal effect. These results indicate that form cues can affect the pooling of 1D but not 2D signals. It is possible that the form cues do this by disambiguating the family of possible 2D solutions by providing the direction of motion, hence turning the 1D signals into 2D signals.

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43.503 **Different pooling of motion information for perceptual speed discrimination and behavioral speed estimation**

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To measure speed and direction of moving objects, the cortical motion system pools information across different spatiotemporal channels. Here, we investigate this integration process for two different tasks. Primate ocular following responses are driven by speed information extracted by population of speed-tuned neurons. They provide an excellent probe for speed estimation. We contrasted these responses with a psychophysical speed discrimination task ran in the same subjects and with the same stimuli. We used short presentations (250ms) of "motion clouds" (Schrater et al 2000) in which the width of the spatial frequency distribution (σsf) was varied for different mean speed (10-50°/s). Eye movements were recorded with an EyeLink1000, using classical paradigm for ocular following. Stimuli were displayed on a CRT monitor (1280x1024@100Hz) and covered 47° of visual angle. All experiments were run on 2 naive subjects. We found that larger σsf elicited stronger initial eye velocity during the open-loop part of tracking responses. This facilitating effect was larger with higher speeds. By contrast, larger σsf had a detrimental effect upon speed discrimination performance. Speed discrimination thresholds were significantly higher (52%) with large spatial frequency distributions, irrespective of the mean stimulus speed. These results provide a framework to investigate how motion information is adaptively pooled for solving different motion tasks.

Paul R. Schrater, David C. Knill and Eero P. Simoncelli (2000) " Mechanisms of visual motion detection" Nature Neuroscience 3, 64 - 68.

Acknowledgement: CODDE project (EU Marie Curie ITN), CNRS

43.504 **A dynamical neural model of motion integration**

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We propose a dynamical model of 2D motion integration where diffusion of motion information is modulated by luminance information. This model incorporates feedforward, feedback and inhibitive lateral connections and is inspired by the neural architecture and dynamics of motion processing cortical areas in the primate (V1, V2, and MT).

The first aspect of our contribution is to propose a new anisotropic integration model where motion diffusion through recurrent connectivity between cortical areas working at different spatial scales is gated by the luminance distribution in the image. This simple model offers a competitive alternative to less parsimonious models based on a large set of cortical layers implementing specific form or motion features detectors.

A second aspect that is often ignored by many 2D motion integration models is that biological computation of global motion is highly dynamical. When presented with simple lines, plaids or barberpoles stimuli, the perceived direction reported by human observers, as well as the response of motion sensitive neurons, will shift over time. We demonstrate that the proposed approach produces results compatible with several psychophysical experiments concerning not only the resulting global motion perception, but also concerning the oculomotor dynamics Our model can also explain several properties of MT neurons regarding the dynamics of selective motion integration, a fundamental property of object motion disambiguation and segmentation.

As a whole, we present an improved motion integration model, which is numerically tractable and reproduces key aspect of cortical motion integration in primate.

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43.505 **A model of figure-ground segregation from texture accretion and deletion in random dot motion displays**

Timothy Barnes[1](barnes@cns.bu.edu), Ennio Mingolla[1]; [1]Department of Cognitive and Neural Systems, Boston University

Accretion or deletion of texture unambiguously specifies occlusion and can produce a strong perception of depth segregation between two surfaces even in the absence of other cues. Given two abutting regions of uniform random texture with different motion velocities, one region will appear to be situated farther away and behind the other (i.e., the ground) if its texture is accreted or deleted at the boundary between the regions, irrespective of region and boundary velocities (Kaplan 1969, P&P 6(4):193–198). Consequently, a region with moving texture appears farther away than a stationary region if the boundary is stationary, but it appears closer (i.e. the figure) if the boundary is moving coherently with the moving texture. Computational studies demonstrate how V1, V2, MT, and MST can interact first to create a motion-defined boundary and then to signal texture accretion or deletion at that boundary. The model's motion system detects discontinuities in the optic flow field and modulates the strength of existing boundaries at those retinal locations. A weak speed-depth bias brings faster-moving texture regions forward in depth, which is consistent with percepts of displays containing shearing motion alone — i.e., where motion is parallel to the resulting emergent boundary between regions — in which the faster region appears closer (Royden et al. 1988, Perception 17:289–296). The model's form system completes this modulated boundary and tracks the motion of any boundaries defined by texture. The model includes a simple predictive circuit that signals occlusion when texture defined boundaries unexpectedly appear or disappear.

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43.506 **Humans assume isotropic orientation structure when solving the 'aperture problem' for motion**

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We examined how global direction judgements with stimuli prone to the "aperture problem" depend on the local orientation structure of the stimulus. Observers adjusted the orientation of a line to match the overall direction of four randomly positioned Gabors whose carrier velocities were consistent with rigid-translation in a single random direction. The four Gabor orientations were either randomly distributed or evenly spaced at 45° intervals. Response variability was ~20° in the evenly spaced condition and ~30° in the random orientation condition. The degree of correlation between observers' errors when retested with identical stimuli was greater in the random orientation condition, demonstrating that the increase in variability is almost entirely determined by trial-by-trial differences in the orientation structure of the stimuli. In contrast the majority of the errors (~80%) in the evenly spaced condition are random. Because two or more different velocities uniquely specify a particular global direction, an ideal-observer that fits a cosine to the local velocity distribution will not produce errors, while adding random noise will produce unpredictable errors (unlike human observers). However when the motion energy model is incorporated as a local motion stage, the representation of each local velocity is no longer discrete and the energy from differently oriented elements may overlap. Predictable errors may then arise from a mismatch between

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the local motion energy distribution (on a trial-by-trial basis) and a global motion stage that assumes an isotropic orientation structure (i.e. a cosine). The model now generates errors in the random orientation condition that correlate with the observers' errors (R2 ~0.48). This compares to an R2 of ~0.56 for the correlation between observers' test-retest errors, demonstrating that the model captures around 85% of the stimulus-driven variability.

43.507 Feature invariant spatial pooling of first- and second-order motion signals for solution of aperture problem

Kazushi Maruya[1], Shin'ya Nishida[1]; [1]NTT Communication Science Laboratories

The visual system solves the aperture problem by means of integrating local 1-dimensional motion signals into a global 2-dimensional motion. Although it is well known that motion pooling occurs within first-order (luminance-based) motion or within second-order (non-luminance-based) motion of the same type, whether it generally occurs across different motion types in a feature-invariant manner remains a matter of controversy in the past plaid literature. Furthermore, this issue has neither tested with objective performance measures, nor under the condition where local 1-dimensional motion signals are cleanly separated in space with no possibility of local artifacts. Here we challenged this problem by measuring direction-discrimination performance of a four-aperture motion stimulus. The stimulus consisted of four oscillating bars, simulating a situation where the contour of a 12.8 x 12.8 deg diamond was translating along a circular path, and seen through four Gaussian apertures (SD: 1.07 deg), each located at the center of an edge. The attribute that defined each oscillating bar was either luminance, temporal frequency of dynamic random dots, or binocular disparity of dynamic random-dot stereogram. The results indicate that observers could judge the direction of global circular translation (clockwise or anti-clockwise) not only when all the edges were defined by the same attribute, but also when adjacent bars were defined by different attributes, although the attribute had some influence on the performance of direction discrimination and the quality of perceived global motion. In addition, motion pooling between first-order and second-order motions was possible even when first-order motion that did not contain obvious positional shift of features that might be detected by second-order mechanism. These results indicate that second-order motion signals do contribute the solution of aperture problem either solely or in corporate with first-order signals.

43.508 Neural responses involved in 1D motion spatial pooling

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To compute two-dimensional (2D) trajectory of visual motion, the visual system has to integrate one-dimensional (1D) local motion signals not only across orientation, but also across space. While previous studies found the evidence suggesting that monkey MT/MST or human MT complex (hMT+) is involved in the integration of spatially-overlapping 1D motion signals, it remains unclear where and when in the brain 1D signals are spatially pooled. Here we non-invasively recorded human neural responses related to the pooling of 1D motion signals using a whole head MEG system (PQ2440R; Yokogawa). The first experiment recorded MEG responses evoked by the change from incoherent (0% coherence) to coherent (30, 50, 71 or 100%) Global-Gabor motion (Amano et al, 2009, Journal of Vision). Patches with 1.7 deg stationary Gaussian envelopes were presented within an annulus whose inner and outer diameters were 5 and 27 deg, respectively. The second experiment tested the direction-selectivity of the responses to Global-Gabor stimuli by using an adaptation paradigm. Motion coherence of both test and adaptation stimuli was 100%. The global motion direction of adaptation stimulus was fixed while that of test stimulus was randomly chosen from the two opposing (adapted and non-adapted) directions. We made the orientations of test Gabors orthogonal to those of adaptation Gabors to exclude local adaptation effects. In both experiments, beamformer analysis found the evoked activities in hMT+ peaking at around 150-200 ms. The responses monotonically increased with the increase in motion coherence (Exp. 1), and were significantly smaller for the adapted global direction than for the opposite direction (Exp. 2). Our finding that hMT+ responses show both coherence dependency and direction selectivity to global motion supports the idea that hMT+ is the locus of 1D motion spatial pooling.

43.509 Low-level mechanisms do not explain paradoxical motion percepts

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Classic psychophysical studies have shown that increasing the size of low contrast moving stimuli increases their discriminability, indicating spatial summation mechanisms. More recently, a number of studies reported that for moderate and high contrasts, size increases yield substantial deteriorations of motion perception — a result described as psychophysical spatial suppression. While this result resembles known characteristics of suppressive center-surround neural mechanisms, a recent study (Aaen-Stockdale et al., 2009) argued that observed size-dependent changes in motion perception can be explained by differences in contrast sensitivity for stimuli of different sizes. Here, we tested this hypothesis using duration threshold measurements — an experimental approach used in several spatial suppression studies. The results replicated previous reports by demonstrating spatial suppression at a fixed, high contrast. Importantly, we observed strong spatial suppression even when stimuli were normalized relative to their contrast thresholds. While the exact mechanisms underlying spatial suppression still need to be adequately characterized, this study demonstrates that a low-level explanation proposed by Aaen-Stockdale et al. (2009) cannot account for spatial suppression results.

43.510 A Bio-Inspired Evaluation Methodology for Motion Estimation

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Evaluation of neural computational models of motion perception currently lacks a proper methodology for benchmarking. Here, we propose an evaluation methodology for motion estimation which is based on human visual performance, as measured in psychophysics and neurobiology. Offering proper evaluation methodology is essential to continue progress in modeling. This general idea has been very well understood and applied in computer vision where challenging benchmarks are now available, allowing models to be compared and further improved. The proposed standardized tools allow to compare different approaches, and to challenge current models of motion processing in order to define current failures in our comprehension of visual cortical function. We built a database of image sequences to depict input test cases corresponding to displays used in psychophysical settings or in physiological experiments. The data sets are fully annotated in terms of image and stimulus size and ground truth data concerning dynamics, direction, speed, etc. Since different kinds of models have different kinds of representation and granularity, we had to define generic outputs for each considered experiment as well as correctness evaluation tools. We propose to use output data generated by the considered model as read out that relates to observer task or functional behavior. Amplitude of pursuit or direction likelihoods are two examples. We probed several models of motion perception by utilizing the proposed benchmark The employed models show very different properties and internal mechanisms, such as feedforward normalizing models of V1 and MT processing and recurrent feedback models. Our results demonstrate the usefulness of the approach by highlighting current properties and failures in processing. So we provide here a valuable tool to unravel the fundamental mechanisms of the visual cortex in motion perception. The complete database as well as detailed scoring instructions and results derived by investigating several models are available at http://www-sop.inria.fr/neuromathcomp/software/motionpsychobench

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43.511 Monkey and humans exhibit similar direction suppression effects

Catherine Lynn[1](clynn05@qub.ac.uk), William Curran[1]; [1]School of Psychology, Queen's University Belfast

Single cell recording studies of motion-processing neurons in nonhuman primates provide important data with which to develop models of motion processing in the human visual system. Bearing this in mind, it is important to establish whether activity of motion-processing neurons in nonhuman primates mirrors that of human motion-processing neurons. Previous research (Snowden et al, 1991) has mapped out direction tuning of suppressive effects in macaque MT neurons. Specifically, a neuron's spiking

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rate in the presence of its preferred motion is suppressed when an additional direction is added to the stimulus; despite the fact that the additional motion direction causes the neuron to fire when presented in isolation. We used a motion adaptation phenomenon, the direction aftereffect (DAE), to test whether this pattern of suppression applies to human motion-sensitive neurons. Motion adapters that evoke a stronger response in neurons usually result in greater changes in the neurons' direction tuning functions, which are thought to impact on DAE magnitude. We measured DAE magnitude following adaptation to random dot kinematograms, in which either all dots moved in the same direction (45 deg clockwise from vertical up) or half had a direction of 45 deg and the other half moved in one of several other directions clockwise from 45 deg. We then measured DAE magnitude following adaptation to each of the individual directions used in the first experiment. If macaque MT is an accurate model of human motion-processing, it would predict that 1) DAE magnitude will drop off with increasing direction difference in experiment 1, and 2) additional directions causing DAE suppression will induce a measurable DAE when presented in isolation. This is precisely the pattern of results we obtained; supporting the view that the response properties of nonhuman motion-processing neurons mirror those of human motion-processing neurons.

43.512 **Human MT+ response saturates rapidly as a function of sampling density in natural dynamic scenes**

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It is known from macaque single cell electrophysiology that response to random dot optic flow movies saturates rapidly in MST as a function of dot density. In this experiment we used fMRI to investigate if human MT+ similarly saturates as a function of sampling density with more naturalistic optic flow scenes. We recorded grayscale movies using a camera moving forward. We covered the movies with a uniform grey area on which transparent hard-edged circular apertures of a fixed size (0.2 times the height of the clip in diameter) were placed in random locations. We presented movies visible through 10, 40 and 160 circular apertures. In a fourth condition we "cut out" the motion visible through the 160 apertures and randomly rearranged the apertures, so that local motion was preserved, but no global motion associated with forward movement remained. Participants viewed these movies in the scanner, whilst performing a central foveal attention task. We localised regions of interest from separate sessions for V1, V2, V3, V4 and MT+. We found that although V1 and other early striate areas increase their response with the number of apertures, area MT+, although responding significantly above baseline to all conditions does not respond differentially to the different number of apertures. This result holds if we split area MT+ into MT and MST, based on ipsilateral responses. As the amount of visible motion across these conditions does not affect the MT+ response we suggest this is due to the early saturation of response with the amount of motion present. However, we found no difference in any of the visual areas between the scrambled and normal 160 aperture conditions, suggesting these results are not necessarily dependent on the presence of coherent global motion.

Acknowledgement: The Leverhulme Trust

Face perception: Neural processing

Vista Ballroom, Boards 513–529

Monday, May 10, 8:30 - 12:30 pm

43.513 **Characterizing the face processing network in the human brain: a large-scale fMRI localizer study**

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A whole network of brain areas showing larger response to faces than other visual stimuli has been identified in the human brain using fMRI (Sergent, 1992; Haxby, 2000). Most studies identify only a subset of this network, by comparing the presentation of face pictures to all kinds of object categories mixed up (e.g., Kanwisher, 1997), or to scrambled faces (e.g., Ishaï, 2005), using different statistical thresholds. Given these differences of approaches, the (sub)cortical face network can be artificially overextended (Downing & Wiggett, 2008), or minimized in different studies, both at the local (size of regions) and global (number of regions) levels. Here we conducted an analysis of a large set of right-handed subjects (40), tested with a new whole-brain localizer to control for both high-level and low-level differences between faces and objects. Pictures of faces, cars and their phase-scrambled counterparts were used in a 2x2 block design. Group-level (random effect) and single subject (ROI) analyses were made. A conjunction of two contrasts (F-SF and F-C) identified 6 regions: FFA, OFA, amygdala, pSTS, AIT and thalamus. All these regions but the amygdala showed clear right lateralization. Interestingly, the FFA showed the least face-selective response among the cortical face network: it presented a significantly larger response to pictures of cars than scrambled cars [t=9.3, much more than amygdala (t=2.6), AIT (t=2.1) and other regions (NS)], and was also sensitive to low-level properties of faces [SF – SO; t=5.1; NS in other areas]. These observations suggest that, contrary to other areas of the network, including the OFA, the FFA is a region that may contain populations of neurons that are specific to faces intermixed with populations responding more generally to object categories. More generally, this study helps understanding the extent and specificity of the network of (sub)cortical areas particularly involved in face processing.

43.514 **The contribution of Fourier amplitude spectrum differences to the early electrophysiological (i.e. P1) amplitude difference between face and nonface object categories**

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Event-related potential (ERP) studies in humans indicate that the early activation of visual face representations in the human brain takes place during the time-window of the occipito-temporal N170 component. Similarly to the N170, the P1 visual component preceding the N170 has also been reported as being larger in response to face compared to nonface stimuli. This observation has been taken by some authors as evidence for an early sensitivity to faces in the visual cortex at around 100 ms. However, because the P1 component is highly sensitive to manipulations of the spatial frequency content of an image, part of the P1 amplitude difference between faces and nonfaces may be related to differences between the Fourier amplitude spectrums (FAS, a parameter that conveys the global low-level statistics of an image) of these categories. To identify the contribution of the FAS to the P1 amplitude difference between face and nonface stimuli we recorded ERPs while subjects viewed faces and cars either in their original unaltered version or in a version in which the Fourier phase information of one category was combined with the FAS of the other category. When presented in their original version, faces elicited a larger P1 compared to cars, in line with previous observations. This effect was most consistent over the right hemisphere occipito-temporal electrodes. In contrast, switching the FAS between faces and cars resulted in a larger P1 for cars, again mainly over the right occipito-temporal electrodes. These findings suggest that the P1 amplitude difference between face and nonface stimuli are, at least partly, related to differences in the FAS between these categories. Moreover, even though these P1 differences do not reflect face categorization per se, they may nevertheless reflect the use of lower-level visual statistic frequently associated with a human face to allow fast basic-level face categorization.

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43.515 **Dynamics of face detection revealed by fMRI: the right FFA gets it first**

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Our goal was to use fMRI to uncover dynamics of visual scene face detection in the human brain, by means of a paradigm that slowly and gradually reveals faces. Such paradigms have been used previously to examine top-down facilitation (e.g., Eger et al., 2007; James et al., 2006) and to dissociate multiple stages in visual recognition (e.g., Carlson et al., 2006). Here, we used the RISE methods (Sadr & Sinha 2004) to create image sequences of visual scenes in which faces or cars are revealed progressively as they emerge from noise. Participants were asked to respond as soon as they detected a face or car during the sequence presentation. Among the face-sensitive regions identified based on localizer data, the right fusiform face area ("FFA") showed the earliest difference between face and car activation. Specifically, the right FFA showed higher activation to faces than to cars before the more posteriorly located face-sensitive area of the lateral occipital cortex ("Occipital Face Area", "OFA"). Whole-brain analysis confirmed these findings, with a face-sensitive cluster in the right fusiform gyrus showing face selectivity shortly before successful behavioral detection. Overall, these observations suggest that following low-level visual analysis, a face stimulus is detected initially by responses of populations of neurons in the right middle fusiform gyrus, spreading to a whole network of (sub)cortical face-sensitive areas for further processing. Our results provide interesting evidence for non-hierarchical emergence of face-selectivity among known face-sensitive cortical regions, that is, with " OFA" face-specific responses not necessarily preceding face-specific "FFA" activation (Rossion, 2008).

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43.516 **Cerebral lateralization of the face-cortical network in left-handers: only the FFA does not get it right**

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Face processing is a function that is highly lateralized in humans, as supported by original evidence from brain lesion studies (Hecaen & Anguerlergues, 1962), followed by studies using divided visual field presentations (Heller & Levy, 1981), neuroimaging (Sergent et al., 1992) and event-related potentials (Bentin et al., 1996). Studies in non-human primates (Perrett et al., 1988; Zangenehpour & Chaudhuri, 2005), or other mammals (Peirce & Kendrick, 2001) support the right lateralization of the function, which may be related to a dominance of the right hemisphere in global visual processing. However, in humans there is evidence that manual preference may shift or qualify the pattern of lateralization for faces in the visual cortex: face recognition impairments following unilateral left hemisphere brain damage have been found only in a few left-handers (e.g., Mattson et al., 1992; Barton, 2009). Here we measured the pattern of lateralization in the entire cortical face network in right and left-handers (12 subjects in each group) using a well-balanced face-localizer block paradigm in fMRI (faces, cars, and their phase-scrambled versions). While the FFA was strongly right lateralized in right-handers, as described previously, it was equally strong in both hemispheres in left-handers. In contrast, other areas of the face-sensitive network (posterior superior temporal sulcus, pSTS; occipital face area, OFA; anterior infero-temporal cortex, AIT; amygdala) remained identically right lateralized in both left- and right-handers. Accordingly, our results strongly suggest that the face-sensitive network is equally lateralized for left- and right-handers, and thus the face processing is not influenced by handedness. However, the FFA is an important exception since it is right-lateralized for right-handers but its recruitment is more balanced between hemispheres for left-handers. These observations carry important theoretical and clinical implications for the aetiology of brain lateralization depending on the left- or right-handedness and the neuropsychological undertaking of prosopagnosic patients.

43.517 **Dissociable temporal components of neural similarity in face perception: An ERP study**

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Psychological models suggest that perceptual similarity can be subdivided into geometric effects, such as metric distance in stimulus space, and non-geometric effects such as stimulus-specific biases. However, the time course of neural similarity processing remains unclear. We investigated this question using a neural adaptation paradigm to study event-related potentials (ERP) related to facial similarity. We find an ERP component between the "face-selective" N170 and N250 responses (the "P200") that is modulated by transitions of face appearance, consistent with neural adaptation to the geometric similarity of face transitions. In contrast, the N170 and N250 reflect non-geometric stimulus bias, with different degrees of adaptation depending upon the direction of face transition within the stimulus space. Thus, the behavioral distinction between geometric and non-geometric similarity effects is consistent with dissociable neural responses across the time course of face perception. In line with prior results implicating the N170 and N250 in perception and memory, respectively, these data support an intermediate role of the P200 in consolidation of the perceptual representation. Together, these results demonstrate that the neural coding of perceptual similarity, in terms of both geometric and non-geometric representation, occurs rapidly and from relatively early in the perceptual processing stream.

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43.518 **Delineate the temporal sequence and mechanisms for perceiving individual faces**

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In two event-related potential (ERP) studies, we examined neural correlates of individual face perception. In Study 1, 36 individual female and 9 male faces were randomly presented, and participants were instructed to press a button for male faces. Based on similarity ratings from a previous behavioral study, the female faces could be located in a multidimensional "face-space". The facial characteristics representing the "face-space" and therefore important for judging face similarities include eye color, face width, eye size and top-of-face height. The face-sensitive N170 component was affected by all these factors. In addition, there was a hemisphere difference: the right N170 amplitude was related to eye color and face width, while the left N170 amplitude was related to eye size and top-of-face height when bottom-of-face height was small. In Study 2, we created a set of faces that varied in identity strength by morphing each of the 36 female faces with an average face formed from the entire set; the relative weighting of an original face ranged from 100% to 0% in 10% decrements. Participants were instructed to press a button whenever they detected a target identity. Accuracy data indicated an ambiguous region between 30% and 60% identity strength. Neither the P1 nor the N170 to non-target faces were influenced by identity strength. However, the amplitude of the P2 component (230-270 ms) became smaller as identity strength decreased, with no categorical boundary effect. Collectively, these results provide electrocortical evidence of structural decoding of individual faces before 200 ms that involves rather fine-tuned analyses of multiple facial characteristics, which might be carried out separately by two hemispheres. Following structural decoding, the electrocortical evidence of individual face identification occurs around 250 ms with minimal response to "average" faces.

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43.519 **DIY ERPs**

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We detail the use of several off-the-shelf hardware and software components to create an inexpensive "homemade" ERP device. We used this machine to try to find the N170 to faces relative to other object classes and to faces relative to inverted faces. We took hardware bandpass filtered (1-100 Hz) analog outputs of a common polygraph (Grass Instruments model 79D; used models were available at the time of abstract submission for well under $700) which normally provides output to pens, and instead sent the signal through a National Instruments USB data acquisition card. MATLAB was used to present stimuli and to analyze signal output. We have thus far used single electrodes placed via the 10-10 system and with regard to published coordinates. Electrodes were placed over the left and right FFA and we used the ear as reference. Despite the paucity of electrodes, initial results are promising and show strong negative deflections to faces in the range of 100-200 ms post-stimulus. The goal of our poster presentation is to present our hardware and software methods in detail to the vision community and to gather feedback that might be helpful to us and to other small colleges with minimal cognitive neuroscientific equipment budgets.

43.520 **Dynamic and static faces: Electrophysiological responses to emotion onsets, offsets, and non-moving stimuli**

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In real life, facial expressions are fleeting occurrences that appear suddenly, like a burst of happiness or flash of anger, and then, just as quickly, the expression vanishes from the face. What are the brain mechanisms that allow us to discern the rapid onset and offset of facial expressions quickly and effortlessly? In this study, we examine the neural correlates of dynamic facial expressions using event-related potentials (ERPs). Participants were presented with happy, angry or neutral faces while EEG was recorded from

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36 scalp electrodes. In the expression onset condition, a neutral face was presented for 500 ms, immediately followed by either a happy or angry face for 500 ms. In the expression offset condition, the happy or angry face was shown for 500 ms, immediately followed by a face with a neutral expression for 500 ms. The onset and offset conditions were compared to a static condition in which a single happy, angry and neutral face was shown for 500 ms. The EEG data showed that in the right posterior scalp sites, the onset of the happy or angry expression elicited a larger potential than their static versions suggesting that dynamic faces are more salient than static images. Moreover, the direction of the dynamics appears to be critical where the onset expressions produced larger brain potentials than offset expressions. These findings indicate that observers are more sensitive to the dynamic expressions than static expressions. However, the direction of the facial dynamics also seems important where the sudden appearance of a facial expression elicited more brain activity than its abrupt disappearance.

43.521 **TMS evidence for feedforward and feedback mechanisms of face and body perception**

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Neuroscientists seeking to understand the cognitive mechanisms that underlie visual object perception have used functional magnetic resonance imaging (fMRI) to identify spatially distinct cortical regions in the human brain selective for different object categories. One such region, the occipital face area (OFA), shows a stronger response to faces than to other object categories and has been proposed to be the first stage in a cortical network specialized for face perception. We sought to more precisely establish when the OFA is engaged in face perception using transcranial magnetic stimulation (TMS). Ten subjects performed a delayed match to sample face discrimination task while double pulse TMS (separated by 10ms) was delivered over each subject's functionally localised OFA. Results showed that TMS disrupted task performance at two distinct latencies, 40-50 ms after stimulus onset and 100-110ms after stimulus onset. In a second experiment we investigated whether TMS delivered over an adjacent body-selective region, the extrastriate body area (EBA), would produce a similar temporal pattern of impairment. Ten subjects performed a delayed match to sample body discrimination task while double pulse TMS was delivered over each subject's functionally localised EBA. Results again showed two impairment windows, the first at 40-50ms and the second at 100-110ms after stimulus onset. The first impairment window at 40-50ms appears to reflect an early feed forward stage of face and body processing. The later impairment window at 100-110ms could reflect a second wave of feed forward information or task specific feedback mechanisms originating from higher cortical areas.

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43.522 **Turn that frown upside-down! Inferring facial actions from pairs of images in a neurally plausible computational model**

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Most approaches to image recognition focus on the problem of inferring a categorical label or action code from a static image, ignoring dynamic aspects of appearance that may be critical to perception. Even methods that examine behavior over time, such as in a video sequence, tend to label each image frame independently, ignoring frame-to-frame dynamics. This viewpoint suggests that it is time-independent categorical information that is important, and not the patterns of actions that relate stimulus configurations together across time. The current work focuses on face perception and demonstrates that there is important information that can be extracted from pairs of images by examining how the face transforms in appearance from one image to another. Using a biologically plausible neural network model called a conditional Restricted Boltzmann Machine that performs unsupervised Hebbian learning, we show that the network can infer various facial actions from a sequence of images (e.g., transforming a frown into a smile or moving the face from one location of the image frame to another). Critically, after inferring the actions relating two face images from one individual, the network can apply the transformation to a test face from an unknown individual, without any knowledge of facial identity, expressions, or muscle movements. By visualizing the factors that encode and break down facial actions into a distributed representation, we demonstrate a kind of factorial action code that the network learns in an unsupervised manner to separate identity characteristics from rigid (affine) and non-rigid expression transformations. Models of this sort suggest that neural representations of action can factor out specific information about a face or object such as its identity that remain constant from its dynamic behavior, both of which are important aspects of perceptual inference.

43.523 **Preference bias is induced by task-irrelevant motion only if it is weak**

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It has been found that our preference decision on a visual stimulus is influenced by memory, decision history, and gaze bias. It is generally thought that the stronger the signals of these factors are and the more highly correlated they are to a task, the more influential they are on preference decision. However, here, we report that preference decision is modulated by task-irrelevant motion only when the motion signal is weak. Twenty subjects were asked to choose one of two faces, presented on the left and right of a central fixation point, by moving a joystick to the left or right without eye movements. On each trial during face presentation, a task-irrelevant random dot pattern (moving either leftward or rightward) was presented at one of several coherence levels (0, 5, 10, 20, 50, and 100%). Subjects' choices were significantly biased toward direction of task-irrelevant motion when motion signal was weak (5% coherence), but not higher coherence levels. Following each choice, the subjects were asked to rate their relative preference for the chosen face ("How much do you like the chosen face compared with the other?") using the joystick on a five-point scale. Subjects' relative preferences were significantly elevated when position of the chosen face corresponded to direction of (5% coherent) task-irrelevant motion. These effects were not observed when task-irrelevant motion moved upward or downward. Another control experiment showed that these effects did not occur when preference decision was made without the lever movement, suggesting that the effects were not simply due to eye movements or attention shifts induced by task-irrelevant motion. On the contrary to the general thought, these results indicate that preference decision on a visual stimulus is gravely influenced by apparently "trivial" signal—the signal that is not only irrelevant to the decision but also extremely weak.

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43.524 **Neural representation of face perception in the fusiform face area**

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Human functional magnetic resonance imaging (fMRI) studies have shown that the fusiform face area (FFA) resides at one of the highest levels of the visual pathways and is specialized for face perception (Kanwisher, et al., 1997). Although previous fMRI studies employing fMRI adaptation paradigms suggested norm-based encoding is adopted in this area (Loffler, et al., 2005; Jiang, et al., 2006), it is unclear whether reconstructing the perceived face from the fMRI signals without using the fMRI rapid adaptation paradigm is feasible, which we investigated in this study. We employed a database of photo-realistic human face images. In the fMRI experiment, participants were required to gaze at an unfamiliar face image, which is a morphed image using two face images in the database, for the target period, and to memorize it. The morphing was norm-based, based on principal component analysis (PCA) (Blanz and Vetter, 1999). After a blanking period, the two face images used for the morphed image were presented, and the participants were requested to report which face was similar to the morphed image (discrimination period). The FFA was identified by contrasting the brain activities between the target period and the blanking period, so that our analysis focused on the identified FFA regions (fROI). We found the correlative area in FFA with face variations. Face discrimination behaviors were well explained by the signal detection theory based on a face space model. We then examined whether the target face can be reconstructed from the fROI signals by using canonical correlation analysis (CCA) which finds the maximally correlated low-dimensional space between the fROI data and the target image. A good reconstruction performance in terms of the similarity between a true and reconstructed face images in the CCA space was obtained for around 30% of the trials, supporting the norm-based encoding in FFA.

43.525 **Orientation-encoding in the FFA is selective to faces: Evidence from multivoxel pattern analysis**

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The fusiform face area (FFA) is a region of the human ventral visual pathway that exhibits a stronger response to faces than to objects. The role of this region within the face perception network is not well understood, and its face selectivity has been debated. Furthermore, it is unclear which specific properties of visual stimuli are systematically reflected in the patterns of activation of this region. There is evidence from various sources that FFA might encode orientation. This includes psychophysics of face selective view-point aftereffects, fMRI adaptation results, and electrophysiological experiments that have revealed neurons that are highly tuned to face orientation in the macaque homologue of FFA. Here we directly explored the encoding of orientation using a combination of functional magnetic resonance imaging (fMRI) and multivoxel pattern analysis (MVPA). We presented subjects with synthetic images of faces and cars that were rotated in depth and presented either above or below fixation. We explored orientation-related information available in fine-grained activity patterns in FFA and early visual cortex. Distributed signals from the FFA allowed above-chance classification of within-category orientation information only for faces. This was also generalized to faces and objects presented in different retinotopic positions. In contrast, classification in early visual cortex resulted in equal, above-chance classification of face and car orientation information, but only when trained and tested on corresponding retinotopic positions. Classification across position was substantially decreased for both categories in early visual cortex. We conclude that category-selective effects of stimulus orientation are reflected in the fine grained patterns of activation in FFA, and that the structure of these patterns is partially translation invariant.

43.526 **Complex Contextual Processing in V1 during Face Categorizations**

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Primary visual cortex (area V1) and higher visual areas are reciprocally connected. To understand the nature of this reciprocal processing in more detail, we investigated the importance of area V1 (and its subregions) during complex face categorization tasks. It is generally assumed that gender or expression classification of faces is a complex cognitive task that relies on processing in higher visual areas. Here we tested the hypothesis that primary visual cortex (V1) is involved in the processing of facial expressions. In an fMRI experiment we delineated the borders of area V1 and subsequently mapped the cortical representation of eye and mouth regions during a face categorization task. We then trained a multivariate pattern classifier (linear SVM) to classify happy and fearful faces on the basis of V1 data from these "eye" and "mouth" regions, and from the remaining V1 area. We found that all three regions resulted in successful classification depending on task. In a second step we investigated the spatial distribution of the most informative vertices throughout V1 in more detail. Again we saw the importance of the cortical representation of the eyes and mouth, but also a strong contribution from outside these regions, i.e. in "non-diagnostic" V1. Our findings are compatible with the idea that contextual information modulates area V1 not only in very restricted regions of processing of the most diagnostic information but also in a more distributed way.

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43.527 **Does he look scared to you? Effects of trait anxiety upon neural dissimilarity measures for ambiguous and pure emotional expressions**

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Previous work has shown that trait anxiety is associated with interpretative biases in the perception of facial expressions, specifically an increased tendency to judge ambiguous facial expressions as fearful. Using functional magnetic resonance imaging and both univariate and multivariate analysis techniques, we investigated the neural correlates of these biases in perception. We focused specifically on neural regions previously implicated in face processing: the superior temporal sulcus (STS), amygdala and fusiform face area (FFA). Subjects were presented with pictures of faces that showed one of three pure emotional expressions (fear, sad, surprise) or intermediate morphs between these same expressions. These expressions were selected based on previous research indicating that these dimensions are the ones where anxiety-related perceptual biases are most likely to be observed. BOLD response parameter estimates were calculated using univariate regression and multivariate pattern analysis. No anxiety-related differences were observed in the univariate analysis. For the multivariate analysis, a linear classifier was used to quantify (dis)similarities between neural representations of intermediate morphs and those of end-point pure expressions. It was predicted that for the two continua containing fear, individual differences in trait anxiety would modulate the extent to which neural representations of intermediate morphs showed greater similarity to pure fear than the other constituent expression. Bilateral regions of interest were investigated focusing on the superior temporal sulcus (STS), amygdala and fusiform face area (FFA). Results from this preliminary study indicated that anxiety-related biases in the neural representations of ambiguous expressions containing some percentage of the expression fear were predominantly observed in STS, with high trait anxious individuals showing reduced distances between the neural representations for these morphs and those for pure fear. Additional data from a follow-up experiment will be presented. Results are discussed in the context of content-based models of anxiety.

43.528 **Right middle fusiform gyrus processes facial features interactively: evidence from a balanced congruency design**

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The features composing a face are not processed in isolation by the visual system. Rather, they are encoded interactively as commonly illustrated by the composite illusion. Interactions between face features are observer-dependent as they are sensitive to face orientation in the picture plane. Interactive face processing (IFP) as indexed by the composite illusion presumably arises in face-preferring cortical regions located in the right middle fusiform gyrus, coined rFFA. Yet, composite illusion is a limited marker of IFP because it restricts the study of IFP to a single response modality ("same" responses) and the sharp edges introduced in composite stimuli are known to impair the processing of face information. The present experiment re-addresses IFP in the human brain using the congruency paradigm, which bypasses previous limitations: (1) IFP is measured in all response modalities and (2) face stimuli are not distorted by artificial edges. In a slow-event-related design, subjects were presented with face pairs and decided whether a target face region (i.e. eyes+eyebrows) was same or different while ignoring the other distracter features (e.g. nose and mouth). In congruent conditions, target and distracter features call for an identical decision. In incongruent conditions, they call for opposite decisions. Faces were presented at upright and inverted orientations. Our results reveal that performance was better when the target region was embedded in a congruent than an incongruent face context, indicating that distracter and target features were processed interactively. In the rFFA, neural response was as strong in incongruent conditions as when all features differed in a pair, suggesting that feature incongruency was treated as full identity change in this region. Inversion eliminated these differences in rFFA activity. This pattern was not found in other face-selective regions. Our results thus strengthen the view that rFFA is the main site for face interactive processing.

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43.529 The Role of Isolated Face Features and Feature Combinations in the Fusiform Face Area

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A critical issue in object recognition research is how features of objects are integrated into a perceptual whole. Much of the previous research on perceptual integration has focused on the role of configural or holistic processing with faces. There has also been a considerable amount of fMRI research investigating the response properties of face-selective areas of cortex, such as the fusiform face area (FFA). Here, we investigated the neural mechanisms of facial feature integration in humans using fMRI. Gaussian windows were applied to whole faces to create facial features representing the left eye, right eye, nose, and mouth. Individual subject thresholds were found for four-feature combinations using a staircase procedure while they performed a one-back matching task. During imaging, stimulus conditions included features in isolation and in combinations of two (both eyes) or four. Two specific regions of interest (ROI) were localized, the right FFA and the lateral occipital complex (LOC). The activation pattern of the rFFA was significantly different from the LOC. The LOC showed similar levels of activation to all stimulus conditions. The rFFA showed low levels of activation with mouth and nose features, greater activation with eye features and the greatest activation with the four-feature combination. The two-feature eyes combination stimulus did not produce more activation than the eye features in isolation. The results converge with previous behavioral and eye-tracking results to suggest a greater contribution of eye features than other types of features for face recognition. The results also suggest that activation in the rFFA represents a heterogeneous population of neurons that represent isolated features in addition to specific combinations.

Multisensory processing: Visual-auditory interactions

Vista Ballroom, Boards 530–547

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43.530 The Auditory Capture of Visual Timing Extends to Short-Range Apparent Motion

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Freeman and Driver (2008) reported that brief sounds can bias the perceived direction of visual apparent-motion stimuli (see also Getzmann, 2007), an effect attributed to “temporal capture” of visual stimuli by the sounds (Morein-Zamir et al., 2003). Cortical area MT is a key substrate in visual motion perception (e.g. Britten et al., 1992; Salzman et al., 1990), but the spatial and temporal intervals (i.e. 14 deg and 300 ms, respectively) of Freeman and Driver’s stimuli are much too large to engage area MT (Mikami et al., 1986 a, b; Newsome et al., 1986). Since such long-range motion stimuli are reportedly more sensitive to higher-order influences than are short-range motion (Horowitz & Treisman, 1989; Shiffrar & Freyd, 1993), we asked whether sound also impacts the perception of motion stimuli known to engage area MT. In experiment 1, subjects (N=7) judged the dominant motion direction of vertically-oriented bars that alternated between right and left of fixation. Spatial intervals ranged from 0.2 deg to 3.0 deg and temporal intervals varied from 60 ms to 240 ms. Without sound, perceived direction favors the smaller temporal interval (e.g. rightward motion is favored if the left-right interval is smaller than the right-left interval). We found that sounds systematically biased perceived direction in a manner consistent with temporal-capture. In experiment 2, subjects (N=7) judged the relative speeds of silent two-frame motion stimuli with those accompanied by two brief sounds (which either lagged or led the presentation of the individual bars). In further support of the temporal-capture hypothesis, perceived speed was determined by the timing of the sounds. Taken together, our findings suggest that brief stationary sounds may be able to shift the temporal tuning of area MT neurons for visual motion stimuli.

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43.531 Crossmodal interaction in metacontrast masking

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Metacontrast masking (MM) refers to the phenomenon of reduced target visibility due to a temporally lagging and spatially non-overlapping mask, and it has been attributed to inhibition between low-level visual channels such that transient activity triggered by the onset of the delayed mask inhibits sustained activity regarding the contours of the preceding target. Theories of MM have considered it to occur exclusively in the visual domain, without concerning signals from other modalities, such as audition. The current study aims to explore the possible effects of sound on MM by using a contour discrimination task and measuring the perceptual sensitivity change (d’) of the visual target with or without a sound. In Experiment 1, the sound was presented at different points in time with respect to the target. The results showed that the visibility of the masked target was elevated when sound was presented before the target. Accordingly, in Experiment 2, we adopted a spatial cueing paradigm in which the spatial congruency of the sound and target was manipulated. In Experiment 3, the target-sound SOA was manipulated further to probe the temporal window of the effect of sound on MM. An equivalent visual cue also was used for comparison in Experiments 2 and 3 to examine whether within- or cross-modal spatial cues would shift attention to its location in the standard MM task. The results showed that MM was affected by sound at the time when masking was reduced in the period of recovery from maximal masking SOA, indicating that sound enhanced target visibility in MM by orienting attention to its location, probably through a feedback modulation, to sustain the object representation of the visual target. This study sets a new example of audio-visual interaction for a phenomenon classically considered to be visual only.

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43.532 Task-irrelevant sound facilitates visual motion detection

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Different sense modalities interact in a variety of perceptual tasks. For example, auditory motion can influence visual motion direction discrimination (Meyer & Wuerger, 2001; Soto-Faraco et al., 2002). Many multisensory integration phenomena have been explained well by interactions at an inference level (e.g., Bayesian or maximum likelihood inference). However, signals of different modalities may also interact at a sensory level. This study tests whether sound can affect perceptual sensitivity to visual motion, aside from any inference or decisional influence. Subjects performed a 2IFC visual coherent motion detection task, in which one interval contained coherent motion in a fixed direction (e.g., 0°), and the other contained random motion. Subjects were asked to detect which interval contained the coherent motion stimulus. In addition to visual trials, our task-irrelevant congruent group experienced audiovisual trials in which sound moved in BOTH intervals, in the same direction as the coherent visual stimulus. Since sound moved identically in both intervals, it provided no indication as to which interval contained the visual coherent motion, and thus was task-irrelevant. Another group received audiovisual trials with task-relevant sound (i.e., moving only in the interval with coherent visual motion), and a third group experienced task-irrelevant incongruent sound (i.e., moving in both intervals but in the opposite direction of visual motion). As expected, subjects performed best when the visual stimulus was accompanied by congruent, task-relevant sound. Surprisingly though, visual motion detection was also significantly enhanced by the task-irrelevant congruent sound. Task-irrelevant sound moving in the opposite direction of visual motion did not yield any benefit, ruling out the possibility that the effect results from general alerting or attentional modulation by sound. These results suggest that auditory motion can facilitate perception of visual motion at a sensory level, independent of its contribution to inference and decision processes.

43.533 Audiovisual relative timings determine sound-induced flash fission versus flash fusion effects

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When observers are required to make judgments of the number of rapidly presented flashes of light, there is a tendency to either overestimate the count (‘flash fission’) or underestimate the count (‘flash fusion’), depending on the duration of the inter-flash interval (Bowen, 1989). Similarly, pairing the flashes with more or less loud, rapid beeps also results in fission

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and fusion effects (the sound-induced flash illusion, Andersen, Tiippana, & Sams, 2004; Shams, Kamitani, & Shimojo, 2000, 2002). Our aims were to determine how much these sound induced effects are dependent upon timings between clicks and flashes, and how these critical timings relate to the audiovisual 'window of integration' of around 100msec. A high contrast, 2º disc was flashed (11.7 ms, 7º periphery) in the presence of 0, 1, 2, or 3 beeps (7 ms, ~ 75dbA, 3.5 kHz) with various audiovisual relative timings between 12 and 300 msec. Results from naïve observers demonstrate flash fusion when >100 ms separated all stimuli, whereas flash fission was reported for separation <50 ms, with the transition from fission to fusion occurring rapidly. These results were replicated in stepped-on, ramped-off or ramped-on, stepped off discs. Large and consistent fission effects occurred when the sounds were presented: 1. during the ramp and 2. within 100 ms of the transient. A control experiment showed that no consistent illusory rapid change was induced by the beeps in a disc smoothly ramping on and off. We propose that the fission effects are occurring as the result of an intersensory process, whilst the fusion effect are occurring as the result of response bias.

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43.534 **Synchronized sound bursts disrupt visual apparent motion**

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Identical discs moving in opposite trajectories generate perception of an event that is bistable between a passing and a bouncing percept. This bistability can be biased toward bouncing when a burst of sound is presented at the time of trajectory contact. This cross- modal effect is considered to involve arousal and/or an event-based interpretation that a burst of sound implies collision. Alternatively, a synchronized sound burst may facilitate a bouncing percept by disrupting continuous motion perception. We employed a motion-aftereffect paradigm to test this possibility because the strength of motion processing can be inferred from the duration of the motion aftereffect without asking observers to introspect about the quality of perceived motion. This paradigm also allowed us to evaluate effects of sound on motion adaptation (by presenting sound bursts during adaptation) as well as on motion perception (by presenting sound bursts during perception of the motion aftereffect). We used a flicker motion aftereffect so that we could present brief (10 ms) bursts of white noise either synchronously or asynchronously with the visual stimuli. The adaptor stimulus displayed rotational apparent motion and the test stimulus displayed rotationally ambiguous flicker, which appeared to rotate in the direction opposite to adaptation until the adaptation wore off. The frame rate was always 4 Hz (producing robust apparent motion). The synchronized sound bursts reduced the duration of the motion aftereffect whether they were presented during adaptation or test. These effects were not due to increased arousal or cross-modal distraction because the sound bursts produced no effects when they were presented in anti-phase with the visual display. Synchronized sound bursts thus interfere with visual apparent motion processing both in terms of reducing motion adaptation and disrupting motion perception. This cross-modal effect may originate from the experience that sound bursts frequently accompany changes in motion direction.

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43.535 **Pitch changes cue cardinal visual-spatial location only during alignments of allo- and egocentric space**

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Variations in sound frequencies can cue up or down visual locations even when visual stimuli are unambiguous. However, it is not clear whether this crossmodal phenomenon occurs for non-cardinal directions, or whether the processes underlying it derive from an allocentric or egocentric representation of visual space. To investigate these questions, we used a yes/no color-matching task that participants performed either with their heads upright (matched allo- and egocentric axes) or tilted 90-degrees (disassociated allo- and egocentric axes). Specifically, the first of two colored discs was presented at fixation and the second was presented in one of four positions equidistant from fixation (colors matched on 70% of trials). Brief sounds (500 ms) changing from low-to-high pitch or high-to-low pitch were played over headphones; these frequency-modulated sweeps began at the onset of the first disc and ended at the onset of the second. Participants were told to respond to the color match between the two discs and ignore the uninformative sounds. The location of the second disc was in one of four cardinal directions (Upper, Lower, Right, Left) or four ordinal directions (Upper-Left, Upper-Right, Lower-Left, Lower-Right). The low-to-high sweeps speeded responses to the Upper disc (also the Right disc to a lesser degree), and the high-to-low sweeps speeded responses to the Lower disc (also the Left disc to a lesser degree); these effects were driven by pitch change rather than absolute pitch. The sweeps had no effects on ordinal disc locations, and the head tilt eliminated the sound-sweep effects at all locations. Thus, visual-spatial cueing by pitch change is specific to cardinal directions, this cuing occurs only when allo- and egocentric axes are aligned, and the multisensory integration processes contributing to this effect may result from associative learning during everyday upright experience.

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43.536 **Learning arbitrary visuoauditory mappings during interception of moving targets**

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The brain represents multisensory mappings relevant for interaction with the world. These mappings mostly involve intrinsically relevant signals, such as vision and proprioception of the hand in reaching. Here, we studied how more arbitrary maps are learned. The employed visuoauditory map coupled visual target position to the pitch of an accompanying sound. Our participants thus had to reach to intercept a moving target. The pitch of the accompanying sound was a function of target position either on the screen or relative to the fixation direction (in different subsets of participants, n = 5 for both, so far), which was also varied in the experiment. Participants sat in front of a monitor with their heads immobilized by a bite-bar. Targets appeared on a variety of positions and moved with a variety of velocities (left or right). After 500 ms the fixation point changed size and color, indicating that the reaching movement could be initiated. Our design involved a pre-test (intercepting visual targets), a learning phase (intercepting visual and audible targets, while the duration of target visibility was progressively reduced), and a testing phase (intercepting audible targets). Finger position at the moment of contact with the screen was determined using Optotrak, and fixation quality was assessed using EyeLink II. Participants in both groups could perform the task reasonably: even for the audible targets the pointing positions were significantly correlated with the target position at interception. We are currently analyzing the pointing errors within subjects as a function of fixation direction, initial target position and target velocity. This will provide a general idea of factors playing into the control of interception. More importantly, however, we will test the effect of mapping (screen versus gaze-centered) between participants, in order to examine whether the arbitrary mapping was better represented in screen- (/world-) or gaze-centered coordinates.

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43.537 **The role of luminance transients in the generation of the sound-induced flash illusion**

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The sound-induced flash illusion (Shams, Kamitani, & Shimojo, 2000, 2002) is a striking example of auditory 'capture'. Flashes are perceived to either increase in number when paired with more beeps ('flash fission') or decrease when paired with fewer beeps ('flash fusion'; Andersen, Tiippana, & Sams, 2004). In actual fact, the standard flash is comprised of two transients: an onset and offset luminance step, and so the beeps may simply be producing a bias to respond to these transients. In addition, our unisensory results have shown that naïve observers under-report the number of flashes (11.7 msec duration, SOA = 57 msec) when there are more than two. To control for these potential confounds, we developed a single transient stimulus: a 2º disc, 7º peripheral, with luminance ramped on (to 99% contrast) or off in 350 msec. With trained naïve observers, these ramped stimuli

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were randomly interspersed with single or multiple standard flashes in the presence of 0, 1, 2 or 3 beeps. Observers were instructed to count either the number of transients or flashes seen depending on the condition. With our single transient stimulus greater fission effects were observed than with standard flashes, but only when beeps occurred during the ramp. For standard flashes, fission and fusion were observed dependent on the relative timing of the audiovisual stimuli. Despite the fact that our single transient stimulus eliminated bias towards reporting two events, a greater number of transients were counted than with a two-transient flash. It is suggested that ambiguity in the ramp stimulus makes an associated transient more vulnerable to auditory capture. Thus, consistent with the law of inverse effectiveness, the more accurately perceived auditory stimuli dominate the visual percept.

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43.538 **Reciprocal interference from sound and form information in stimulus identification**

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Past studies have shown that incongruent visual information can bias the perception of location of sound, as well as the perception of sound identification. We used an audiovisual Stroop-like task to investigate whether incongruent sound and shape information interferes with stimulus identification at a conceptual level. Healthy undergraduates learned to identify novel shapes that were associated with distinct sounds and non-words (e.g., a curved shape has a high-pitched sound and is called "baiv"). After an initial training phase, participants completed a speeded naming task where they were simultaneously presented with a shape and a sound. They were instructed to identify the shape, the sound, or the stimulus presented, and the order of conditions was counterbalanced across participants. Crucially, 25% of test trials consisted of incongruent information: the sound and shape presented were not one of the learned associations. An analysis of the reaction times revealed a main effect of instructions: participants responded fastest when identifying shapes, and slowest when identifying sounds. We also observed a main effect of congruency: participants responded faster on congruent trials than on incongruent trials. These main effects were qualified by a two-way interaction between instructions and congruency: the size of the interference was largest when participants were asked to identify the sound and ignore visual information. This study demonstrates that incongruent information can impact the identification of stimuli at a conceptual level. Importantly, though vision is perceived as being the dominant sense in humans, irrelevant sound information still interfered with visual shape identification.

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43.539 **The effects of characteristic and spatially congruent sounds on visual search in natural visual scenes**

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Crossmodal facilitation has been an emerging area in visual spatial perception in recent years. While there has been much research into the visual effects on sound localization (e.g ventriloquist effect), relatively little is known about how sound can influence visual spatial perception. Moreover, very little is known about how sounds can influence attentional deployment a visual search task. Here we investigated whether characteristic and/or spatially congruent sounds can affect visual search performance in a complex visual scene. In Experiment 1a, participants were asked to indicate the presence or absence of a visual target in a complex visual scene. In this experiment, the sound could be spatially congruent or incongruent but the sound was always semantically relevant to the visual target. Results showed a significant benefit for spatially congruent sound when targets were relatively small and appeared in peripheral vision. In Experiment 1b, we varied the number of visual targets (6) and manipulated both the spatial congruency and the characteristic relevance of a sound. In both experiments, we found that sound significantly affected visual search performance (even though participants were instructed to ignore the sound) but characteristic sound had a greater effect on visual search performance than spatial congruency. However, when the target was more difficult to locate, spatially congruent sounds benefitted performance. Our findings suggest that characteristic and spatially congruent sound can affect visual search performance and have important implications for our understanding of multisensory influences on target detection in realistic visual scenes.

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43.540 **Viewing condition shifts the perceived auditory soundscape**

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Early-blind individuals have superior sound processing abilities compared to sighted individuals (Lessard et al., 1998 Nature 395: 278). Here we ask whether sound-processing ability was affected in normally sighted individuals by closing one or both eyes. Sound localization: Participants judged the location of ramped-onset double bursts (30 ms each separated by 30 ms) of white noise played through 16 speakers equally spaced along the azimuth (from -90 to 90 °) in a semicircular array and hidden behind a curtain. Participants listened under four viewing conditions: 1) eyes closed, 2) eyes open, 3) left eye open, and 4) right eye open. Perceived sound location was reported relative to a visual scale. Participants were more accurate in the central visual field and less accurate in the periphery with eyes closed compared to when both eyes were open. When viewing monocularly the perceived location of all sounds shifted toward the centre of the visible visual field (left for left eye viewing, right for right eye viewing) and error increased in the non-visible field. These findings suggest that the perceived position of centrally located sound sources (even when no useful visual information is available) are shifted toward the centre of the visible, visual field. Sound discrimination: Participants were asked to discriminate the relative location of two sound bursts. Two arrays of 8 speakers were equally spaced between 40 – 60 ° in the left and right periphery. Participants listened under the same viewing conditions as in the localization task. Participants had lower thresholds with both eyes open than with both eyes closed or viewing monocularly. In normally sighted individuals sound discrimination ability is not improved when eyes are closed. Viewing condition differentially affects spatial sound processing depending upon the nature of the task.

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43.541 **Aurally aided visual search in depth using 'virtual' crowds of people**

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It is well known that a sound can improve visual target detection when both stimuli are presented from the same location along the horizontal plane (Perrott, Cisneros, McKinley, & D'-Angelo, 1996; Spence & Driver, 1996). However in those studies, the auditory and visual stimuli were always congruent along the depth plane. In previous experiments, we demonstrated that it is not enough for an auditory stimulus to be congruent along the horizontal plane; it must be congruent in depth as well. However, congruency along the depth plane may not be crucial in virtual reality (VR). It is well known that visual distance perception in VR suffers from a compression of space, whereby objects appear closer to the observer than they are intended to be. In the following experiment we presented virtual scenes of people and the participant's task was to locate a target individual in the visual scene. Congruent and incongruent virtual voice information, containing distance and direction location cues, were paired with the target. We found that response times were facilitated by a congruent sound. Participants were significantly worse when the sound was incongruent to the visual target in terms of either the horizontal or depth plane. Ongoing experiments are also investigating the effects of moving audio-visual stimuli on target detection in virtual scenes. Our findings suggest that a sound can have a significant influence on locating visual targets presented in depth in virtual displays and has implications for understanding crossmodal influences in spatial attention and also in the design of realistic virtual environments.

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43.542 **Classification of Natural Sounds from Visual Cortex Activity**

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We investigated whether contextual auditory information is contained in the neural activity pattern of visual cortex in a category-specific manner. While being blindfolded, subjects were presented with three types of natural sounds: a forest scene (animate/non-human), a talking crowd (animate/human) and traffic noise (inanimate). We used multivariate pattern analysis (linear support vector machines) to classify the three different sounds from BOLD activity pattern in early visual cortex as identified with retinotopic mapping. Preliminary results show above chance classification in visual areas V2 and V3. This suggests that contextual information from the auditory modality shapes the neural activity pattern in early visual cortex, in a category-specific manner and in the absence of visual stimulation.

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43.543 **Learning to bind faces and voices: a gender-congruency advantage**

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Faces and voices of familiar people are mutually informative, i.e. hearing a familiar person's face allows the observer to infer the speaker's face and vice-versa. Development of this cross-modal knowledge may be due to simple associative pairing or may represent a specialized process in which faces and voices are bound into an 'identity'. Here, we present two experiments suggesting that binding into an identity is essential to efficiently learning face-voice pairs. In both experiments we compared how well people learned to match faces and voices across three types of face-voice pairs: when the faces an voices werae recorded from the same individual ('True Voice'), when they belonged to different individuals of the same gender ('Gender Matched'), and when they belonged to individuals of different gender ('Gender Mismatched'). In Experiment 1, where the faces and voices were presented statically, subjects showed much better performance in the Gender Matched vs. Mismatched conditions, as well as a smaller advantage for the True Voice vs. Gender-Matched condition. These results suggest that when faces and voices are congruent— and are thus likely to be bound into an identity— learning is improved relative to when they are incongruent. In Experiment 2, we introduced a dynamic condition, where the audio of the false voices (both Gender Matched and Gender Mismatched) was dubbed onto the video of the paired face. Performance for the Gender-Mismatched pairs showed strong improvement in the dynamic condition relative to the static condition. No such difference between static and dynamic conditions was found for the other, congruent, face-voice pair conditions. These results suggest that that the dubbing of the incongruent face-voice pairs 'forced' them to be bound into an identity, improving learning. We conclude that that binding into an identity is a critical factor in developing cross-modal knowledge of faces and voices.

43.544 **Audiovisual Phonological Fusion and Asynchrony**

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Our perception of the world involves the integration of many stimuli from different sensory modalities over time. When auditory and visual stimuli are presented asynchronously, subjects identify them as occurring at the same time despite up to three hundred milliseconds of offset (Conrey & Pisoni, 2006; Van Wassenhove et al., 2007). Moreover, when auditory and visual information differ slightly in content, subjects often perceive them as being part of the same event. In Audiovisual Phonological Fusion (AVPF), the auditory information indicates one speech sound (e.g., /l/) but the visual information indicates another (e.g., /b/), and the conflicting information is integrated to form a percept that contains both of these sounds (/bl/) (Radicke, 2007). The current study investigated the relationship between AVPF and temporal asynchrony. Subjects were presented with stimuli that differed in the amount of temporal offset ranging from 300 ms of auditory lead to 500 ms of visual lead and were asked to perform two tasks. In the fusion task, subjects were asked to report what they thought the speaker said. In the asynchrony judgment task, subjects were asked to determine whether the auditory and visual portions occurred at the same time ("in sync") or at different times ("out of sync."). The stimuli presented in both tasks were the same, but the ordering of the tasks was manipulated. We found that (1) AVPF was moderately robust to temporal asynchrony; (2) synchrony judgments were robust for AVPF stimuli; and (3) the ordering of the tasks can modulate performance; i.e., subjects who complete the perceptual fusion task first are more likely to judge items as occurring at the same time on the asynchrony judgment task.

Acknowledgement: NIH-NIDC R01-00111

43.546 **Integration and the perceptual unity of audio-visual utterances**

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When multisensory stimuli are unified as an event from one common source, the integration of these stimuli is considered to be facilitated. Some studies estimated the degree of perceptual unification by using participants' subjective reports concerning whether they felt the stimuli were coming together, although this conversely reflects the occurrence of integration. We investigated whether integrated speech perception affects the unification of audio-visual utterances. The visual stimulus was a movie of two bilateral faces uttering /pa/ and /ka/ respectively, and the auditory stimulus was one channel of voiced utterance of /pa/ or /ka/ from one of two speakers. When the auditory utterance is /pa/, audio-visual integration might elicit speech perception altered like /ta/, based on the McGurk illusion in Japanese participants. In addition, whether the auditory and visual stimuli of the corresponding spatial locations were consistent was manipulated to make the unification distinct or not. In our task, participants reported both the face perceived as the talker and the syllable perceived to be uttered by the talker. In this situation, participants would report the unified information source as the talker. If the outcome of integrated speech perception affects the unification, the judgment about the talker should be related to the auditory utterance as the presence or absence marker of the illusory perception. The results showed that the perceived talker was not affected by the kind of auditory utterance, although the participants reported illusory hearing only for the auditory /pa/. When the audio-visual stimuli were presented repeatedly for more distinct unification, the judgment about the talker was influenced only by the frequency of the presentation, and not by the auditory utterance. Moreover, these results were independent of the spatially manipulated ambiguity. These findings indicate that the perception of unity of audio-visual information is the cause and not the result of integration.

43.547 **Crossmodal constraints on human visual awareness: Auditory semantic context modulates binocular rivalry**

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The world provides contextual information to multiple sensory modalities that we humans can utilize in order to construct coherent representations of the environment. In order to investigate whether crossmodal semantic context modulates visual awareness, we measured participants' dominant percept under conditions of binocular rivalry while they listening to an ongoing background auditory soundtrack. Binocular rivalry refers to the phenomenon whereby when different figures are presented to the corresponding location in each eye, observers perceive each figure as being dominant in alternation over time. In Experiment 1, the participants viewed a dichoptic figure consisting of a bird and a car in silence (no-sound condition) or else they listened to either a bird, a car, or a restaurant soundtrack. The target of participants' attentional control over the dichoptic figure and the relative luminance contrast between the figures presented to each eye were varied in Experiments 2 and 3, and the meaning of the sound (i.e., bird or car) that participants listened to was independent of the manipulations taking place in the visual modality. In all three experiments, a robust modulation of binocular rivalry by auditory semantic context was observed. We therefore suggest that this crossmodal semantic congruency effect cannot simply be attributed to the meaning of the soundtrack automatically guiding participants' attention or else biasing their responses; instead, auditory semantic contextual cues likely operate by enhancing the representation of semantically-congruent visual stimuli. These results indicate that crossmodal semantic congruency can serve as a constraint helping to resolve perceptual conflict in the visual system. We further suggest that when considering how the dominant percept in binocular rivalry (and so, human visual awareness) emerges, information from other sensory modalities also

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needs to be considered; and, in turn, that multisensory stimulation provides a novel means of probing the mechanisms underlying human visual awareness.

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3D perception: Spatial layout

Vista Ballroom, Boards 548–556

Monday, May 10, 8:30 - 12:30 pm

43.548 Comparing different measures of space perception across real and virtual environments

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A direct comparison between perceptual judgments in real and virtual environments (VEs) provides a way to evaluate the "perceptual fidelity" of the VE, testing whether the VE allows observers to behave as they do in the real world. We have previously demonstrated that participants underestimate distances to targets on the ground in VEs when compared to their performance in the real world (e.g., Thompson et al. 2004, Presence) and that judgments of the width of perceived passability of an aperture are overestimated relative to shoulder width (Creem-Regehr et al. 2008, VSS). However it is unknown how judgments of perceived affordances directly compare to those made in the real world. The present study allowed for a comparison between distance judgments and perceived affordances across closely matched procedures and settings in a real and virtual environment. Participants viewed two poles in a real classroom or a virtual model of the same classroom. Similar to previous results, participants significantly underestimated the distance to the target in VEs as compared to the real classroom. Affordance judgments of passability between the two poles were analyzed as a percentage of participants' shoulder widths. When in a VE, participants required significantly wider spaces to indicate passage than when in the real classroom. The result of a greater passability width to shoulder width ratio in the VE is consistent with an underestimation of perceived size of the aperture. This may be associated with underestimation of distance or other factors such as uncertainty of scale or judgments made with respect to the observer's unseen body. Future work will assess the generalizability of these results by testing other distance, size and affordance judgments in matched real and virtual spaces. The effectiveness of VEs to accurately portray real world environments and the utility of VEs as perceptual tools will be discussed.

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43.549 Perceived slant from optic flow in active and passive viewing of natural and virtual surfaces

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Motivation. Recent evidence suggests that extra-retinal signals play an important role in the perception of 3D structure from motion (SfM). According to the stationarity assumption (SA, Wexler, Lamouret, & Droulez, 2001), a correct solution to the SfM problem can be found for a moving observer viewing a stationary object, by assuming a veridical estimate of the observer's translation. According to SA, perception of surface slant should be: (1) more accurate for active than for passive vision; (2) more accurate for natural than for virtual objects (because of the cue-conflict inherent to virtual stimuli). Method. We performed three experiments involving both active and passive observers. The task was to estimate the slant of a static random-dot planar surface. We manipulated the surface slant and the translation speed the observer's head. The translational displacements and orientation of the participant's head were recorded on-time by an Optotrack Certus system and the virtual stimuli were generated in real time on a high-definition CRT (passive observers received a replay of the same optic flow). Natural simuli were dotted planar surfaces. Results. Perceived surface orientation increased with both increasing slant and translation velocity. These systematic biases were found for both virtual and natural stimuli, and for both active and passive observers. Conclusion. Extra-retinal information available to active vision is not sufficient for a veridical solution to the SfM problem. Also for active vision, the first-order properties of the optic flow are the main determinant of perceived surface slant. If the first-order properties of the optic flow are kept constant, the surface is perceived as having a constant orientation, regardless of actual orientation; if the first-order properties of the optic flow are varied (e.g., by manipulating the translation speed of the observer's head), surface slant is perceived as varying, regardless of whether distal slant is constant.

43.550 Scale expansion in the estimation of slant

Frank Durgin[1](fdurgin1@swarthmore.edu), Zhi Li[1]; [1]Department of Psychology, Swarthmore College

Although it is widely believed that perception must be veridical for action to be accurate, an alternative view is that some systematic perceptual errors (e.g., scale expansion) may improve motor performance by enhancing coding precision. Sloped surfaces look and feel (when stood upon) much steeper than they are. The visual perception of geographical slant (GS: surface slant relative to the horizontal) can, in theory, be estimated by combining estimates of optical slant (OS: surface slant relative to the line of gaze) and gaze declination (GD: direction of gaze relative to the horizontal): GS = OS - GD. In studies of downhill slant perception (Li & Durgin, JOV 2009), we found that this simple geometric model predicted visual slant perception based on measured scale-expansion in both perceptual variables: Estimates of optical slant and estimates of the orientation of the axis of gaze itself. Here we show that the same model can be applied to uphill surface orientation. Using an immersive VR system with corrected and calibrated optics, in two experiments we measured (1) the perceived geographical slant of irregular 3D surfaces presented straight ahead or above or below eye level by 22.5 or 45 deg, and (2) the perceived direction of gaze when looking at targets ranging in visual direction from -52.5 to +52.5 deg from horizontal. All surfaces were simulated at a viewing distance of 1.5 m. The best-fitting model of the slant estimation data estimated that gaze direction was exaggerated by a factor of 1.5, exactly as found when directly measured. The model fit to the data estimated that changes in optical slant over the entire measured range were perceptually scaled by a factor of 1.4 at this viewing distance. Scale expansion of optical slant may serve a functional role in the evaluation of upcoming ground plane orientation during locomotion.

Acknowledgement: Swarthmore College Faculty Research Grant

43.551 Slant perception differs for planar and uneven surfaces

Zhi Li[1](zhi.li.sh@gmail.com), Frank Durgin[1]; [1]Psychology Department, Swarthmore College

Simulated environments often seem too small. Attempts to improve the perception of scale often involve applying realistic but planar textures to environmental surfaces. We have adopted a different approach in which three-dimensional objects ("rocks") that provide binocular, motion, and surface-occlusion cues for surface unevenness are embedded in simulated planar surfaces. Here we provide direct evidence that perceived surface orientation is more veridical when such uneven textures are used, especially in near space. The simulated surfaces used in this study were presented in an immersive virtual environment through a head mounted display using pincushion-corrected and calibrated optics with full head-motion compensation. Participants made verbal estimates of the geographical (relative to horizontal) orientations of large surfaces presented at different simulated distances, but scaled in 3 dimensions so that the projected textures were equivalent across distances. At the nearest viewing distance (1 m), estimates of surface orientation for slopes below 30 deg were fairly accurate when the textures were rendered with rocks. (They protruded about 5 cm at this distance.) When the rocks were instead flattened against the surface, so that surface unevenness was compressed to less than 0.01 cm ("flagstones"), slanted surfaces in the same range appeared much more frontal than they were. At a much farther viewing distance (16 m) perceived surface orientation was steeper for both types of displays, but the surfaces embedded with rocks (now boulders), still appeared less frontal than the surfaces embedded with (equally large) flagstones. The near and far-space effects of uneven surfaces may be moderated somewhat differently. The far-space effect, in particular, may reflect the presence of gradients of surface self-occlusion for uneven surfaces. Factors affecting perceived surface orientation may also play an important role in scaling perceived distance.

Acknowledgement: Swarthmore Faculty Research Grant

43.552 Looking for skies without gravity – differentiating viewing directions without vestibular information change

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In previous research we showed that physically shorter distances towards zenith are seen as equal to physically longer distances towards horizon. This anisotropic tendency is a consequence of an interaction of non-visual (vestibular and proprioceptive) with visual information. The aim of the present research was to investigate whether the same regularity can be found even when there is no change in non-visual information. Two experiments were done, in which 28 participants had the task to equalize perceived distances of three stimuli in three directions (separation between directions was 45 degrees). In the first experiment participants performed estimates while sitting on a chair, and in the second while lying on a rotating chair, on a left side of their body. In both experiments, experimenter moved participants towards different directions. In the first experiment, looking at different directions changes vestibular information, while in the second, vestibular information is constant. We used customized equipment to present stimuli and special glasses to prevent subjects' eye movements. On both experiments, results have shown that on 1m distance perceived distance was the same on all directions. Also, in both experiments, on 3m and 5m distance there was a significant difference between two most extreme directions (with 90 degrees separation angle), but no significant difference between nearby directions (with 45 degrees separation angle). In the first experiment, horizontal direction was perceived as shortest and vertical as longest. In the second, the last direction while subject was rotated upwards was perceived as the shortest, and the last direction while subject was rotated backwards was perceived as the longest. These results suggest that anisotropy of perceived distance exists in both cases, when there is a change in vestibular information, and when vestibular information is constant.

43.553 Memory for others' height is scaled to eye height

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Sedgwick (1973) noted that the perceived size of objects can be scaled relative to an observer's own eye height (EH). EH scaling has been shown to affect judgments of relative size, such that accuracy is best for objects at eye height (Bertamini, Yang, & Proffitt, 1998). The present study extended these findings to determine whether EH scaling is preserved in memory. In three experiments, we assessed how an observer's own height influences memories of others' heights. If EH scaling is preserved in memory, then judgments should be most accurate for targets that match the observer's height and should decline with deviation from that height. In Experiments 1 and 2, participants viewed target faces on sticks of varying heights. After each, they turned to face a comparison face and judged whether the comparison was taller or shorter than the target. Target and comparison heights were adjusted so that each participant viewed targets that were shorter, taller, and the same as their own height. In both experiments, we found that participants were most accurate judging targets that were near their own height. Whereas in Experiment 1 participants were always standing, we manipulated current height in Experiment 2 by having a seated and standing condition. Because accuracy was best for congruent trials (e.g., judging targets near seated height while seated), we concluded that people are using their current height to aid in judgments. To test the real-world implications of these findings, in Experiment 3, participants judged the heights of other people, rather than artificial targets. Again, we found that eye height influenced judgments of others' heights. These experiments provide evidence that EH scaling used in perception is preserved in memory.

43.554 Perception of the height of a barrier is scaled to the body

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When walking through or judging passage through an aperture, people allow for a margin of safety (Warren & Whang, 1987). Furthermore, this margin is preserved when the body is widened by holding a large object (Wagman & Taylor, 2005). In a series of five experiments, we question whether actions and judgments toward a different dimension, height, are also scaled to the body. In Experiment 1, participants allowed for a 3% margin of safety when walking under a horizontal barrier. In Experiment 2, participants were made taller by wearing a helmet and strapping blocks under their shoes. For both manipulations, participants were conservative in their walking behavior (e.g., allowing for a larger margin of safety). In the final 3 experiments, participants judged whether they could walk under barriers viewed from a static position and visually matched the height of the barrier to a horizontally projected line. In Experiments 3 and 4, participants who viewed the barriers while wearing the blocks or the helmet required a similar margin of safety for passage under as participants whose height was not altered. Visually matched estimates were also no different when wearing the blocks as compared to not. However, participants wearing a helmet visually matched the height to be shorter than participants who did not wear a helmet. In the final experiment, experienced helmet wearers (ROTC members) showed no difference in visually matched estimates of height compared to those not wearing a helmet. Overall, the results suggest that people allow for a margin of safety when walking under a barrier, which is preserved when judging from a static position and when height is altered. However, estimates of the height may differ based on the type of judgment being made and experience with alterations to height.

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43.555 When does cortical arousal enhance performance in visual perception tasks?

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Intro: Cold pressor stimulation (CPS, immersing the foot in ice-water for 50 seconds) decreases contrast thresholds without changing verbal distance estimates (Woods et al., 2009). Apparently, enhancing cortical arousal influences some visual tasks but not others. The factors that elicit this influence remain unclear. To begin investigating this issue, we conducted two experiments representing intermediate steps between the contrast threshold and verbal distance estimation methodologies: a Depth Threshold task (modeled on the 2AFC contrast threshold methodology, but in the depth domain) and a Distance Difference Threshold task (similar to the Depth task but with targets presented successively rather than in pairs). Methods: Depth Threshold: Two groups (N's = 18) underwent either CPS or "Sham" stimulation (immersing the foot in room temperature water for 50 seconds). On each trial participants binocularly viewed two white rods against a black background and judged which rod was closer, with depth separation being adjusted adaptively across trials. Threshold (82% correct criterion) was estimated before and after stimulation. Distance-Difference Threshold: Seventeen participants sequentially viewed 2 cones in identical checkerboard-covered alleyways (interstimulus interval ≈ 1.5s), judging which cone was closer. Thresholds were determined before and after CPS. Distance difference was adjusted adaptively across trials. Results: Depth thresholds decreased following CPS ($t=3.4$, $p=0.003$), but remained unchanged following Sham stimulation ($t=0.19$, $p=0.84$). Distance-difference thresholds did not change from Baseline to Post-Stimulation ($t=0.21$, $p=0.83$). Discussion: When present, arousal-related affects could stem from either enhanced attention or bona-fide changes in visual appearance. These factors are difficult to tease apart. In a separate experiment, we found that CPS did not affect contrast thresholds in a 2AFC task when the interstimulus interval was increased to 1.5 s. Thus, our results suggest that some aspect of the simultaneous or near-simultaneous comparison between stimuli may be crucial for eliciting arousal-related effects in visual tasks.

Acknowledgement: National Science Foundation Graduate Research Fellowship (Woods)

43.556 Depth perception and the horizontal vertical illusion depend on figural proportions

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We investigated the effect of varying figural proportions on perceived depth and on the horizontal vertical illusion in the frontal plane. Stimuli were rectangles 10cm in width and varying in length from 8cm to 20 cm. The rectangles were presented, one at a time, either in depth (lying on the surface of a table) or in the frontal plane (standing vertically on the table). Viewing was either monocular or binocular at a distance of 108cm. Observers verbally estimated the length of each rectangle assuming a width of 100 arbitrary units. Results were normalized by dividing estimated length by true length. For frontal plane rectangles, binocular and monocular results were very similar. When true length was 10 (equal to width), the normalized estimated length was 1.05. This was a significant horizontal vertical illusion (without a bisection component) of 5%. As the true length increased, the normalized estimated length increased significantly. A linear regression line fitted to the normalized results had a slope of 0.0165, indicating that for every 10% increase in length, relative to width, another 1.65% was added to the horizontal vertical illusion. For rectangles receding in depth, monocular and binocular results were quantitatively different although qualitatively similar. When true length was 1.0, the monocular normalized estimated length was 0.76 and the corresponding binocular length was 0.88, showing depth compression in both cases. As the true length increased, the normalized estimated ratios increased significantly, with regression line slopes of 0.005 monocularly and 0.010 binocularly. Thus, for all four conditions, the estimated length to width ratio, when normalized so that the correct value was always 1.0, increased significantly as length increased. This produced an increasing horizontal vertical illusion for stimuli in the frontal plane and a decreasing compression of perceived depth for receding stimuli.

Tuesday Morning Talks

Perceptual organization: Grouping and segmentation

Tuesday, May 11, 8:15 - 10:00 am
Talk Session, Royal Ballroom 1-3
Moderator: Steven Franconeri

51.11, *8:15 am*

Two Processes in Feature Misbinding: (1) Enabling Misbinding and (2) Contributing Features

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Peripheral visual objects may be mistakenly perceived to have the features of objects in the central visual field (illusory conjunctions). An ambiguity-resolving mechanism is posited to use information from the center to resolve peripheral ambiguity (Wu, Kanai & Shimojo, Nature 2004). RATIONALE: (a) If objects with no motion do not cause motion ambiguity and ambiguity is necessary for misbinding, then misbinding of motion should not occur for objects without motion. (b) If the central stimulus initiates resolution of motion ambiguity, then misbinding should not occur when the center is blank. (c) If the center contributes essential information to resolve ambiguity, then the misbound feature values within the periphery should be in the central stimulus. METHODS: The stimulus had random dots, each one red or green. The central stimulus was either (1) blank or (2) had red dots moving upward and green dots moving downward. The peripheral stimulus always had red and green dots: peripheral red dots either (1) had no motion (constant locations presented either steadily or pulsed on and off), or (2) had ambiguous motion (a new random location, independently for each dot in each frame, or a new random direction of movement, independently for each dot in each frame). Peripheral green dots moved (1) upward (same direction as central red dots) or (2) downward (opposite from central red dots). Observers reported the directions of motion of the majority of peripheral (1) red dots and (2) green dots. RESULTS: No misbinding of motion was found when peripheral red dots did not move or when the center was blank. When central red dots and peripheral green dots moved in opposite directions, the misbound motion of randomly moving peripheral red dots could be in either direction. CONCLUSION: The center initiates misbinding but is not the sole source for misbound feature values.

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51.12, *8:30 am*

Warped spatial perception within and near objects

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We report that spatial perception is systematically distorted in the space in and around objects. Two dots placed inside a rectangular object's boundaries appeared farther apart than two equivalently spaced dots placed outside of the object. We measured this expansion effect by placing reference dots in one corner of a monitor (either inside an object or without an object present), and asking participants to match the spacing of dots in the opposite corner. In four different experiments, we found significant distortions of spatial distance judgment for reference dots inside objects compared to outside, ranging up to 15% greater in a rectangular object in one experiment (N=20). To test whether this effect is modulated by the strength of perceived organization, we compared the magnitude of illusory expansion across 1.) separated portions of a partially occluded rectangle compared with separated objects; 2.) within an illusory Kanizsa square compared to when the inducers were rotated 180 degrees; and 3.) within a single rectangle compared with two separate rectangles. In all three cases, the strong-structure conditions (the occluded rectangle, illusory square, and single object) showed a significantly greater expansion than weaker-structure conditions. This illusion could not be explained by a simple depth-based account, which would predict perceived contraction of space in the region occluding an object. However, the illusion did reverse to a contraction effect for dot spacings that were near the edges of the objects and larger than the object. In conclusion, space is systematically distorted by perceived structure. We propose that the allocation of attention to the surface of a selected object may result in distortions in spatial perception.

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51.13, *8:45 am*

Evidence For A Modular Filling-in Process During Contour Interpolation

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Purpose. Information near filled-in regions alters the perception of interpolated shape, but it is unknown whether this process depends on top-down influences. Here, we consider whether observer strategy can reduce filling-in effects when interpolation normally occurs, or elicit such effects when interpolation normally does not occur. Method. Subjects discriminated briefly-presented, partially-visible fat and thin shapes, the edges of which either induced or did not induce illusory contours (relatable and unrelatable condition, respectively). Half the trials of each condition incorporated task-irrelevant distractor lines, known to disrupt the filling-in process. Half of the observers were asked to treat the visible parts of the target as belonging to a single thing (group strategy); the other half were asked to treat the parts as disconnected (ungroup strategy). A strategy was encouraged by giving subjects pictures of the fat and thin response templates in the instruction phase of the experiment, and at the end of each trial. These pictures depicted either unitary shapes or fragmented shapes, depending on the strategy. Results. There were three main results. First, distractor lines impaired performance in the relatable condition ($p<0.001$), but not in the unrelatable condition ($p>0.7$). Second, for both relatable and unrelatable stimuli, strategy did not alter the effects of the distractor lines ($p>0.7$). Finally, the attempt to group relatable fragments improved performance ($p<0.001$) while the attempt to group unrelatable fragments did not ($p>0.3$). Conclusions. These results suggest that a) filling-in during illusory contour formation cannot be easily removed via top-down strategy; b) filling-in cannot be easily manufactured from stimuli that fail to elicit interpolation; and c) actively grouping fragments can readily improve discrimination performance, but only when those fragments form interpolated contours. These findings indicate that while discriminating filled-in shapes depends on strategy, filling-in itself is relatively encapsulated from top-down influences.

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51.14, *9:00 am*

Grouping by common fate occurs for only one group at a time

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Grouping allows the visual system to link separate regions of the visual field into a single unit for some types of processing. Although much past work examines when grouping will occur, and the relative strength of different types of grouping, less is known about the mechanism that causes the separate regions to become linked. We present a series of experiments demonstrating that a type of motion-based grouping, often called "common fate," may be driven by selection of a common motion vector among the grouped objects. Selecting in a spatially global manner for the motion vector currently exhibited by one object should also activate other objects that exhibit the same pattern of motion, affording the shape created by the group, as well as a feeling that objects 'go together'. This account makes a counter-intuitive prediction, that only one motion vector, and hence one common fate group, can be created at a time. Participants performed a search for a common fate group among non-common fate groups. Displays contained four pairs of moving dots, where one dot per pair was constrained to a small region near fixation, the other was located in the periphery. Among the four dot-pairs, one to four were locked in common motion, and we measured response times for participants to find at least

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one synchronized dot pair. Search slopes were highly serial (~750ms/pair), but were flat when one motion vector was precued. We propose that selection of an object's motion vector is a prerequisite for grouping by common fate, but this vector selection can group an unlimited number of objects sharing a pattern of motion.

51.15, *9:15 am*

Early activation of contextual associations during object recognition

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Our visual system relies on stored memory associations to achieve recognition. Objects in natural scenes tend to be grouped by a particular semantic context and these contextual associations are employed during object recognition. Behavioral research has demonstrated that stimuli congruent with the scene context are recognized more easily than incongruent stimuli (e.g., Palmer, 1975; Biederman et al., 1982; Davenport and Potter, 2004). Investigations of context-related activity using fMRI (e.g. Bar and Aminoff, 2003; Aminoff et al., 2008, Peters et al., 2009) revealed a network of regions that are consistently engaged by contextual associations of objects and scenes. This network comprises the parahippocampal cortex (PHC), retrosplenial complex (RSC), and medial prefrontal cortex (MPFC). To understand how this context network is recruited and activated to facilitate recognition, one needs to first reveal its temporal and connectivity properties. Therefore, we investigated the spatiotemporal dynamics of contextual association processing here with a combination of fMRI and magnetoencephalography (MEG). We contrasted the neural response to objects with strong contextual associations (SCA) with the response elicited by weak contextual associations (WCA). Both fMRI and MEG responses revealed stronger activations in the context network for the SCA vs. WCA comparison. To explore the spatiotemporal dynamics of this process, we analyzed the phase synchrony, a measure of neural coupling, in the MEG data. The results show stronger overall phase synchrony for SCA objects than for WCA objects within the context network. Furthermore, we found an early, enhanced phase synchrony between the visual cortex and PHC, followed by PHC-RSC, and then by somewhat later RSC-MPFC coupling, occurring mainly in the beta band between 150-450 ms. Our findings reveal for the first time the spatiotemporal and connectivity properties of context processing. Implications of these findings to our understanding of how contextual information is used during recognition will be discussed.

Acknowledgement: NIH NS056615, NSF 0842947, NIMH K01-MH083011-01

51.16, *9:30 am*

Color Contrast Polarity of Boundary Edge Affects Amodal and Modal Surface Completion

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Two loci on a natural surface are more likely to have the same than different colors. Does the visual system capitalize on this ecological regularity to integrate partially occluded fragments into a larger common surface? In particular, when the geometrical relationship between the boundary edges of two image fragments are appropriate for amodal surface completion between them, do these edges need to have the same color contrast polarity (CP)? To answer this, we investigated whether the color CP of equiluminous, spatially aligned rectangles affects the amodal surface completion between them, and the consequent formation of the modal surface that occludes the amodal surface. We found using three divergent psychophysical tasks that separated rectangles with the same color CP (red/red or green/green), rather than with opposite color CP (red/green or green/red), tend to integrate into a partially occluded surface. First, observers subjectively reported the perceived illusory contour (modal surface) as stronger when the separated rectangles had the same color CP. Second, observers were more efficient in discriminating the orientation of modally completed ellipses, formed from aligned rectangles with the same color CP. Orientation discrimination was worse when the aligned rectangles had opposite color CP, which negated the formation of the modally completed ellipse. Third, when motion signals were added to the edges of the separated rectangles with the same color CP, the rectangles were more likely to be perceptually integrated and seen to move in synchrony (global motion). In all experiments, we also varied the luminance contrast of the yellow background relative to the equiluminous rectangles. We found the contribution of color CP to surface completion remains substantial with either the brighter or darker background. This indicates that even when the aligned rectangles carry the same luminance CP information, color CP information can exert an effect on the surface completion process.

Acknowledgement: NIH (R01 EY015804)

51.17, *9:45 am*

Border ownership signals reflect visual object continuity

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Theories of visual cognition have postulated a processing stage where elementary features are linked together to form more complex representations termed "object files" or "proto-objects". The neural basis of the linking is not known. How is the representation of a square different from the representation of four lines? One hint comes from the observation of border ownership (BOS) selectivity in monkey visual cortex. About half of the neurons in area V2 are selective for which side of a border in the receptive field is the figure and which side is the ground. The left-hand side of a square, for example, produces high firing rates in neurons of figure-right preference and low firing rates in neurons of figure-left preference. These neurons combine information from various figure-ground cues, including stereoscopic depth, occlusion features and global shape. Do these neurons just integrate figure-ground cues, or do they reflect the formation of proto-object representations? One important characteristic of visual objects is continuity. The system can identify given objects across a sequence of changing images. If BOS signals reflect object-related coding, they should show this continuity. But if they merely represent the figure-ground cues, they should change whenever the cues change. To answer this question we devised stimuli in which the figure-ground cues reverse, while the objects remain the same. During an initial motion phase, the figure-ground cues indicate one side of ownership. At the end of the motion, the static configuration gives cues indicating the opposite side of ownership. We find that the initial BOS assignment persists for seconds despite the change in the figure-ground cues of the stimulus, indicating that the continuity of the objects dominates the neural response. Thus BOS signals reflect the emergence of proto-object representations.

Motion: Mechanisms

Tuesday, May 11, 8:15 - 10:00 am
Talk Session, Royal Ballroom 4-5
Moderator: Mehrdad Jazayeri

51.21, *8:15 am*

Monkey and humans exhibit similar motion-processing mechanisms

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Single cell recording studies have provided detailed understanding of motion-sensitive neurons in nonhuman primates. Previous research has revealed linear and non-linear increases in spike discharge rate in response to increasing motion coherence and density, respectively, and a division-like inhibition between neurons tuned to opposite directions. It is not known to what extent these response properties mirror those of motion-sensitive neurons in the human brain. We used an adaptation phenomenon, the direction aftereffect (DAE), to investigate whether motion-sensitive neurons in the human brain respond to varying motion density and coherence in a similar manner to macaque. Motion adapters that evoke a stronger response in neurons usually result in greater changes in the neurons' direction tuning functions, which are thought to impact on DAE magnitude. If motion-sensitive neurons in the human brain respond in a similar manner to macaque, increasing motion density and coherence will result in changes in neural spike discharge similar to those reported for macaque. Given the relationship between neural spiking and aftereffect magnitude, changes in the levels of neural activity will be revealed through DAE measurements; with increasing neural activity leading to increasing DAE magnitude. We measured DAE magnitude as a function of 1) varying adapter

Tuesday AM

dot density; 2) repeating the experiment while adding dots moving in the opposite direction; and 3) varying motion coherence of the adapter. The resultant DAE tuning functions show that changes in activity of human motion-sensitive neurons to changes in motion density and coherence bear a strong resemblance to macaque data. We also show a division-like inhibition between neural populations tuned to opposite directions, which also mirrors neural inhibitory behaviour in macaque. These findings strongly suggest that motion-sensitive neurons in human and nonhuman primates share common response and inhibitory characteristics.

51.22, *8:30 am*

Responses of macaque MT neurons to multi-stable moving patterns

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Neurons in area MT are sensitive to the direction of motion of gratings and of plaids made by summing two gratings moving in different directions. MT component-direction-selective (CDS) neurons respond independently to the gratings of a plaid, while pattern-direction-selective (PDS) neurons combine component information to respond selectively to plaids that move in the direction preferred by single gratings. Adding a third moving grating creates a multistable “triplaid”, which alternates perceptually among different groupings of gratings and plaids. To examine how this multistable motion percept might relate to the activity of CDS and PDS neurons, we measured the activity of 77 MT neurons in anaesthetized macaques to triplaid stimuli in which three identical moving gratings whose directions were separated by 120 deg were introduced successively going from a grating (320 ms) to a plaid (320 ms) to a triplaid (1280 ms). CDS and PDS neurons – selected based on their responses to gratings and plaids – responded strikingly differently to triplaids. CDS neurons maintained their tuning properties for more than 1 s, but PDS neurons were slowly and progressively suppressed and lost their direction tuning properties altogether after 0.3–0.6 s. PDS but not CDS responses to triplaids also depended on the order in which the three components were introduced. We wondered whether these effects might be due to anesthesia and therefore repeated the experiment in area MT of an awake macaque performing a fixation task. Responses to the onset of individual gratings were more transient in the awake macaque than under anesthesia, but the sustained suppression of PDS responses persisted in both conditions. We attribute the differences between CDS and PDS response properties to an opponent suppression that is more potent in PDS cells, and discuss how area MT might contribute to the multistable perception of direction in moving triplaids.

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51.23, *8:45 am*

Distinct binocular mechanisms for 3D motion perception

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The perception of 3D motion relies on two binocular cues, one based on changing disparities over time (CD cue), and one based on the interocular velocity differences (IOVD cue). While both cues are typically present when a real object moves through depth, the CD cue is easy to isolate and has therefore received the most attention. More recently, however, the IOVD cue has been (behaviorally) isolated and shown to play a strong role in the perception of 3D motion.

We probed the mechanisms responsible for 3D motion using a standard motion adaptation paradigm. Observers adapted to random dot motion directly towards or away from them. The strength of the resulting motion aftereffect was determined from the shift in the psychometric function relating dot motion coherence to perceived direction. The shifts in 3D motion thresholds were extremely large—around 45% coherence—double that of frontoparallel aftereffects measured using otherwise identical 2D motion stimuli. These results (and those from a variety of control conditions) are inconsistent with a simple inheritance of 2D aftereffects and reveal adaptation of a unique 3D motion mechanism.

We next adapted observers to 3D motion stimuli that contained the isolated CD or IOVD cue, or combined both cues (like most real-world motion). Each aftereffect was measured using an identical combined-cue variable motion coherence stimulus. Adaptation to either the combined-cue or IOVD-isolating stimuli resulted in the same large aftereffects seen in the first experiment, while adaptation to the CD-isolating stimulus produced aftereffects less than half as large.

These motion aftereffects reveal distinct representation of 3D directions of motion, indicate that separate mechanisms exist for processing the disparity- and velocity-based cues, and support recent work showing that, under many conditions, the velocity-based cue plays a surprisingly fundamental role in 3D motion perception.

51.24, *9:00 am*

Brain areas involved in perception of motion in depth: a human fMRI study

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Recently Likova and Tyler (2007) reported a brain region anterior to the human MT complex (hMT+) that is specialized for motion in depth while Rokers, Cormack and Huk (2009) reported strong involvement of hMT+ itself. To resolve these conflicting results, we developed dynamic random-dot stereograms (RDS) in which we could trace the processing phases of the depth and motion components with functional magnetic resonance imaging. In our RDS, a number of layers composed of black random-dots on frontoparallel planes were stacked in the in-depth direction against a gray background predefining the motion path. In each frame, dots in one of the layers switched from black to white and then returned to black in the successive frame during which the contrast switching took place in another layer. When switching occurred in neighboring layers toward one direction, observers perceived a plane smoothly traversing in depth (condition 1); when the switching occurred in arbitrary layers in succession, observers perceived no coherent motion (condition 2). Both conditions require a prior process of representing a plane (white random-dot layer) in depth, which is possible only after binocular combination. In condition 3 the contrast-switching dots were selected across arbitrary layers, which appeared as twinkling dots in depth (condition 3). By contrasting these conditions in block designs, we found that both hMT+ and a region anterior to hMT+ are involved in the process. First, alternation of conditions 2 and 3, in which surface representation is the only feature in comparison, evoked positive blood-oxygen-level dependent (BOLD) change that is mostly contained in hMT+ and in another visual area, putative V3A. On the other hand, alternation of conditions 1 and 2, in which perception of coherent in-depth motion is the feature of interest, evoked BOLD changes in a region anterior to hMT+ (including the anterior hMT+).

51.25, *9:15 am*

Visual Illusion Contributes to the Break of the Curveball

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In the game of baseball, the curveball follows a (physical) parabolic trajectory from the pitcher’s hand to home plate, but batters often report that the path of the ball appears discontinuous. The perceived discontinuity is referred to as the “break”. The discrepancy between the perceptual and physical trajectories suggests that the break of the curveball is a perceptual illusion. A curveball contains two orthogonal motion signals: a global motion toward the batter (second-order motion), and a local spinning (first-order motion). We have created a simplified visual display to simulate the two orthogonal motion signals in the curveball. In our display, a spinning disk descends vertically on a screen; when viewed foveally, the disk appears to descend vertically, but when viewed with peripheral vision, the disk appears to descend obliquely. We found that the perceived motion direction of the disk deviated from vertical by about 0.67x eccentricity. We computed the moment-by-moment perceived velocity of the curveball from an actual trajectory (Bahill and Baldwin, 2004) by assuming that the batter’s gaze shifts from the ball to the expected point of bat/ball contact when the ball is 0.2 sec from home plate, and by adding a 0.67x eccentricity (degrees) deviation to the physical velocity. The results predict an observer’s perception of a discrete shift from the physical parabolic path traveled by a

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curveball and suggest that the misperception of the curveball's path may be attributable to a transition from foveal to peripheral visual processing of the image of the ball.

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51.26, *9:30 am*

Recovering the functional form of the slow-and-smooth prior in global motion perception

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Human motion perception has been proposed as a rational system for combining noisy measurements with prior expectations. An essential goal is to find means to experimentally discover prior distributions used by the human visual system. We aim to infer the functional form of motion prior from human performance. Stimuli consisted of 144 gratings with random orientations. Drifting velocities for signal gratings were determined by global motion, whereas those for noise gratings were randomly assigned. Observers were asked to discriminate global motion directions between a reference and a testing stimulus. In session 1, human performance was measured at ten different coherence levels, with a fixed angular difference between reference and testing direction. Session 2 measured performance but for ten angular differences with 0.7 coherence ratio. The priors included slowness, first-order and second-order smoothness. We focused on two functional forms for prior distributions: L2-norm (corresponding to Gaussian distribution) and L1-norm regularization (approximating Student's t distribution, whose shape has heavier tails than Gaussian). The weights of the three prior terms were estimated for each functional form to maximize the fit to human performance in the first experimental session. We found that the motion prior in the form of the Student's t distribution provided better agreement with human performance than did Gaussian priors. The recovered functional form of motion prior is consistent with objective statistics measured in natural environment. In addition, large weight values were found for the second-order smoothness terms, indicating the importance of high-order smoothness preference in motion perception. Further validation used the fitted model to predict observer performance in the second experimental session. The average accuracy difference between humans and model across ten experimental levels ranged within 3%~8% for five subjects. This excellent predictive power demonstrates the fruitfulness of this approach.

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51.27, *9:45 am*

Investigating the relationship between actual speed and perceived visual speed in humans

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A number of models have been proposed over the years that are able to estimate the speed of a moving image feature such as an edge but it is not obvious how these models should be assessed in terms of their performance. Over what range of speeds should a model's estimates of image velocity be veridical in order for it to be classed as effective? There is currently a lack of data that can directly inform us as to what the function looks like that links human estimates of speed (v´) to actual speed (v), i.e., v´ = f(v), f = ? On a plot of v´ versus v, it is difficult to establish the absolute location of the function but we will show that there already exists a range of psychophysical data which constrain the form it can take. For example, the U-shaped, speed discrimination (Weber fraction) curves obtained by a number of researchers (e.g., McKee, Vis Res., 1981; De Bruyn & Orban, Vis Res.1988) suggest that the v´= f(v) function for moving edges is s-shaped with the maximum slope occurring at intermediate speeds (approx 4 – 16 deg/s). We have discovered that this s-shape is also predicted by models of speed estimation that feature speed-tuned Middle Temporal (MT) neurons and which incorporate a weighted vector average (centroid) stage (e.g., Perrone & Krauzlis, VSS, 2009). Because the range of speed tunings in MT is naturally constrained at both the high and low speed ends, the centroid estimate of the MT activity distribution is biased as a result of 'truncation effects' caused by these lower and upper bounds; speed estimates in the model are overestimated at slow input speeds and underestimated at high input speeds producing an s-shaped, v´= f(v) function similar to that predicted by the speed discrimination data.

Acknowledgement: JP & RK supported by a Royal Society of New Zealand Marsden Fund grant.

Neural mechanisms: Cortex

Tuesday, May 11, 11:00 - 12:45 pm
Talk Session, Royal Ballroom 1-3
Moderator: Melissa Saenz

52.11, *11:00 am*

Perceptual learning and changes in white matter in the aged brain revealed by diffusion-tensor imaging (DTI)

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An extensive body of research has shown that vision declines with increased age. Recent research (Yotsumoto et al., 2008; Ni et al., 2007) has shown that perceptual learning can be used to improve visual performance among older subjects (age 65 or older) and that the improved performance is associated with an increase in BOLD signal localized to a trained part of the visual field. An important question is whether the changes in BOLD signal are associated with anatomical changes. To address this question, we used diffusion tensor fractional anisotropy (FA) as a method to index white matter density changes in older subjects trained using perceptual learning. Nine older subjects aged 65-80 underwent three behavioral training sessions of a texture discrimination task (TDT) (Karni and Sagi, 1991). Each session lasted about 45 minutes and was conducted on three separate days. They also participated in two MRI / fMRI sessions before and after the three training sessions. In MRI/fMRI sessions, FA values were obtained using DTI, as well as BOLD activities during the task. Results indicated that FA values decreased below the regions of visual cortical areas retinotopically corresponding to the location of the trained stimulus (trained regions) when compared to those before the training. These findings were associated with improved TDT performance after training and significantly larger BOLD signal in the trained region than untrained regions. These results raise the possibility that at least with older people long-term performance and physiological changes are supported by anatomical changes.

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52.12, *11:15 am*

Retinotopic Organization of Visual-Callosal Fibers in Humans

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Introduction: The visual cortex in each hemisphere is linked to the opposite hemisphere by axonal projections that pass through the splenium of the corpus callosum. Earlier work suggests there may be retinotopic organization within the splenium: Dougherty and Wandell (2005) traced callosal fibers from the splenium to a broad region of visual cortex that included multiple extrastriate regions and found a ventral-dorsal mapping (upper vs. lower visual field) running from the anterior-inferior corner to the posterior-superior end of the splenium. However it is not clear whether these results are due to dorsal and ventral visual areas projecting to different regions of the splenium, or whether individual visual areas also show retinotopic organization within the splenium. Here, we demonstrate consistent retinotopic organization of V1 fibers within the human splenium. Methods: High-angular resolution diffusion-weighted MR imaging (HARDI, 72 diffusion directions) and probabilistic diffusion tractography were used to track fibers between seed points in the splenium and retinotopically-defined sub-regions of V1 in 6 human subjects with normal vision. V1 was divided into sub-regions (three eccentricity bands, upper vs. lower visual field representations) based on functional retinotopic mapping in each subject. Each tractography seed point within the splenium was then labeled according to its profile of connection probabilities to these V1 reti-

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notopic sub-regions. Results: For all 12 hemispheres, we found retinotopic organization of V1 fibers within the splenium. The eccentricity mapping (of fovea to periphery) runs from the anterior-superior corner to the posterior-inferior end of the splenium. This runs orthogonal to a ventral-dorsal mapping (upper vs. lower visual field) running from the anterior-inferior corner to the posterior-superior end of the splenium. These results give a more detailed view of the structural organization of the human splenium than previously reported and offer new opportunities to study structural plasticity in the visual system.

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52.13, *11:30 am*

Flexibility of temporal receptive windows (TRWs) in the human brain

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Real-life events vary in their temporal scales; accordingly, different brain areas must process information at scales appropriate for their functional properties. Denoting the period during which an incoming stimulus can affect the neural response as an area's "temporal receptive window" (TRW), we previously used fMRI to identify areas with TRWs ranging from very short (<3 sec) in early visual cortex to very long (>40 sec) in anterior cortex, e.g., the Frontal Eye Fields (FEF), (Hasson, Yang, Vallines, Heeger & Rubin, 2008). Because a given real-life event can also vary in pace, we hypothesized that TRWs must be flexible enough to allow processing at a range of paces. Here, we investigated the flexibility of TRWs by measuring fMRI activity while observers viewed clips of a feature film that were time-stretched or time-compressed (x0.3, x0.6, x1.5 and x3.0), and later, the original versions of those clips. Observers completed post-scan questionnaires to assess their comprehension of the plot of each clip. Localizer scans were obtained to define early visual cortical areas (standard methods) and anterior, long-TRW ROIs (based on Hasson et al., 2008). Response reliability of each ROI was assessed by computing the correlations between the time-courses of the responses to two repetitions of the same clip within and across-observers. Flexibility of an area's TRW was assessed by computing the correlation between the time-courses of the response to an original clip and the response to a pace-modified clip, after un-stretching or un-compressing the latter. Correlations between the responses to the pace-modified and original clips were comparable to those between two repetitions of the original, more so in long-TRW areas (e.g., FEF) and when comprehension was good. These data suggest that durations of TRWs may be determined not by time per se, but by the number of accumulating sub-events.

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52.14, *11:45 am*

Gamma-aminobutyric acid concentration is reduced in visual cortex in schizophrenia and correlates with orientation-specific surround suppression

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The neural mechanisms that underlie perceptual and cognitive deficits in schizophrenia remain largely unknown. The gamma-aminobutyric acid (GABA) hypothesis proposes that reduced GABA concentration and neurotransmission in the brain result in cognitive impairments in schizophrenia. However, few in vivo studies have directly examined this hypothesis in individuals with schizophrenia. We employed magnetic resonance spectroscopy (MRS) to measure visual cortical GABA levels in subjects with schizophrenia and demographically matched healthy control subjects and found that the schizophrenia group had an approximately 10% reduction in visual cortical GABA concentration relative to the control group. We further tested the GABA hypothesis by correlating visual cortical GABA levels with orientation-specific surround suppression, a behavioral measure of visual inhibition thought to be dependent on GABAergic synaptic transmission. Subjects performed a contrast decrement detection task within a vertically-oriented annulus grating. For some trials, the grating was surrounded by either a parallel vertical grating or an orthogonal horizontal grating. Thresholds for contrast decrement detection were largest for the parallel surround condition, and the ratio of thresholds in the parallel and orthogonal surround conditions indexes the component of surround suppression that is selective for stimulus orientation. Previous work from our group has shown that subjects with schizophrenia exhibit reduced orientation-specific surround suppression of contrast decrement detection (Yoon et al., 2009). For subjects with both MRS and behavioral data, we found a highly significant positive correlation between visual cortical GABA levels and magnitude of orientation-specific surround suppression. Concentrations of GABA in visual cortex were not correlated with contrast decrement detection thresholds for stimuli that did not contain a surround. These findings suggest that a deficit in neocortical GABA in the brains of subjects with schizophrenia results in impaired cortical inhibition and that GABAergic synaptic transmission in visual cortex plays a critical role in orientation-specific surround suppression.

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52.15, *12:00 pm*

Dynamic synthesis of curvature in area V4

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Object perception depends on integration of small, simple image fragments (represented in early visual cortex) into larger, more complex shape constructs (represented in intermediate and higher-level ventral pathway visual cortex). We have previously described a dynamic process for shape integration in macaque monkey posterior inferotemporal cortex (PIT) (Brincat & Connor, 2006, Neuron; VSS 2008; VSS 2009). In PIT, linear tuning for individual curved contour fragments evolves into nonlinear selectivity for more complex multi-fragment configurations over a time course of approximately 60 ms. Here, we describe the antecedent stage of shape integration in area V4, which provides feedforward inputs to PIT. In V4, early responses reflect linear tuning for individual contour orientation values, comparable to orientation tuning in early visual cortex (V1, V2). These signals evolve into nonlinear tuning for curvature (change in orientation along contours) over a time course of approximately 50 ms. The emergence of V4 curvature responses matches the time course of V4-like curvature signals in PIT, implying that this dynamic process in V4 provides critical input signals to PIT. These results suggest a comprehensive model of sequential shape synthesis in the ventral pathway. Orientation signals emerge first, and are dynamically synthesized into curvature signals in V4. V4-like curvature signals appear with nearly the same time course in PIT, and are subsequently synthesized into larger, more complex shape constructs. The time course of this transformation complements an extensive body of human psychophysical and neurophysiological research showing that object perception develops over a span of several hundred milliseconds from very crude distinctions to finer categorization and identification.

52.16, *12:15 pm*

Encoding a salient stimulus in the lateral intraparietal area (LIP) during a passive fixation task

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When exploring a visual scene, some objects preferentially grab our attention because of their intrinsic properties. In this study, we examined the responses of neurons in LIP to salient stimuli while naive animals performed a passive fixation task. We defined the salient stimulus as a color popout among stimuli of another color; either red or green. The animals started a trial by fixating a central spot after which a circular array of 6 stimuli was flashed for 750 ms. The array was arranged so that only one of the stimuli was in the receptive field (RF). The animals had to keep fixation to be rewarded. We used 4 different conditions: the field condition, in which all the stimuli had the same color; the distractor condition, in which the salient stimulus was presented outside the receptive field, so a distractor was inside the RF; the popout condition, in which the salient stimulus was inside the RF; and the singleton condition, in which only a single

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stimulus was presented inside the RF. We recorded from 42 LIP neurons and found that the mean response to a salient stimulus was significantly higher than the mean response to a distractor, but significantly lower than the mean response to a singleton. The time at which the popout activity rose above the distractor activity was relatively early suggesting that bottom-up information from early visual areas converges at LIP. Interestingly, there was a tight correlation in response to the popouts and distractors of similar colors, suggesting gain control. We also found that some LIP neurons prefer a particular color, but these neurons still had elevated responses to a popout compared to a distractor, consistent with the presence of gain control. Together these results indicate that LIP highlights salient stimuli even when they are task irrelevant.

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52.17, *12:30 pm*

Visual responses of the dorsomedial area V6A to the presentation of objects to be grasped

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The medial posterior parietal area V6A has been recently shown to encode the different types of grips used to grasp objects of different shapes (Fattori et al., Journal Neurosci, in press). As V6A contains many neurons activated by visual stimulations (Galletti et al., 1996; 1999), and receives a direct visual input from the extrastriate visual area V6 (Galletti et al., 2001), the aim of the present study was to ascertain whether cells in V6A encode the visual features of the objects to be grasped. 153 neurons were recorded from 2 monkeys trained to perform reach-to-grasp movements to objects with different shapes: ball, handle, ring, plate, stick-in-groove. The monkeys fixated a LED, one object was illuminated for 500 ms, then, after a variable delay (0.5- 2s) the animal reached and grasped the same object in the dark. About 70% of V6A cells (109/153) showed visual responses to object presentation; 80% of these visual neurons (88/109) showed also reach-to-grasp-related discharges. About 30% of visual neurons displayed selectivity for an object or a set of objects (31/109), and half of these cells (17/31) showed reach-to-grasp responses modulated by the type of grip used to grasp them. At population level, the strenght of neural modulations to the visual features of objects to be grasped is similar to that for coding the grip postures suitable for grasping these objects. From these data it turns out that most of V6A neurons are visually driven by the objects presented in peripersonal space, with neurons discriminating the object type, and neurons able to code both object types and grip types. We conclude that area V6A is a visuomotor area of the dorsomedial visual stream involved in coding both the execution of reach-to-grasp actions and the visual features of objects to be grasped.

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Attention: Object attention and object tracking

Tuesday, May 11, 11:00 - 12:45 pm
Talk Session, Royal Ballroom 4-5
Moderator: Todd Horowitz

52.21, *11:00 am*

Beam me up, Scotty! Exogenous attention teleports but endogenous attention takes the shuttle

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Analyzing a scene requires shifting attention from object to object. Several studies have attempted to determine the speed of these attentional shifts, coming up with various estimates ranging from two to thirty shifts per second. The discrepancy among these estimates is likely a result of several factors including the type of attention, cue and stimulus processing times, eccentricity, and distance between objects. Here, we adapt a method pioneered by Carlson et al (2006) that directly measures attentional shift times. We present 10 'clocks', with single revolving hands, in a ring around fixation. The observers are asked to report the hand position on one of the clocks at the onset of a transient cue. We use different combinations of exogenous and endogenous cuing to determine shift times for both types of attention. In experiment 1, we first endogenously cue a clock with a central arrow. While the observer attends that clock, on some trials we cue the same clock exogenously to evaluate 'baseline' processing time, and on other trials we exogenously cue another clock at a variable distance (1, 2 or 5 clocks away) to determine the shift time for exogenous attention. Similarly in experiment 2, we exogenously cue one clock and ask observers to either report the observed time (baseline), or (in other blocks) endogenously shift their attention to another clock at a variable distance from the cued clock to determine the shift time for endogenous attention. In agreement with previous studies, our results reveal that endogenous attention is much slower than exogenous attention (endogenous: 250-350 ms; exogenous: 100-150 ms). Surprisingly, the dependence of shift time on distance was minimal for exogenous attention, whereas it was several times higher for endogenous attention. This qualitative difference suggests distinct neural mechanisms for the two modes of attention.

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52.22, *11:15 am*

Reward Driven Prioritization Modulates Object-based Attention in Human Visual Cortex

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Most of the recent evidence suggests that stimuli that are rewarded strongly attract visual attention and consequently modulate neural activity in the visual cortex. This raises a possibility that reward and attentional systems in the brain are greatly interconnected. However, to date, control mechanisms of attentional and reward systems have been investigated independently, and the nature of this relationship remains poorly understood. To investigate the neural mechanisms of reward and attention, using event-related fMRI, we employed a variant of the Egly, Driver and Rafal paradigm complemented with three different monetary reward schedules: (i) reward delivered randomly to either the same- or different-object target; (ii) higher reward delivered to the same-object target; and (iii) higher reward delivered to the different-object target. Since the exact same visual stimuli are presented in all three experiments, any differences in neural activity can only be attributed to the reward manipulation. It was observed that reward schedule exclusively modulated activation in the early visual areas. BOLD response was enhanced for the same-object location as compared to the different-object location when reward schedule was biased toward the same-object location (same as the traditional object-based effect). On the contrary, reward schedule biased toward the different-object location reversed the traditional object-based effect, exhibiting enhanced BOLD activation for the different-object location as compared to the same-object location. Behavioral results also supported the reward-based modulation effect, as evidenced by faster RTs for object locations with higher reward, independently of whether such location was in the same- or different-object. Importantly, the magnitude of the object-based effect was not modulated by reward schedule differentially (neither behaviorally nor in BOLD response). These results indicate that reward priority exclusively guides attention, and suggest the possibility that the control mechanisms of reward and attentional systems in the brain are interdependent.

52.23, *11:30 am*

Probing the distribution of attention to targets and distractors in multiple object tracking

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How is attention allocated during multiple object tracking (MOT)? In previous research, we have demonstrated a significant enhancement of the anterior N1 component (150ms post-stimulus) for task-irrelevant probes on targets relative to distractors (Drew et al. 2009). We argued that this reflects attentional enhancement for targets during MOT. Here we use this ERP component to study how attentional allocation responds to various tracking challenges. In Experiment 1, observers tracked 2 targets among 2, 4, or 6 distractors. The anterior N1 amplitude to targets increased relative to distractors as distractor load increased. In Experiment 2, observers tracked 2, 3, or 4 targets among 6 distractors. Here the target-distractor ampli-

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tude difference decreased as target load increased. Note that both of these manipulations vary the density of the display, yet the attentional system responds differently depending on whether additional items are targets or distractors. Increased distractor load leads to increased attentional focus on targets, while increased target load tends to reduce this focus. We suggest that the first effect reflects a strategic decision to increase the attentional allocation to targets faced with greater threat from distractors. In contrast, the second effect presumably reflects failures of attention as attention is spread more thinly across targets. These results suggest that during multiple object tracking attention is focused more tightly on targets as spacing decreases, but this strategy is inhibited by increased target load. Thus the attentional system responds flexibly and intelligently to protect targets from distractor interference.

Acknowledgement: NIMH

52.24, *11:45 am*

Object attention sharpens the tuning of the perceptual template and interacts with task precision

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The identification of two attributes of a single object exceeds the identification of the same attributes, one in each of two objects. If focusing attention on one object narrows the tuning of the perceptual template, the effect should be magnified when the similarity of the alternatives fall on the rapidly changing portion of the template where performance is most sensitive to changes tuning. Recent results suggest that attention effects depend on discrimination precision. The goal of the current project was to extend the taxonomy of attention by quantitatively examining the interaction between focusing attention and judgment precision. Observers made moderately precise judgments of the orientation (±10°) and phase (center light/dark) of one Gabor object or the orientation of one and the phase of another in six levels of external noise. The objects appeared at 7 deg eccentricity left and right of fixation. The family of contrast psychometric functions in different external noises showed object attention effects at all contrasts, with a magnitude that varied considerably across observers. An elaborated perceptual template model, the ePTM (Jeon, Lu, & Dosher, 2009), that deals with non-orthogonal stimuli, accounts for the full family of contrast psychometric functions in both single-object and dual-object conditions for these moderately precise discriminations, providing a direct test of template sharpening. The ePTM framework provides a systematic account of object attention and the joint effects of external noise, contrast, and orientation difference, with object attention resulting in narrower tuning and therefore higher asymptotic performance across external noise levels and a reduced effect of external noise, as suggested by (Liu, Dosher, & Lu, 2009) . Object attention affects the tuning of the template and excludes external noise with its impact dependent upon judgment precision. The attention-precision framework provides an explanation of variation in the magnitude of attention effects in different tasks.

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52.25, *12:00 pm*

Predictability matters for multiple object tracking

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Most accounts of multiple object tracking (MOT) suggest that only the spatial arrangement of objects at any one time is important for explaining performance. In contrast, we argue that observers predict future target positions. Previously this proposition was tested by studying the recovery of targets after a period of invisibility (Fencsik, Klieger, & Horowitz, 2007; Keane & Pylyshyn, 2006). Here, we test the predictive hypothesis in a continuous tracking paradigm.

In two experiments, we asked observers to track three out of twelve moving disks for three to six seconds, and varied the average turn angle. We held speed constant at 8°/s, but direction for each disk changed with probability .025 on each 13.33 ms frame. Observers marked all targets at the end of the trial. Experiment 1 used turn angles of 0°, 30°, and 90°, while Experiment 2 used 0°, 15°, 30°, 45°, 60°, 75°, and 90°. Turn angle was fixed for all objects within a trial but varied across trials. In both experiments, accuracy was maximal at 0° and declined as turn angle increased (Exp 1: p = .001; Exp 2: p = .001). In Experiment 2, the steepest decline in accuracy was from 0° to 30°, while accuracy was roughly constant from 45° to 90°.

These data demonstrate that it is easier to track predictably moving targets. Since velocity, density, and other factors known to affect MOT performance were constant, this suggests that observers predict target motion online to improve tracking. Furthermore, the pattern of data in Experiment 2 is compatible with a model in which the visual system assumes that target trajectories will vary only within a narrow 30° band.

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52.26, *12:15 pm*

Splitting attention over multiple objects

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We often need to deal with multiple objects at once, when we monitor for changes in a set of objects, compare the features or locations of multiple objects, or store the appearances of objects in memory. In some tasks, juggling multiple objects might require sequential processing, while in others it may be possible to draw information from multiple objects simultaneously. In a series of experiments using both static and moving objects, we explore the underlying mechanism and limits of selecting multiple objects. First, we show that simultaneous selection can occur. Participants were asked to mentally mark a set of locations in an array that would contain a search target, and task accuracy suggested that they could search exclusively through those locations in a later display. But when the search task was made more difficult by making targets more featurally similar to distractors, fewer locations could be marked. This result suggests that marking locations entails encoding information from those locations (Awh & Jonides, 2001), and that tougher searches require selecting fewer locations, which cannot be recovered. Second, we show that multiple locations are not encoded as a constellation that relies on shape memory. Participants searched through several marked locations, and performance was not impaired by adding a shape memory dual task. A control task showed that adding an identical dual task to a single shape memory task did impair performance, suggesting that marking does not rely on shape memory. A third set of experiments using multiple object tracking tasks suggests that once objects are selected, they can move and selection can be maintained with no additional cost. Finally, we argue that in both location marking and multiple object tracking tasks the key performance and capacity-limiting factor is the spacing among objects.

52.27, *12:30 pm*

Chasing vs. Stalking: Interrupting the Perception of Animacy

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Visual experience involves not only physical features such as color and shape, but also higher-level properties such as animacy and goal-directed behavior. Perceiving animacy is an inherently dynamic experience, in part because agents' goals and mental states may be constantly in flux -- unlike many of their physical properties. How does the visual system maintain and update representations of agents' goal-directed behavior over time and motion? The present study explored this question in the context of a particularly salient form of perceived animacy: chasing, in which one shape (the 'wolf') pursues another shape (the 'sheep'). The participants themselves controlled the movements of the sheep, and the perception of chasing was assessed in terms of their ability to avoid being caught by the wolf -- which looked identical to many moving distractors, and so could be identified only by its motion. In these experiments the wolf's pursuit was periodically interrupted by short intervals in which it did not chase the sheep. When the wolf moved randomly during these interruptions, the detection of chasing was greatly impaired. This could be for two reasons: decreased evidence in favor of chasing, or increased evidence against chasing. These interpretations were tested by having the wolf simply remain static (or jiggle in place) during the interruptions (among distractors that behaved similarly). In these cases chasing detection was unimpaired, supporting the 'evidence against chasing' model. Moreover, random-motion interruptions only impaired chasing detection when they were grouped into fewer temporally extended chunks rather than being dispersed into a greater number of shorter intervals. These results reveal (1) how perceived animacy is

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determined by the character and temporal grouping (rather than just the brute amount) of 'pursuit' over time; and (2) how these temporal dynamics can lead the visual system to either construct or actively reject interpretations of chasing.

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Tuesday Morning Posters

Memory: Objects and features in working and short-term memory

Royal Ballroom 6-8, Boards 301–316

Tuesday, May 11, 8:30 - 12:30 pm

53.301 Dual Memory Systems Store Direction of Motion Information for Multiple Moving Objects

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Purpose: The ability to establish and maintain the identities of moving objects is essential to behavioral success, yet very little is known about the underlying mechanisms. The multiple-object tracking experimental paradigm (MOT-EP) has been used extensively for studying how attention, position and motion cues contribute to this task. Among the unresolved issues are the relative importance of motion information and the role of various memory mechanisms. We sought to quantify the capacity and the temporal dynamics of the memory systems involved in storing direction-of-motion information when viewing a multiple-object motion stimulus. Methods: Observers viewed three to nine objects in random linear motion and reported motion direction of a cued object after motion ended. In three experiments, we (1) measured performance as a function of set-size, (2) characterized the temporal dynamics of memory using seven cue delays ranging from 0ms to 3s, and (3) examined interactions between the dynamics of memory and the read-out processes by comparing performance with partial and full report. Results: Direction reports show a graded deterioration in performance with increased set size. This lends support to a flexible-capacity theory of MOT-EP. Temporal dynamics of memory follows an exponential function that decays within 1s to a steady-state plateau above chance performance. This outcome indicates the existence of two complementary memory systems, one transient with high-capacity and a second sustained with low-capacity. For the transient high-capacity memory, retention capacity was equally high whether object motion lasted 5s or 200ms. We found a significant partial-report advantage, which provides further support for a rapidly decaying high-capacity memory. Conclusions: Our results show that dual memory systems store direction of motion information for multiple moving objects. This finding provides a possible reconciliation to seemingly contradictory results previously published in the literature.

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53.302 Feature coactivation in object file reviewing: Response time distribution analyses

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Object file studies using object reviewing paradigm revealed that object features can be accessed through addressing their spatiotemporal locations. In the divided attention literature, evidence for coactivation of different features has been reported using redundant signals paradigm. These two lines of research lead to a question whether object files play significant roles in integrating features, which remains unsolved because evaluation of feature coactivation requires response time (RT) distribution analysis, never done with object reviewing paradigm. The current study conducted RT distribution analyses with a new task combining object reviewing and redundant signals paradigms. Observers saw a preview display composed of two colored boxes containing a letter, above and below the fixation, followed by a linking display. Then, they saw a target display with a single object, and judged whether the target contains color or shape of preview objects as quickly as possible. For match trials, features are either at the same-object (SO) or different-object (DO) as in the reviewing paradigm. Type of match was color, shape, or color-and-shape (object) as in the redundant signal paradigm. In the object condition, the mixed condition combining one SO and one DO features was also included. Mean RT revealed significant redundancy gain in both SO and DO conditions, and object-specific preview benefit in all match type conditions except for the color condition. Race model inequality test using RT distribution showed evidence for feature coactivation in SO and DO conditions with similar magnitudes, not supporting the idea that feature coactivation is modulated by access to an object file. Further analysis with ex-Gaussian distribution for color-shape conditions revealed that faster and slower RT components were modulated by match of single feature, and of feature combination, respectively, suggesting that object file reviewing is feature-based, but response selection is sensitive to feature combinations.

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53.303 Dual processes in the recognition of objects in visual working memory

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Empirical evidence has suggested two independent retrieval processes, intentional recollection and automatic process based on familiarity, operate in retrieving long-term memory. Yonelinas (1994) and Wixted (2007) proposed different models describing the relationship between recollection and familiarity: the dual process signal detection (DPSD) model and the unequal variance signal detection (UVSD) model. The major difference between these two models is the purity of processes. In the DPSD model, recollection and familiarity do not contribute to a single retrieval performance. In contrast, UVSD model suggests that the two processes are simultaneously used while retrieving. The phenomenon change blindness has revealed that the visual information around us is not always encoded or functional available. Thus, the change detection paradigm has been widely used as an indirect method to measure whether visual information is functional available in visual working memory. Previous studies have shown that recognition of pre-change objects is worse than recognition of a post-change object (Beck & Levin, 2003; Mitroff, Simons, & Levin, 2004). However, the memory retrieval process underlying change detection, or visual working memory, has not yet been exhaustively discussed. In this study, we investigated different retrieval processes involved in recognizing a pre-change object after change detection and the purity of processes in the retrieval process. We adopted a Bayesian analysis to estimate the proportion of each process involved in recognition under successful and failed change detection. Our results showed that the UVSD model provides a better fit than the DPSD, suggesting the simultaneity of two processes in retrieving visual working memory. Moreover, the mean parameter value of recollection was higher under successful detection than detection failure. In contrast, there was no difference in familiarity between successful and failed change detection. Recollection is involved in successful change detection.

53.304 Spatio-Temporal Working Memory is Impaired by Multiple Object Tracking

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Our previous study (Zhang, Xuan, Fu, & Pylyshyn, in press) showed that object-location working memory (WM) was impaired by a secondary multiple object tracking (MOT) task but non-spatial visual WM could survive the MOT task. Thus there might be no competition between perceptual objects selected and objects maintained in visual WM. Considering that spatio-temporal WM and short-term object-location tasks might use different memory mechanisms (Zimmer, Speiser, & Seidler, 2003), competition of perception and attention system was examined by looking at the dual-task interference between a spatio-temporal WM task (Corsi Block Task, CBT) and a secondary MOT task in the present study. In Experiment 1, CBT performance was shown to be impaired by the secondary MOT task, while passively viewing the MOT scene but tracking none of the objects did not result in any damage to the CBT performance. In Experiment 2, we found

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that tracking per se could be harmful to the spatio-temporal WM. In Experiment 3, results showed that tracking more targets or tracking in higher speed caused more impairment to the spatio-temporal WM. In experiment 4, low spatio-temporal WM load (2 or 3 locations) was also showed to be impaired by the MOT task. In sum, spatio-temporal WM seemed to be vulnerable to a secondary MOT task. In a CBT task, to remember a temporal location sequence needs to shift spatial attention between these locations in rehearsal and impairment will be present when interrupted by tracking. Furthermore, in all experiments, MOT performance was shown to be not impaired by the spatio-temporal WM load, indicating that perceptual system has a priority in accessing limited resource over memory system.

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53.305 **Feature binding across visual and manual domains: Evidence from a VSTM study**

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In this study, binding in visual short-term memory (VSTM) across visual and manual domains was investigated. Six human observers performed a yes-no recognition task for object appearance in three experimental conditions (fully counterbalanced) in which unfamiliar, nonverbal 1/f noise discs served as stimuli. In the memory display, four stimuli (each subtending 2 deg) were presented sequentially (each for 850ms) at random spatial positions. Following a 1000ms blank interval, a test stimulus was presented. In condition 1, observers executed hand movements (spatial tapping) during the memory display by touching a pointer on a graphics tablet at a position corresponding to the screen coordinate of each stimulus as it appeared. The test stimulus was presented at one of the coordinates used in the preceding memory display. Condition 2 was identical to condition 1, except that spatial tapping was not performed. In condition 3, both memory and test stimuli were presented at (different) random coordinates; observers performed spatial tapping during the memory display (like condition 1), except that the positions of test stimuli did not correspond to preceding hand/screen positions. In all three experimental conditions, the cursor was invisible. Observers completed a training session in which the cursor was visible to associate graphics tablet coordinates with screen coordinates. Performance, measured in d', was significantly greater in condition 1 than in conditions 2 [$F(1,5)=20.35$, $p<0.01$] and 3 [$F(1,5)=10.14$, $p=0.02$]. Performance was not significantly different between conditions 2 and 3 [$F(1,5)=4.54$, $p=0.09$]. These findings suggest that a spatially correlated manual action facilitates VSTM, providing evidence that perception and action bind across representational domains to associate relevant stimulus properties, consistent with event file theory (Hommel, 1998; 2004). Furthermore, given that our stimuli are unlikely to accrue VLTM support, these findings support the notion that visuo-manual binding occurs even where semantic and associative VLTM cues are minimized.

53.306 **Feature-based versus Object-based forgetting in Visual Working Memory**

Akina Umemoto[1](akumemoto@gmail.com), Edward Awh[1]; [1]Department of Psychology, University of Oregon

The bilateral advantage refers to a phenomenon in which performance is enhanced for visual information that is processed from both visual hemifields rather than a single hemifield. Alvarez and Cavanagh (2005) provided a compelling demonstration of the bilateral advantage in a multiple object tracking task in which there was an apparent doubling of capacity when items were tracked bilaterally instead of unilaterally, suggesting independent resources for tracking in the two hemispheres. We reported last year that working memory (WM) for orientations also showed a reliable bilateral advantage. We are aware, however, of several studies that have failed to find a bilateral advantage for color WM, consistent with claims that the effect may relate to the efficiency of spatial selection per se (e.g., Alvarez and Cavanagh, 2005; Delvenne, 2005). To provide a rigorous comparison of how the bilateral presentations affect orientation and color WM, we measured the effect in a within-subject design in which subjects stored one of the two features, or both features from the same set of stimuli. Preliminary results suggest a selective bilateral advantage for orientation. The results will be discussed in the context of feature-based versus object-based models of forgetting in visual WM.

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53.307 **Using eye movements to measure attention to objects and features in visual working memory**

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Theories have proposed that attention is used to maintain feature bindings in visual working memory. Previously, we showed that people overtly shift gaze to the locations of objects held in visual working memory to aid maintenance. To test the hypothesis that the primary role of such overt attentional selection during working memory retention is to maintain the bindings of object features we compared eye movement behavior in two conditions. In the conjunction condition, we tracked subjects' eye movements while they were required to remember the shape and color of one, three, or six objects to perform a change-detection task. In the color-only condition, subjects remembered just the color of single-feature objects. If spatial attention mechanisms are primarily used to maintain feature bindings and not features themselves, then we should observe significantly more fixations of the locations of conjunction objects compared to color-only memory items. However, the pattern of eye movements we observed during the retention intervals was similar across conditions. That is, observers fixated the locations of the objects whether they were remembering one feature or a conjunction of features and fixating an item during the retention interval that then changed improved change-detection accuracy. These findings suggest that spatial selection mechanisms operating during visual working memory tasks aid maintenance of both simple features and more complex object representations.

53.308 **Attention is not required to maintain feature bindings in visual working memory**

Amanda van Lamsweerde[1](avanla1@lsu.edu), Melissa Beck[1]; [1]Psychology Department, Louisiana State University

Attention plays an important role in the perception of accurate feature bindings. However, it is not clear whether continued attention is needed to maintain feature bindings in VWM. Although some research shows that changes to feature bindings are more difficult to detect than changes to individual features, additional research has shown that some attention-demanding tasks do not disrupt binding memory more than single feature memory. Experiment 1 tested the role of attention in feature binding maintenance by replicating the finding that feature bindings are more difficult to remember than individual features in a whole report change detection task (Wheeler & Treisman, 2002), suggesting that attention is important for maintaining feature bindings. However, Experiment 2 directly measured shifts of attention through eye tracking and manipulated whether a change occurred to an object within the focus of attention, a previously attended object, or an unattended object. The results suggest that attention is not required to maintain feature bindings. Therefore, while feature bindings may be more difficult to remember than individual features in some instances, attention is not required to maintain feature bindings in VWM.

53.309 **Visual working memory for multiple feature changes: evidence from synaesthesia**

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Our visual working memory is used to hold information about the environment relevant to our current goals. In grapheme-colour synaesthesia, people have an involuntary experience of colour when they see a letter. Thus, for synaesthetes, a letter identity change should also induce a change in the synaesthetic colour. We tested whether this additional information affected performance on a change-detection task that depends on visual working memory. Synaesthetes and matched controls viewed two sequential displays with 4 or 8 items. In separate blocks the items were white letters, white non-letters, coloured letters, or coloured non-letters. On 50% of trials there was a change in one item between the displays, and on the other 50% of trials the displays were identical. In the white conditions, the identity of one item changed (e.g., from one white letter to another).

In the coloured conditions, the identity and colour of one item changed. Synaesthetes showed superior performance to controls in the white letter condition at the smaller setsize, where their accuracy was equivalent to the coloured letter condition. In the non-letter condition, where no synaesthetic colours were elicited, performance did not differ between the groups, ruling out a baseline difference in change-detection ability. Thus, synaesthetic colours can act as an additional cue to the presence of a change, akin to a real colour change.

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53.310 **Strategic Control of Visual Working Memory for Global and Local Features**

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Previous studies have demonstrated a bias to focus on global over local features in both visual attention and visual working memory. In two new studies, we created novel stimuli too complex to be remembered in every detail. We examined the effect of the varying presentation delays of post-stimulus instructions that directed participants to focus on global or local features. We predicted that instructions to focus on specific features would reduce working memory load, but at the cost of diminishing memory for other features of the stimulus. In study 1, participants viewed polygons made up of twenty lines which were grouped into four colors. The polygons were displayed for 1 sec, followed by a 0-4 sec delay. Next, instructions were given to focus on either a part (1/4 of the polygon), an object (1/2 of the polygon), or the whole polygon. After another 0-4 sec delay, participants selected between four images, only one of which matched the initial stimulus. Consistent with our previous research, instructions increased accuracy. However, instructions also influenced error types. Participants who had been instructed to focus on global features erroneously selected lures with a large change to only one part. Participants who had been instructed to focus on object-level properties erroneously selected lures with small changes to every part, yet kept the original global shape. In the second study, participants viewed Navon figures made up of polygons instead of letters. Lures contained either global changes, local changes, or both global and local changes. Instructions guided participants to focus on each of these levels. The presence of instructions lead to a decrease in performance if the instructions were shown immediately after the stimulus, indicating that visual information must be consolidated within working memory before strategic control of focus can occur.

53.311 **The time course of consolidation of ensemble feature in visual working memory**

Hee Yeon Im[1](heeyeon.im@jhu.edu), Justin Halberda[1]; [1]Johns Hopkins University

Collections of visual objects can be grouped and statistical properties of the group encoded as ensemble features. It is known that ensemble features can be represented from a group of multiple items from a very brief display. In the current study, we measured the time-course of consolidation of average orientation into visual working memory and compared it to that of individual orientation. There were two separate blocks for individual orientation and ensemble orientation. For both blocks, participants performed a change-detection task for orientations of colored gratings, and shortly after the presentation of the memory array, pattern masks were presented to disrupt further consolidation (a method similar to Vogel et al, 2006). The stimulus onset asynchrony (SOA) was varied randomly from trial to trial. Half of the trials in a block included a change: either the orientation of one of the individual gratings (individual block) or the average orientation of one set of gratings (ensemble block). Participants indicated whether the two arrays were the same or different. The pattern of performance as a function of SOA for the individual block was consistent with a previous study reporting the consolidation of color for individual items (Vogel et al., 2006). Important and new, the pattern of performance as a function of SOA was identical across the individual and ensemble blocks. The rate of consolidation for the ensemble feature was comparable to that for the individual feature. This result suggests that ensemble features are extracted from an ensemble group just as an individual feature is extracted from a single object with the same rate of consolidation time required.

53.312 **Ensemble statistics influence the representation of items in visual working memory**

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Influential models of visual working memory treat each item as an independent unit and assume there are no interactions between items. However, even in displays with simple colored circles there are higher-order ensemble statistics that observers can compute quickly and accurately (e.g., Ariely, 2001). An optimal encoding strategy would take these higher-order regularities into account. We examined how a specific ensemble statistic -the mean size of a set of items- influences visual working memory. Observers were presented with 400 individual displays consisting of three red, three blue, and three green circles of varying size. The task was to remember the size of all of the red and blue circles, but to ignore the green circles (we assume that ignoring the green circles requires the target items to be selected by color, Huang, Treisman, Pashler, 2007; Halberda, Sires, Feigenson, 2006). Each display was briefly presented, then disappeared, and then a single circle reappeared in black at the location that a red or blue circle had occupied. Observers used the mouse to resize this new black circle to the size of the red or blue circle they had previously seen. We find evidence that the remembered size of each individual item is biased toward the mean size of the circles of the same color. In Experiment 2, the irrelevant green circles were removed, making it possible to select the red and blue items as a single group, and no bias towards the mean of the color set was observed. Combined, these results suggest that items in visual working memory are not represented in isolation. Instead, observers use constraints from the higher-order ensemble statistics of the set to reduce uncertainty about the size of individual items and thereby encode the items more efficiently.

53.313 **Complexity and similarity in visual memory**

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Retaining information in an active and accessible state over the short-term is critical for any cognitive activity. It has been estimated that immediate visual memory (also known as short-term memory or working memory) can maintain only about four objects simultaneously. However, the basic determinants of this capacity limit remain a matter of debate. For example, whether capacity is reduced as object complexity increases is yet unresolved. On the other hand, many researchers agree that in change detection tasks – which are widely used to investigate capacity limits of immediate memory – similarity between the memory and the test items (memory-test similarity) negatively affects change detection performance. In contrast, similarity between memory items (memory-array similarity) has been shown recently to benefit performance, at least for simple objects. In the present study, similarity continua were used to manipulate memory-test and memory-array similarity for both simple and complex objects, in order to thoroughly examine the impact of complexity and memory-array similarity on the retention of information in memory. Results show that the number of memory representations is fixed across object complexity, but that their resolution (or precision) decreases as complexity increases. In contrast, memory-array similarity increases mnemonic resolution, an increase that even compensates for the deleterious effect of complexity.

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53.314 **The effect of grouping on visual working memory**

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The purpose of our study was to investigate the effect of grouping on visual working memory using a change-detection task. In Experiment 1, we presented the sample display with either 2, 4 or 6 colored circles for 100 ms, followed by a blank period of 900 ms, and the test display until response. Two circles were connected by a line in the grouped condition while a line was merely presented between two circles without connection in the non-grouped condition. Participants' task was to detect the color change between the sample and the test display. The color was changed only for one circle and for the 50% of trials. To report changes, participants had to press the left mouse button and indicate the location of the change. They reported no change by pressing the right mouse button. When we calculated

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the correctness in detection of color changes regardless of the correctness in locations, performance in the grouped condition did not significantly differ from the non-grouped condition. However, when we computed the correctness based on both color changes and locations, performance in the non-grouped condition was significantly better than in the grouped condition. If the visual system treated a grouped item as an object, changes in the grouped condition would have been less salient because only part of the object changed its color in this condition. We tested this hypothesis in Experiment 2. The potential location of changes was designated by presenting only one pair (grouped or non-grouped) at test display. When participants knew the potential location of changes, their performance in the grouped condition did not significantly differ from that in the non-grouped condition. Our findings suggested that grouped items were treated as objects in visual working memory and this grouping effect paradoxically caused the reduction of working memory capacity.

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53.315 **Don't stop remembering: Motivational effects on visual short-term memory maintenance**

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Although it has been shown that motivation (e.g. monetary incentive) can enhance short-term memory capacity, little is known about how and where this effect occurs. Recent progress in visual short-term memory (VSTM) research suggests at least two major possibilities (Awh et al., 2006). That is, (1) motivation facilitates attentional gating at VSTM encoding, and/or (2) motivation supports VSTM maintenance by keeping sustained attention active. Previous studies, however, have failed to distinguish these two, since they manipulated motivational factors before encoding, and therefore possibly modulated the two processes simultaneously. Thus, the goal of the current study was to unravel this confound and examine the plausibility of the second account in particular. A VSTM task (Vogel & Machizawa, 2004) was combined with retro-cueing paradigm (e.g. Lepsien & Nobre, 2006). In each trial, monetary incentive cues appeared during 1,000 ms retention period (500 ms after memory array) as two pure tones that differed in frequency, which indicated high and low rewards that participants could obtain in that trial, if they answered correctly. In order to prevent random response especially in low motivation condition, we assigned negative reward (punishment) for incorrect answer in both conditions. Results showed that the VSTM performance (percentage of correct answers) was significantly facilitated in high reward condition than the other, providing the first evidence that motivation can affect VSTM maintenance directly. Possible neural bases for this effect will be discussed with the data from a follow-up ERP study.

53.316 **The role of attention in working memory for emotional faces**

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Face identities are better remembered in working memory (WM) when faces are angry versus happy or neutral (Jackson et al., 2009: JEPHPP, vol 35). This 'angry benefit' correlates specifically with activity in the globus pallidus (Jackson et al, 2008: PLoS One, vol 3), part of the basal ganglia that has been suggested to act as an attentional filter allowing only relevant information into WM. This finding is broadly consistent with evidence that threatening faces capture attention more efficiently than non-threatening faces. Could the angry face benefit in WM be due to greater attentional capture by angry versus happy/neutral faces? To investigate this, we presented a single emotional face (angry or happy) among one or three neutral faces in a WM encoding display. In other (non-singleton) conditions, all faces shared the same expression (as in the original studies). WM for face identity was tested 1000ms later by asking whether a single probe face was 'present' or 'absent' in the encoding display. WM was probed for emotional singletons and neutral others. If angry faces capture attention better than happy faces, enhanced WM for angry versus happy singletons, and poorer WM for neutral others when accompanied by an angry versus happy singleton, is expected. However, we found non-significant WM differences in these condition comparisons, suggesting that attentional capture does not underpin the original angry face benefit. Interestingly, at high load, WM was better when an angry singleton (1 angry among 3 neutral) versus angry non-singleton (1 angry among 3 other angry) was probed, an effect not significant for happy faces. This suggests that angry but not happy singletons may be preferentially prioritised for WM selection via emotional grouping. The ability to isolate in WM an angry face from several other non-angry faces might reflect enhanced preparation to prioritize a threat response if required.

Perceptual learning: Mechanisms and models

Royal Ballroom 6-8, Boards 317–331

Tuesday, May 11, 8:30 - 12:30 pm

53.317 **Greater focused attention to a task target leads to stronger task-irrelevant learning**

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Mere exposure to task-irrelevant coherent motion leads to performance improvement on the motion (Watanabe et al, 2001). The underlying mechanism for such task-irrelevant perceptual learning (TIPL) has yet to be clarified. TIPL could arise as a result of distraction from a central task or attentional leakage from location of a task target. We tested whether any of these possibilities is true. In Experiment 1, hierarchical letters (Navon, 1977) were presented at the center of a display. Participants (n=4) were asked to recognize either large compound or small component letters in a block design. A task-irrelevant 5% coherent motion display was presented in a periphery. Given a fixed high contrast, small (harder) letters induced stronger TIPL than large (easier) letters. In Experiment 2 (n=8), only small letters were used as targets for recognition, with two letter contrasts alternating across blocks. Given a fixed scale of task targets, low-contrast (harder) letters induced stronger TIPL than high-contrast (easier) letters. In Experiment 3 (n=9), the task was to recognize regular letters at the center, in large or small size, again using a block design. Given a fixed task difficulty controlled by the staircase method throughout training, small letters did not induce weaker TIPL than large letters. In all the experiments training lasted five days. Given that with a harder task, the degree of involvement of focused attention is greater and the attentional window size is smaller toward the task targets (e.g., Ikeda & Takeuchi, 1975; Rees et al., 1997; Yi et al., 2004), our results cannot be explained by the mere involvement of the traditional focused attention concept in task-irrelevant processing. The results are rather in accordance with the model in which a harder task at a central field more greatly boosts signals outside a window of focused attention and leads to greater TIPL.

Acknowledgement: This work is supported by NIH-NEI R21 EY018925, R01 EY015980-04A2, and R01 EY019466.

53.318 **Different properties between reward-driven exposure-based and reward-driven task involved perceptual learning**

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It has been found that sensitivity to a visual feature is enhanced when the feature is repeatedly paired with reward (Seitz, Kim & Watanabe, 2009, Neuron). We call this type of learning reward-driven exposure-based perceptual learning (REPL). In a previous study (Kim, Seitz, Watanabe, 2008, VSS), we presented three different orientations (60 deg separated from each other) which were followed by reward at the probabilities of 80% (positive contingency), 50% (zero-contingency) and 20% (negative contingency), respectively. We found significant performance improvement for both the positive-contingency orientation and zero-contingency orientation, but no significant improvement for the negative-contingency orientation. Given that PL occurs not only as a result of exposure (Watanabe, Sasaki and Nanez, 2001) but also of task-involvements (Fahle & Poggio, 2002), a question arises as to whether reward-driven task-involvement PL (RTPL) occurs in the same way as REPL. To address this question, in the present study, we trained a new group of four subjects with an operant conditioning procedure in which subjects performed an orientation discrimination task, and the reward was given only when the subject answered correctly. To compare these results with REPL, we conducted sensitivity tests before and after operant training. After training, we found significant performance improvement only for the positive contingency orientation. These results suggest that the mechanisms underlying REPL and RTPL are different. One possible model is that when subjects were trained with the

RTPL procedure, the learning of 50% reward probability was inhibited by an attentional signal, whereas this inhibition did not occur when they were trained with the REPL procedure.

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53.319 **Visual Learning with Reliable and Unreliable Features**

Robert Jacobs[1](robbie@bcs.rochester.edu), A. Emin Orhan[1], Melchi Michel[2]; [1]Center for Visual Science, University of Rochester, [2]Center for Perceptual Systems, University of Texas at Austin

Previous studies on sensory integration showed that people weight information based on a sensory cue or feature proportional to that feature's reliability. However, these studies tell us little about the implications of feature reliability for perceptual learning. Here, we address this issue in the context of perceptual learning of binary classification tasks. We develop a Bayesian model that, unlike previous models, allows us to compute not just point estimates, but complete distributions over the weights associated with different features (via Markov chain Monte Carlo sampling of the weights of a logistic regressor). Using the model, we develop ideal observers for a simple two-dimensional binary classification task and for a binary pattern discrimination task that was used in Experiment 2 of Michel and Jacobs (2008). We find that the statistical information provided by the stimuli and corresponding class labels on a finite number of training trials strongly constrains the possible weight values associated with unreliable features, but only weakly constrains the weight values associated with reliable features. To test whether human observers are sensitive to these properties of the task environment, we apply the model to a human subject's experimental data (the stimuli that the subject saw and the subject's responses). We find that the subject was indeed sensitive to this statistical information. Additional analyses indicate that subjects showed sub-optimal learning performances because they tended to underestimate the magnitude of weights associated with reliable features. A possible explanation for this result is that people performing this task might be regularized learners with a strong bias toward small weight values. Alternatively, it may be that people are engaging in exploration of the weight space, rather than exploiting their potentially near-optimal knowledge regarding the weight values associated with visual features.

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53.320 **Brain plasticity associated with supervised and unsupervised learning in a coherent-motion detection task**

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We investigated the role of trial-by-trial feedback during training on the neural correlates of perceptual learning in a coherent-motion detection paradigm. Stimuli were four patches of randomly moving dots were presented simultaneously, one in each visual quadrant. Over six training sessions (with a total of 5340 trials per observer) subjects learned to detect coherent motion in a predefined quadrant. During training, half of our subjects received feedback after each response, indicating whether they were correct or incorrect on that trial, whereas the other subjects did not get feedback. We investigated whether the presence of feedback during training had an effect on learning success (performance, reactions times) and on the resultant BOLD response to motion stimuli presented within the trained quadrant (measured in three separate sessions). Behavioral data of 4 subjects showed improved performance with increasing practice. Feedback led a significant benefit in performance and to lower reactions times. After training with feedback, subjects exhibited bilateral BOLD responses in hMT+ that first increased (from session 1 to 2) and then decreased (from session 2 to 3). Without feedback during training the BOLD signal in hMT+ was reduced and showed a shallower, monotonic learning curve. These results point to a learning-specific alteration in the activity of MT neurons that selectively respond to coherent-motion stimuli. Trial-by-trial feedback enhanced performance and led to a different time course of the BOLD response over training.

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53.321 **Category Learning Produces the Atypicality Bias in Object Perception**

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When a morph face is produced with equal physical contributions from a typical parent face and an atypical parent face, the morph is judged to be more similar to the atypical parent. This discontinuity between physical and perceptual distance relationships, called the "atypicality bias" (Tanaka, Giles, Kremen, & Simon, 1998), has also been demonstrated with the object classes of birds and cars (Tanaka & Corneille, 2007). The present work tested the hypothesis that the atypicality bias is not a product of static physical properties of typical or atypical exemplars, but emerges only after the category structure of a given stimulus domain (and thus the nature of its typical members) has been learned. Participants were trained to discriminate between two categories of novel shape stimuli ("blobs") with which they had no pre-experimental familiarity. Although typical and atypical blob exemplars appeared with equal frequency during category training, the typical blobs within a given family were structurally similar to one another, whereas the atypical blobs were dissimilar to each other and to the typical exemplars. The magnitude of the atypicality bias was assessed in a preference task administered pre- and post-training. The blobs elicited no bias prior to category training, but, as predicted, elicited a significant atypicality bias after training. This change in object perception with category learning is considered from the standpoint of theories that represent item similarities in terms of the relative locations of items in a multi-dimensional space. We propose that category learning alters the dimensions of the space, effectively increasing the perceptual distance between the morph and its typical parent, with the result that the morph appears more similar to its atypical parent than to its typical parent.

53.322 **Cholinergic enhancement augments the magnitude and specificity of perceptual learning in the human visual system: a pharmacological fMRI study**

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The neurotransmitter acetylcholine (ACh) has previously been shown to play a critical role in cognitive processes such as attention and learning. In this study, we examined the role of ACh in perceptual learning (PL) of a motion direction discrimination task in human subjects. We conducted a double-blind, placebo-controlled, crossover study, in which each participant trained twice on the task, once while cholinergic neurotransmission was pharmacologically enhanced by the cholinesterase inhibitor donepezil and once while ingesting a placebo. Relative to placebo, donepezil increased the improvement in direction discrimination performance due to PL. Furthermore, PL under the influence of donepezil was more specific for the direction of motion that was discriminated during training and for the visual field locations in which training occurred. In order to study the neural mechanisms underlying these effects, we measured fMRI responses to either trained or untrained directions of motion before and after training, in both placebo and drug conditions. Spatial specificity was assessed by comparing pre- and post-training fMRI responses in portions of retinotopic cortex representing the spatial locations of trained and untrained stimuli. Direction specificity was assessed with fMRI adaptation (fMRI-A), a procedure based on the fact that when presented with a pair of stimuli in succession, neurons will typically respond more weakly to the second stimulus if they also responded to the first stimulus. Consequently, two consecutively presented stimuli will generate a smaller response if they excite overlapping populations of neurons. In each block, an adapting direction (trained or untrained) was presented, and in each trial an additional probe stimulus, which differed from the adapting direction by some angular offset, was shown. The dependence of the response amplitude on this angular offset allowed the generation of adaptation 'direction tuning curves' for motion-sensitive areas in visual cortex.

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53.323 **Learn to be fast: gain accuracy with speed**

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Our recent neurophysiological findings provided evidence for collinear facilitation in detecting low-contrast Gabor patches (GPs) and for the abolishment of these collinear interactions by backward masking (BM). It was suggested that the suppression induced by the BM eliminates the collinear

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facilitation. Moreover, our recent behavioral study showed that training on a BM task improves the processing speed. Here we applied perceptual learning on BM in a detection task that strengthens the facilitatory lateral interactions, in ten overnight sessions, in order to study whether reinforced facilitatory interactions can overcome the suppressive effects induced by BM. Event-Related Potentials (ERPs) were recorded before and after the training. Low-contrast, foveal target GP was simultaneously flanked by two collinear high-contrast GPs. In the BM task, another identical mask was presented at different time-intervals (ISIs). Before training, BM induced suppression of target detection, at the ISI of 50 ms, in agreement with earlier behavioral findings. This ISI coincides with the active time-window of lateral interactions. After training, our results show a remarkable improvement in all behavioral measurements, including percent correct, sensitivity (d'), reaction time and the decision criterion for this ISI. The ERP results show that before training, BM canceled the physiological markers of facilitation at the same ISI of 50 ms, measured as the amplitude of the negative N1 ERP peak (latency of 260 ms). After the training, the sensory representation, reflected by P1 peak, has not changed, consistent with the unchanged physical parameters of the stimulus. Instead, the shorter latency (by 20 ms, latency of 240 ms) and the increased amplitude of N1 represent the development of facilitatory lateral interactions between the target and the collinear flankers. Thus, previously effective backward masking became ineffective in disrupting the collinear facilitation. We suggest that perceptual learning that strengthens collinear facilitation results in a faster processing speed.

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53.324 **Changes in Fixation Strategy May account for a portion of Perceptual Learning observed in visual tasks**

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Perceptual learning in visual discrimination can be observed by monitoring an increase in an observer's ability to perform a certain task with practice. Perceptual learning has been previously linked to several different mechanisms that can account for the increase in an observer's ability: learning to perform the task it self (Anderson, Psychological Review, 94, 192, 1987), learning an optimal response strategy/adjusting criteria (Doane, Alderton, Sohn & Pellegrino, Journal of Experimental Psychology, 22, 1218, 1996), as well as changes in how the physical stimuli are perceived and processed by the observer (Gibson, 1969; Goldstone, Annual Review of Psychology, 49, 585, 1998). Observers can learn to visually fixate on areas of an image/stimuli that provide information necessary to complete their task, while avoiding areas that are not informative. This form of perceptual learning suggests a learned change in the observer's visual fixation strategy, an area of perceptual learning that has not been studied with visual hyperacuity paradigms. During training for visual hyperacuity discriminations based on small differences in the spatial frequency or orientation of suprathreshold sinusoidal gratings, observers had their eye fixations recorded. Results showed a change in fixation strategy for all observers as their experience increased and the difficulty of the discriminations increased. Observers varied in their fixation changes, as well as their final fixation points. There was a negative correlation between fixation variance and number of trials completed, but this value did not reach significance for most observers. These results suggest that observers modify their fixation strategy over time to optimize their performance on the discrimination task. This is somewhat contradicted by the observation that incorrect responses belong to the same distribution of eye fixations as correct responses.

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53.325 **ERP evidence for the involvement of high-level brain mechanisms in perceptual learning**

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Location specificity in perceptual learning can be eliminated through proper training procedures (Xiao et al., CurBio_08), suggesting that learning may result from training improved decision making in non-retinotopic high brain areas. This conclusion gains support from ERP recordings in this study. We trained observers with a Vernier task in the lower right visual field for six days. Pre- and post-training thresholds were compared at the trained and untrained (lower left visual field) locations. 64-channel EEG was recorded pre-/post-training at the trained and untrained locations for Vernier offsets either near the pre-training threshold (5') or sub-threshold (2.8').

Our results show that (1) Vernier learning was specific to the trained location in most observers but transferred significantly in the remaining observers. (2) The frontal P2 (210~270ms), which may be related to decision making, had shorter latency and smaller amplitude after training for all observers showing or not showing location specificity at both locations. (3) The posterior N1 (160ms-200ms), which may be related to spatial attention, increased significantly after training at the trained location but decreased at the untrained location in observers showing location specificity. However, posterior N1 increased significantly at both trained and untrained locations for observers who showed significant learning transfer. (4) The EEG differences were similar at Vernier offsets either near pre-training threshold, which became supra-threshold post-training, or sub-threshold, which became near-threshold post-training.

The ERP evidence is consistent with our rule-learning based perceptual learning model, in which a decision unit in the high-level brain learns the rules of reweighing the V1 inputs (better decision making). Such reweighing rules are unspecific to stimulus locations. However, learned rules can only apply to a new location if the brain can attend to the V1 inputs at the new location properly. The latter can be accomplished through location training.

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53.326 **Increases in perceptual capacity as a function of perceptual learning: behavioral regularities and possible neural mechanisms**

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Standard indicators of the acquisition of visual perceptual expertise include systematic reductions in detection and identification thresholds, along with decreases in mean response times (RTs). One additional regularity documented in recent work has to do with changes in the ability to adapt to variations in perceptual workload, characterized as perceptual capacity, and measured at the level of the hazard function of the RT distribution. The present effort tests the potential of a computational modeling approach capable of accounting for these behavioral results, while simultaneously predicting patterns of scalp-level EEG. The approach is intended to allow for the representation of multiple competing hypotheses for the neural mechanisms responsible for these observable variables (i.e., placing the alternative hypotheses on a "level playing field"), and for the ability to systematically relate these hypotheses to formal models for perceptual behavior. The neural modeling approach uses populations of discrete-time integrate-and-fire neurons, connected as networks. The architecture is based on the known circuitry of early visual areas as well as known connectivity into and out of early visual areas. The architecture is shown to be capable of instantiating a set of prominent competing hypotheses for neural mechanisms (Gilbert, Sigman, & Crist, 2001): changes in cortical recruitment, sharpening of feature-specific tuning curves, changes in synaptic weightings, changes in within-region synchrony, and changes in across-region coherence, in both feed-forward and feed-back relations. In addition, it is shown that under reasonable simplifying assumptions, the models are also capable of making predictions for both observable response behavior and scalp-level EEG. We present data from an initial empirical test of these predictions, suggesting that changes in measures of synchrony across and within sensor regions best account for the prominent increases in perceptual capacity that accrue with the acquisition of perceptual expertise.

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53.327 **Local Perceptual Learning for Motion Pattern Discrimination: a Neural Model**

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Problem. Perceptual learning increases the performance of motion pattern discrimination (Nishina et al., J.of Vision 2009). The results suggest that local, not global learning mechanisms gained the improvement. The question remains which mechanisms of cortical motion processing are involved and how neural mechanisms of learning can account for this achievement.

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Method. We build upon a neural model for motion and motion pattern detection that incorporates major stages of the dorsal pathway, namely areas V1, MT, and MSTd which has been extended by a stage for decision-making in area LIP. MSTd cells are sensitive to patterns of motion by integrating motion direction sensitive MT activities along the convergent feedforward signal pathway. Feedback from MSTd to MT neurons modulates their activity. The strength of connection weights between MT and MSTd neurons can be adapted by repetitive presentation of motion patterns. MSTd to MT feedback also modulates the weight adaptation process by employing a variant of Hebbian learning using Oja's rule (J.Math.Biology 1982). As a consequence MT cell tuning changes and in turn improves the discrimination performance of perceived motion patterns. Results and Conclusion. Model simulations quantitatively replicate the findings of Nishina and co-workers. Specifically, discrimination learning between target and neutral pattern improves from d'=0.075 to d'=0.113. The model predicts that the presentation of rotation patterns leads to the same performance as for the radial motion patterns. In addition, our computational simulations suggest that decision performance as well as the threshold differences for motion discrimination drop if noise is added to the visual stimulus. Our model predicts that feedback from area MSTd to MT stabilizes the learning under conditions when noise significantly impairs the coherence of the input motion. This suggests that while the perceptual learning in this case might indeed be local, more global information is involved for stabilizing the learning process.

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53.328 **Does perceptual learning require consciousness or attention?**

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It has been proposed that visual attention and consciousness are separate (Koch and Tsuchiya, 2007) and possibly even orthogonal processes (Lamme, 2003). The two converge when conscious visual percepts are attended, and hence become available for conscious report. A lack of reportability can however have two causes: the absence of attention or the absence of a conscious percept. This raises an important question in the field of perceptual learning. It is known that learning can occur in the absence of conscious reportability, but given the recent theoretical developments it is now suddenly unclear which of the two ingredients – consciousness or attention – is not necessary for learning. We present textured figure-ground stimuli, and manipulate reportability either by masking (which interferes with consciousness) or with an inattention paradigm (which only interferes with attention). During the second session (24 hours later) learning is assessed via differences in figure-ground ERPs and via a detection task. Preliminary findings suggest that early learning effects are found for stimuli presented in the inattention paradigm, and not for masked stimuli. These results suggest that learning requires consciousness, and not attention, and further strengthen the idea that consciousness is separate from attention.

53.329 **Role of attention in visual perceptual learning: evidences from event-related potentials**

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The role of attention in perceptual learning is a focus question during recent years. However, the brain mechanism of attentional modulation on visual perceptual learning is still unclear. By recording event-related potentials from human adults, the present study investigated how top-down attention modulates visual perceptual learning. 30 subjects were randomly divided into two groups: active & passive learning group. Each subject received 1.5 h's training when ERP was recorded. Subjects of active learning group were trained to discriminate the line orientation, while those of passive learning group just passively viewed the stimuli used in active learning group. All the subjects received tests on line orientation discrimination task just before and after the training, as well as on the next day. Behavioral results showed that, subjects of active training group obtained larger improvement of performance than those of passive learning group. While the learning effect of passive group could transfer to different stimulus orientations and occurred mainly after the training, that of active group was orientation-specific and occurred mainly during the training. ERP results showed that, for passive learning group, both posterior P1(90-110ms) and N1(120-160 ms) decreased in amplitude along 1.5h's training, while posterior P2(210-250 ms) did not change. For the active group, however, P1 did not change; N1 decreased but the decrement was smaller than that of passive group; while P2 increased in amplitude with training. The present study implies that top-down attention does modulate the short-term perceptual learning, leading to the stimulus-specific learning effect in behavioral performance as well as increments of neural activity which are opposite to the sensory adaptation effects caused by stimuli repetition and originate from quite early stage of visual processing, within 100 ms after stimulus onset.

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53.330 **Implicit Learning of Background Texture while Learning to Break Camouflage**

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It can be difficult to recognize a visual object camouflaged against its background, even when the object is familiar and is 'in plain sight'. However, the ability of the visual system to break camouflage can be improved with training. What the visual system learns during such training remains unclear. We hypothesized that learning to break camouflage involves learning, however implicitly, the statistical properties of the background, because this information is computationally helpful in breaking camouflage. To test this hypothesis, we synthesized a large number of novel instances of familiar natural textures (e.g., pebbles) using the texture synthesis algorithm of Portilla and Simoncelli (2000). We created novel camouflaged visual scenes by camouflaging a familiar object (face) against each instance of synthesized texture. We used some of these images to train normal adult human subjects to break camouflage using a two-alternative forced-choice detection paradigm (i.e., target present or absent), until subjects reached a criterion performance of d' ≥ 1.5. We tested the detection performance before and after the training using previously unseen instances of the same texture. We found that the detection performance of the subjects was significantly better after the training relative to the performance before the training (e.g., d' of 0.5 before training vs. 1.5 after training for a typical subject), indicating that the exposure to a given texture improved camouflage breaking in novel instances of the texture. Importantly, detection performance also improved for unfamiliar objects (e.g., 'digital embryos') that the subjects did not encounter during training, suggesting that the transfer of learning was not dependent on learning of the target per se. Moreover, the transfer of background learning was not specific to a given texture. Together, our results indicate the subjects can implicitly learn the background textures of camouflaged scenes even when not explicitly required to learn it.

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53.331 **Understanding how people learn the features of objects as Bayesian inference**

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Research in perceptual learning has demonstrated that human feature representations can change with experience (Goldstone, 1998). However, previous computational models for learning feature representations have presupposed the number of features (Goldstone, 2003) or complex basic units are known a priori (Orban et. al., 2008). We propose a nonparametric Bayesian framework that infers feature representations to represent observed stimuli without specifying the number of features a priori from raw sensory information (Austerweil & Griffiths, 2008). This approach captures two main phenomena from the perceptual learning literature: differentiation (Pevtzow & Goldstone, 1994) and unitization (Shiffrin & Lightfoot, 1997). Additionally, our approach makes a novel prediction about how people learn features. It predicts that people should infer the whole objects as features if the parts which compose objects strongly co-vary across objects and the parts as features if the parts are largely independent. In our first experiment, we demonstrated that one group of participants who observed objects whose parts co-varied did not generalize to unseen combinations of those parts (Austerweil & Griffiths, 2009). The other group of participants who observed parts occurring independently did generalize to seen combinations of parts. We demonstrate that the following pre-existing psychological frameworks or models cannot explain these results: exemplar models (Nofosoky, 1986), prototype models (Reed, 1972), changes of concavity (Hoffman & Richards, 1985), and recognition-by-components (Biederman, 1987). This suggests participants were using distributional information to infer features to base their generalization judgments as our model suggests. In a second experiment, we replicate this effect with a set of rendered 3-D objects, showing the effect works in two very different types of objects. As our computational framework suggests, part correlation is an important cue that people use to infer feature representations.

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Color and light: Surfaces and materials

Orchid Ballroom, Boards 401–410

Tuesday, May 11, 8:30 - 12:30 pm

53.401 Lightness estimation errors in a 3D context

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The problem of recovering reflectance from a single image is inherently under-constrained. Therefore, the visual system must use heuristics or biases to recover reflectance, whilst discounting geometry and illumination. In a previous study, we investigated lightness perception in a 3D context (Dimitrova YD, McOwan P, Johnston A, 2009, Perception 38: ECVP Abstract supplement, p. 31). Participants systematically overestimated reflectance for vertically eccentric illuminant angles and underestimated for illuminant angles close to the horizontal plane. These errors were robust to additional cues to light source direction and depth as well as to the removal of local features. Errors rose significantly with the increase in the ratio of directional to ambient light. Modelling of the data indicated three possible causes of the reflectance misestimation: a light direction bias, a bias in the proportion of ambient to directional light or a simple brightness averaging over the image. To investigate perceived illuminant direction, participants were asked to adjust the illumination direction for a sphere until it matched the lighting direction for a dodecahedron rendered using a range of illuminant elevations. The pattern of light direction adjustments was consistent with a bias of perceived illuminant elevation that is both shifted away from vertically eccentric angles and away from the horizontal plane. These adjustments were similar the results of modelling reflectance errors with a light direction bias. This finding supports the view that the systematic errors in reflectance settings are at least in part caused by a bias in the assumed direction of illumination.

53.402 The effects of color categorization on shadow perception

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As Cavanagh and Leclerc (1989) discussed, a significant change in hue across a cast shadow boundary is unlikely under real-world conditions. Such a change would require both multiple light sources of different hues and minimal interreflections that could otherwise mute differences in hue. Despite this constraint, they found that a change in color across a shadow boundary does not prevent shape from shadow perception, as long as there are luminance differences. The present study sought to demonstrate that rather than being largely ignored by observers, the color constraint on shadows is a cue that can inhibit a shadow percept, even when another shadow cue such as a penumbra is present. Perceptually matched pairs of color patches were generated that consisted of a base color and a possible shadow color, presented as two halves of a circular stimulus image. The base color was categorized as blue but near the blue-green boundary, while the possible shadow colors were adjusted to be each equally different from the base color, either crossing into the green color category or closer to prototypical blue. Possible shadows were always less luminant than the base color. This resulted in blue/blue stimulus pairs and blue/green pairs. Observers then completed a rating task that included these pairs as well as variously achromatic pairs or equiluminant pairs. The blue/blue stimulus resulted in higher shadow ratings than the blue/green pair. We conclude that it is not merely the presence of a color difference that inhibits shadow perception, but instead a categorical difference in color that may then combine with other edge type cues, similar to cue combination theories of shape perception.

53.403 Perception of surface glossiness in infants

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Human adults can easily judge the glossiness of natural surfaces. The present study examined the glossiness perception in infants. Using computer graphics, we created gray-scale images of three objects that had identical 3D structure with different surface qualities. The first object was uniformly matte, the second one was glossy, and the third one was matte but covered with white paint splashes. The glossy and paint surfaces had similar luminance histograms that are positively skewed while the matte surface had a negatively skewed histogram. Twenty four infants, aged 5-6 and 7-8 months, were presented with the two objects side by side. In one condition they were glossy vs. matte, and in the other glossy vs. paint. The results showed that the 7-8-month-old infants, but not 5-6-month-old infants, significantly preferred the glossy object both to the matte and paint objects. The preference for the glossy surface to the paint surface cannot be accounted for by the difference in the histogram statistics, indicating that infants could discriminate between highlight and white paint. These findings suggests that the 7-8-month-old infants are sensitive to the surface quality and have a preference for glossy objects on the basis of neural representations more than simple image statistics. The developmental period of sensitivity to highlights found in present study is consistent with previous finding that the perception of shape from shading emerges around 7 month of age (Granrud, Yonas, and Opland, 1985).

53.404 Hue torus

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One can alter the colour appearance of an object either by painting it or by changing its illumination. Both material and lighting changes can result in a change of hue. We report on an experiment which shows that "material" hues are different from "lighting" hues. Two identical sets of Munsell papers (5R4/14, 5YR7/12, 5Y8/12, 5G6/10, 10BG5/8, 5PB5/12 and 10P5/12) were presented in two displays. In separate sessions of the experiment, the displays were illuminated independently by one of five lights: red, yellow, green, blue and purple, giving a total of 15 possible illumination conditions (red-red, red-yellow, etc). The lights were approximately equiluminant with CIE 1976 u'v'-coordinates (0.382, 0.488), (0.199, 0.530), (0.127, 0.532), (0.183, 0.210), and (0.259, 0.365). Dissimilarity judgments were made between papers in the two displays (as in asymmetric colour matching). Each pair was evaluated 6 times by ranking. As a standard pair, the paper 5Y8/12 lit by the yellow light and the paper 5PB5/12 lit by the blue light were presented at all times during the experiment to indicate the maximal rank. Two trichromatic observers participated in the experiment. The dissimilarity judgements were analyzed by using a non-metric multidimensional scaling technique. The output configuration was of a slightly distorted torus-like pattern ("doughnut"). When one changes the material (reflectance) property moving from paper to paper under the same light, one travels the circumference of the doughnut (referred to as material hue). When one changes the lighting property, moving from light to light for the same paper, one travels the cross-sectional circle of the doughnut (referred to as lighting hue). Thus, the material and lighting hues are found to be dissociated in the dissimilarity space. We conclude, contrary to general belief, that the manifold of object-colour hues is two-dimensional, being topologically equivalent to a torus.

53.405 Both the complexity of illumination and the presence of surrounding objects influence the perception of gloss

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Introduction: Human observers seem to robustly and effortlessly classify material properties, even when the optical input changes completely due to illumination changes. Previous research by Fleming et al. (2003) shows that the complexity of the illumination affects our judgments of glossiness. Here, we investigate the effects of both the nature of the illumination and the presence of context objects on the perceived glossiness of a reference object. Method: We compare perceived glossiness for complicated illumination (containing high frequency variations in the spatial luminance distribution, a bit like sunlight filtered through foliage), collimated illumination and diffuse illumination. As context objects, we use an arrangement of fruits, vegetables and vases that all either retained their original color and glossiness, were all spray painted matte gray, or were all spray painted specular gray. Participants viewed a gray reference object in that was either photographed in isolation or placed in a number of complex scenes, under three different illuminations. They matched the glossiness of a test object that was photographed in isolation on a matte background with collimated illumination to the glossiness of this reference object. Results: We found a huge underestimation of the glossiness of the object when the object was illuminated with a diffuse light source, compared to when the object was illuminated with a collimated light source, whereas glossiness was overestimated when illuminated with a highly complicated light source. In some participants, these biases were slightly reduced when specular or colored context objects were present. Conclusions: Results indicate that a richer environment, with complicated, more natural, illumination and a variety of different context materials, help us judge glossiness more accurately. Acknowledgments: This work was supported by the Netherlands Organization for Scientific Research (NWO).

53.406 **Real-world illumination measurements with a multidirectional photometer**

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The visual system resolves ambiguity by relying on assumptions that reflect environmental regularities. One well-known assumption, used to interpret ambiguous 2D images, is the light-from-above prior. However, recent work has shown the visual system represents more complex assumptions of natural illumination than a single overhead light source (Fleming et al., 2003; Doerschner et al., 2007). To investigate these hidden assumptions previous researchers have used multi-directional photographic methods to measure and statistically characterize natural illumination. These methods provide high-resolution, high-dynamic range images of the complete surrounding scene. For some purposes, such as understanding illumination of Lambertian objects, a coarser lighting measurement that represents the first three orders of spherical harmonics would suffice (Basri and Jacobs, 2001; Ramamoorthi and Hanrahan, 2001). We will describe a multidirectional photometer we have developed, that makes fast and accurate measurements of low-degree spherical harmonic components of real-world lighting. The multidirectional photometer is a 20 cm diameter aluminum sphere, mounted with 64 approximately evenly spaced photodiodes. Each photodiode is filtered to match the photopic spectral sensitivity of the human visual system, and fitted with an aperture that reduces its directional selectivity so as to provide the sharpest image possible with 64 sensors. The device measures light ranging from low-lit indoor scenes to direct sunlight, and makes several complete measurements per second. We discuss design decisions such as how many photodiodes to use, how to distribute the photodiodes over the sphere, and what directional selectivity to give the individual photodiodes. We also discuss a linear-systems approach to using the photodiode measurements to reconstruct ambient lighting as a sum of basis functions. We will present preliminary findings on the statistical characterization of low-degree spherical harmonics of light in natural scenes, and discuss how such measurements can be used to advance our understanding of shape from shading and lightness constancy.

53.407 **A Model of Illumination Direction Recovery Applied to Dynamic Three-Dimensional Scenes**

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Background: Gerhard & Maloney (ECVP 2009) measured the accuracy of human observers in judging the direction of movement of a collimated light source illuminating a simple rendered scene. The scene contained a smooth randomly-generated Gaussian bump landscape. The light source was not directly visible and observers had to judge the direction of movement given only the effect of the illumination change on the landscape. All viewing was binocular. This task is of particular interest because motion direction is ambiguous without this depth information. Eight observers completed the experiment. Observers could accurately judge the direction of movements spanning as little as 10 degrees over 750 msec but judgments were consistently less reliable for some scenes than others. Observers also varied in accuracy. Goal: We present a computational model of the task intended to predict ideal performance, individual differences across observers, and differences in accuracy across scenes. The model recovers change in illumination direction using 1) the luminance map of the stereo images across time, 2) the depth map of the scene that we assume is available to the observer. Model: The ideal model computes luminance gradients at Canny-defined luminance edges in the image and combines this information with a measure of local surface shape to recover illumination direction. To compute motion direction, final position and initial position are compared. Results: We simulated the performance of the model on the stimuli previously viewed by observers in Gerhard & Maloney. The model's variation in direction estimation was 7.2 degrees. Maximum likelihood estimates of human variability based on performance were much larger, 27 to 46 degrees. We use the model to mimic human performance for each observer and also to investigate the scene factors that enhance or diminish performance.

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53.408 **Dissimilarity Scaling of Lightness Across Changes of Illuminant and Surface Slant**

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Purpose. Some studies of lightness and color constancy have described asymmetric matching conditions under which observers are unable to find a perfect match; that is, the best match was associated with a residual perceptual difference (e.g., Brainard, Brunt, and Speigle, 1997). Logvinenko and Maloney (2006) quantified this phenomenon by having observers rate differences in perceived surface lightness across changes surface reflectance and illumination, and modeling the dissimilarity data using multidimensional scaling (MDS). Their data required a two-dimensional representation for lightness, with one dimension corresponding (roughly) to surface reflectance and the other (roughly) to illumination intensity. The finding of a two-dimensional representation explains why observers cannot make a perfect asymmetric lightness match across a change of illumination by adjusting the match stimulus intensity alone. We sought to replicate Logvinenko and Maloney's result, and to extend it to the case where viewing geometry was also varied. Methods. Observers viewed pairs of grayscale matte flat test stimuli, one presented in each of two adjacent illuminated viewing chambers. They rated the dissimilarity of each pair. Observers scaled all possible pairs from a stimulus set containing 6 surface reflectances seen in 3 scene contexts. Across one context change illumination varied, while across the other surface slant varied. Non-metric MDS was used to model the data. Results. The data from each of four observers were well-accounted for by a one-dimensional representation. This representation was similar in structure for all observers; for each the position p of a surface with reflectance r was approximated by $p = \log(r) + c$, where the constant c depended on scene context. Accounting for our dissimilarity data did not require two or more dimensions of perceived lightness. Conclusion. Understanding what variations of viewing conditions produce a lightness representation with multiple dimensions remains to be determined.

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53.409 **Effects of microscale and mesoscale structure on surface appearance**

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Real-world surfaces typically have geometric features at a range of spatial scales. At the microscale, opaque surfaces are often characterized by bidirectional reflectance distribution functions (BRDFs), which describe how a surface scatters incident light. At the mesoscale surfaces often exhibit visible texture – stochastic or patterned arrangements of geometric features that provide visual information about tactile surface properties such as roughness, smoothness, softness, etc.. These textures also affect how light

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is scattered by the surface, but the effects are at a different spatial scale than those captured by the BRDF. Normally both microscale and mesoscale surface properties contribute to overall surface appearance, however under particular illumination and viewing conditions, one or the other may dominate. In this project we investigated how microscale and mesoscale surface properties interact to determine perceived surface lightness. We measured the BRDFs and textures of flat surfaces covered with matte latex wall paints applied by spray or roller, then created computer graphics models of these surfaces and rendered center/surround targets with identical BRDFs but different textures. Observation of the images under directional lighting shows that as the viewing angle changes from normal to grazing, the lightness contrast of the center and surround regions change non-monotonically with the rougher textured surface first appearing lighter than the smoother one, then darker as the specular angle is approached, then potentially lighter again near grazing. This complex behavior is due to both the surface physics and simultaneous contrast effects, and is the cause of the well-known "touch-up problem" in the paint industry. We have conducted psychophysical studies that characterize how the perceived lightness differences of surfaces vary with BRDF and texture properties, and are developing models that can predict lightness differences for various lighting and viewing conditions, and provide prescriptions for minimizing the effect.

53.410 Effects of material on the color appearance of real objects

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The objects in our environment are made from a wide range of materials. The color appearance of the objects is influenced by the geometry of the illumination, the three-dimensional structure of the objects, and the surface reflectance properties of their materials. Only few studies have investigated the effect of material properties on color perception. In most of these studies the stimuli were three-dimensional objects rendered on a computer screen. Here we set out to investigate color perception for real objects made from different materials. The surface properties of the materials ranged from smooth and glossy (porcelain) to matte and corrugated (crumpled paper). We tested objects with similar colors made from different materials and objects made from the same material that differed only in color. The objects were placed on black cloth in a chamber under controlled lighting conditions. In an asymmetric matching task observers matched the color and lightness of the objects by adjusting the chromaticity and the luminance of a homogeneous, uniformly colored disk presented against a black background on a CRT screen. The screen was located close to the objects so that it was not directly illuminated by the lamps that illuminated the objects. To determine the chromatic and luminance distributions of the objects their surfaces were measured with a spectroradiometer at numerous points from the viewpoint of the observers. We also measured the chromatic and luminance distributions of the materials when they could be presented as approximately flat surfaces (paper and wool). The observers' matches were measured with the spectroradiometer. In general observers' matches were close to the true chromatic and luminance distributions due to the objects. However, observers systematically tended to discount the variations in reflected light induced by the geometry of the objects and rather matched the light reflected from the materials themselves.

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Spatial vision: Cognitive factors

Orchid Ballroom, Boards 411–415

Tuesday, May 11, 8:30 - 12:30 pm

53.411 Implicit verbal categories modulate spatial perception

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We report evidence for a differential modulatory effect of spatial verbal categories on categorical and coordinate spatial processing. Kosslyn (1987) proposed a hemispheric bias for processing two types of spatial information. Categorical information refers to spatial relations that are discrete and abstract, as lexicalized by locative prepositions. More fine-grained coordinate information pertains to metric distance important for visual search. Participants made same/different judgments on pairs of dot-cross configurations presented simultaneously for 200ms to the left and right of central fixation. Pairs could be different in respect to either their categorical or coordinate relations. For categorical trials, dots were located in different quadrants the same distance from the center of each cross; for coordinate trials, dots were located in the same quadrant at different distances from the center of each cross. The orientation of the crosses was also manipulated. In AMBIGUOUS trials, crosses were composed of intersecting vertical and horizontal lines forming a +. In UNAMBIGUOUS trials, both crosses were rotated 45° to form an × such that the quadrants were now unambiguously associated with verbal spatial categories (right/left/up/down). Effects of orientation were predicated on the view that UNAMBIGUOUS trials automatically generate unique spatial labels associated with each quadrant whereas AMBIGUOUS trials do not. We predicted that relative to AMBIGUOUS trials, performance on UNAMBIGUOUS trials would be (1) better for categorical stimuli because in UNAMBIGUOUS trials the activation of unique verbal labels should facilitate discrimination between different spatial categories and (2) worse for coordinate stimuli because the stronger spatial category attractor makes discriminating two locations within the same spatial category more difficult. Both predictions were confirmed by the data with all predicted main effects highly reliable. The robust orientation × spatial information-type interactions (Accuracy: $F(1,9)=12.96$, $p<.01$, RT: $F(1,9)=10.28$, $p=.01$), suggest that spatial categories, even when implicit, modulate spatial information processing.

53.412 Magnitude estimation of visual displays: numerosity, area, and mean size

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Many studies have investigated the ability to compute statistical properties of a visual display, such as density (area), numerosity, and mean size. For example, Chong & Treisman (2005) investigated the ability to compute the mean size when number or density was varied. On the other hand, Burr (2008) focused on the ability to calculate numerosity under different densities. However, these researches did not investigate the ability to calculate those properties using same stimuli. In our study, we investigated the relationship among the abilities to judge area, numerosity and mean size by asking participants to make such judgments on same stimuli. A display with filled circles was presented and participants judged the three properties. The method of constant stimuli was used to measure PSEs (Point of Subjective Equalities) of each task on the same display. We used three different standards for each task and had 5 comparison stimuli at each standard. A standard display was presented for 250 ms followed by a test randomly selected from 5 comparison stimuli. Participants decided whether the test stimulus was larger or smaller (area and mean size tasks) or more or less numerous (a numerosity task) than the standard display. We found that PSEs of all three tasks were close to the presented standard, suggesting that all three judgments were accurate. However, participants overestimated all three properties at the highest standard. The amount of overestimation in the mean size judgments was significantly smaller than that in both area and numerosity judgments. These results suggest that the computation of mean size is closely related to that of area and number. It may be possible that the visual system calculates the perceived mean size by the ratio between perceived area and numerosity.

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53.413 The use of spatial frequencies for visual word recognition in each cerebral hemisphere

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A matter of important debate remains regarding whether the range of spatial frequencies (SFs) preferred by the left cerebral hemisphere is higher than that preferred by the right hemisphere. In visual word recognition, relatively low SFs allow access to coarse visual word form and higher SFs to fine letter discrimination. Here, we determined the SF spectrum optimally used by each cerebral hemisphere for visual word recognition. Twelve right-handed normal readers read 1,800 word stimuli, so far, each having been presented for 200 ms either in the right or the left hemifield. We created each word stimulus by randomly sampling the SFs of a word (see Willenbockel et al., in press). The quantity of SFs was adjusted to maintain correct response rate at 50%. For each participant and for each hemifield, we performed a multiple linear regression between the random filters and response accuracy. Regression coefficients were smoothed (FWHM = 2.35), z-scored, and a pixel test was applied (Chauvin et al, 2005). For now, five of the 12 participants yield significant results in both hemifields. Nonetheless, a t-test on the SF peaks of these five subjects already confirms the use of higher SFs for words presented to the right hemifield (M = 1.64 cycles/letter) than for words presented to the left hemifield (M = 1.37 cycles/letter; mean difference = 0.27 cycles/letter, $t(4) = 3.64$, $p < 0.05$). Furthermore, the quantity of SF information necessary for accurate word recognition was 45% greater for words processed by the right hemisphere ($t(4) = 12.20$, $p < 0.001$). Our findings support the hypothesis of a left hemisphere bias for higher SFs, explaining its greater sensitivity for visual word recognition. As the right hemisphere has access to coarser visual word form, it's possible that it remains useful for the recognition of words with lower visual confusability.

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53.414 **Preview search and inhibition of the semantic category.**

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Visual search becomes easier when half of the distracters are presented first and then the rest of stimuli are added (preview effect). Watson and Humphreys (1997) insisted that the preview effect was caused by the "visual marking" mechanism, by which the previewed stimuli were inhibited based on their location. On the other hand, Braithwaite, Humphreys and Hodsoll (2003) revealed that the amount of preview effect decreased, when target and previewed stimuli had the same color (negative carryover). From this phenomenon, it is suggested that the previewed stimuli may be inhibited based on their color and the color-based inhibition cause the negative carryover. The present study hypothesizes that when target and previewed stimuli belong to the same semantic category, the category-based inhibition will cause "semantic negative carryover." To explore this hypothesis, we used similar method to that of Braithwaite et al. (2003) with some exceptions. The biggest change was the type of stimuli. We used line drawings whose familiarity, complexity and shape similarity were controlled. Semantic relationship was then manipulated between target and the previewed stimuli, so there were the same condition and the different condition. As a result, preview effect occurred even with line drawings. We also found that the preview search in the same condition was more difficult than in the different condition (semantic negative carryover). The results suggest that the previewed stimuli were inhibited based on their semantic category, and also that the inhibition was generalized to the semantically associated stimuli.

53.415 **Visual enumeration: A bi-directional mapping process between symbolic and non-symbolic representations of number?**

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Over the last 30 years, numerical estimation has been largely studied. Recently, Castronovo and Seron (2007) pointed out that, according to the type of numerical estimation task (perception vs. production of numerosities), reverse patterns of performance are found (i.e., under- and over-estimation respectively). They postulated the bi-directional mapping hypothesis to account for that particular phenomenon. This hypothesis relies on classical assumptions, assuming the existence of several numerical mental representations, having transcoding routes between them (Dehaene, 1992) and presenting difference in precision (Piazza et al., 2007). Based on these assumptions, the bi-directional mapping hypothesis suggests that the opposite patterns of performance found in perception and production numerical estimation tasks result from the opposite direction of their transcoding activities between the non-symbolic magnitude representation (i.e., the mental number line) and its corresponding symbolic representation. Here, we further investigated the bi-directional mapping hypothesis by submitting participants to 3 visual numerical estimation tasks, involving three different mapping processes: 1) a perception task, involving a non-symbolic (sets of dots) to symbolic (Arabic numeral) mapping; 2) a production task, involving a symbolic (Arabic numeral) to non-symbolic mapping (set of dots); 3) a reproduction task, involving a non-symbolic (set of dots) to non-symbolic (set of dots) mapping. Our results confirmed that different patterns of performance are found according to the type of numerical estimation task: 1) under-estimation in the perception task; 2) over-estimation in the production task; 3) accurate estimation in the reproduction task. Moreover, correlation analyses revealed that the more a participant under-estimated in the perception task, the more he/she over-estimated in the production task. These results gave further support to the bi-directional mapping hypothesis, by directly showing for the first time how different numerical estimation tasks, involving different mapping routes have an impact on the patterns of performance that can be found.

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Attention: Visual working memory

Orchid Ballroom, Boards 416–422

Tuesday, May 11, 8:30 - 12:30 pm

53.416 **Do Visual Working Memory Representations Automatically Bias Deployments of Covert Attention?**

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Theories of attention propose that working memory representations are used to guide visual attention. Empirical tests of this prediction using behavioral measures have led to mixed results. Some conclude that working memory representations automatically guide attention, while others suggest that an individual's strategy determines whether working memory representations guide attention. Here, we used the N2pc component of observers' event-related potentials to directly measure the effect that visual working memory representations had on how covert attention was deployed. Participants maintained an object representation in working memory in service of a change-detection task while performing visual search. On some trials, the search array contained a distractor that exactly matched the object held in working memory and across trials we manipulated its location relative to the search target. If working memory representations automatically bias attention to select matching inputs, then the memory-matching distractor should elicit an N2pc regardless of the location of the target. However, the results did not support this hypothesis. Instead, we found the visual search target elicited a larger amplitude N2pc when the memory-matching item was in the opposite hemifield, suggesting that covert attention was actively directed away from the memory-matching item. The findings of these experiments are inconsistent with the proposal that working memory representations automatically guide attention to memory-matching items, and lend support to the proposal that the influence of working memory representations on attention during visual search is under strategic control.

53.417 **Visual memory encoding is independent of attention**

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Conscious, visual perception depends on information stored in visual working memory (VWM). VWM, however, suffers from capacity limits and only about four objects can be represented at the same time. It is often suggested that our limited selective attention is responsible for this. Recent research has shown the existence of a more vulnerable, but high capacity form of VWM (> 15 objects). This high capacity is evident whenever an attention-guiding cue is presented during stimulus maintenance; then, almost all objects that are shown can be retrieved and reported about. This suggests that not visual memory itself, but its report depends on attention.

To test that hypothesis, we present a study in which we distract participants' attention during stimulus encoding. Visual memory was measured using a Change Detection task. During this task, attention was manipulated in three different ways. In one condition, uncertainty about stimulus presentation was created. In a second condition, participants performed an N-back task during stimulus encoding. In a third condition, an Attentional Blink paradigm was used to decrease attention for the stimulus array. Preliminary results show that engaging attention impairs performance on a classical Change Detection task, but memory is unaffected when a guiding cue is presented during stimulus maintenance. These results suggest that the brain stores many objects independent of attention, and that attention is only necessary to report or otherwise cognitively manipulate these items.

53.418 **Shared VSTM resources for enumerating sets and for encoding their colors**

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Several species, including humans, have been shown to posses the ability to nonverbally represent the approximate number of items in a set. Recently, Halberda et al. (2006, Psychol. Sci.) showed that with displays containing multiple spatially overlapping sets, observers can successfully enumerate three such sets (two subsets plus the superset of all items). This three-set limit on enumeration has been argued to converge with previously observed three-item limits of object-based attention and visual short-term memory (VSTM), with each set functioning as an individual entry to attention and VSTM. This proposal implies that the same VSTM resources may be used both for storing sets for enumeration and for storing single object features such as colors and shapes. In the present study, we tested this proposal using a paradigm similar to that of Halberda et al.: participants briefly viewed displays of dots of different colors and were asked to enumerate the approximate number of dots of a specific color (the probe color). The probe color was given either before or after the display was shown. Accuracy on paired 'probe before' and 'probe after' trials was compared to assess the number of sets that participants could successfully encode. Occasionally, we probed a color that was not present, allowing us to measure the number of colors that participants could encode successfully from the displays. Replicating Halberda et al., we found that participants could successfully enumerate two subsets of the colored dots. Interestingly, participants could only encode about two colors from the same displays. In other words, when participants were able to encode the color of a set, they could also enumerate the number of items in that set successfully. These results indicate that VSTM resources for enumerating sets and for encoding object colors are shared.

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53.419 **Filtering Efficiency in Visual Working Memory**

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What determines when filtering irrelevant items is efficient? In 3 experiments we investigated perceptual load and individual differences in working memory (WM) capacity as determinants of filtering efficiency, using both behavioral and electrophysiological markers. Participants performed a visual search task that contained a target, neutral distractors and a flanker distractor. We used the contralateral delay activity (CDA) to monitor the amount of information being stored in visual WM. The assumption is that when filtering is efficient only the target should be processed in visual WM and irrelevant items could be filtered out early in processing, but as filtering becomes inefficient, more and more irrelevant items will be stored in visual WM. The results indicated that individual differences in WM capacity and perceptual load both independently influenced the filtering of irrelevant information from visual WM. Namely, filtering the flanker was efficient only under high perceptual load (as indicated by behavioral measures), but in both low and high perceptual load, individual differences in WM capacity correlated with filtering efficiency (as indicated by the CDA amplitude). Furthermore, the results identified the target search process as responsible for the inefficient filtering. Interestingly, facilitating the search process by presenting a spatial cue that signaled the target location made filtering more efficient in general, but high WM capacity individuals still benefited to a larger extent relative to low WM individuals.

53.420 **Enumeration by location: Exploring the role of spatial information in numerosity judgments**

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Enumerating a set of visual objects requires the individuation of these items, which inherently relies on location information. To examine the role of location memory in small-number judgments (subitizing), we devised a task that presented observers a brief display of small discs and then required them to mark the location of each disc on a blank screen. In doing so, observers provided an indirect measure of their representation of the numerosity of the display. Observers were tested on three stimulus durations (50, 200, 350 ms) and eight numerosities (2-9 discs); the black discs were approximately 1 degree in visual angle and placed randomly on a gray screen. Following a full-screen mask, observers marked the disc locations on a blank screen by using a mouse pointer to place markers ("X") for each disc. This provided a measure of recall for object locations and display numerosity. ANOVAs on enumeration performance revealed significant main effects for numerosity and display duration (with interactions). High enumeration accuracy was observed for displays containing up to six discs (>90% of trials with perfect recall); error rates increased rapidly for larger numerosities. When observers made counting errors, they were generally underestimates. In the location analysis, error was measured as the distance between a stimulus disc and a paired response disc (discs were paired using nearest-neighbor methods). Location errors were significantly worse in the 50-ms presentation duration and for larger numerosities. We speculate that the process of adding markers for each object provided a way to keep track of which objects had already been counted and thus improved enumeration accuracy. The methodology for this new subitizing task and the implications of the current findings will be discussed.

Acknowledgement: NSF 0549115

53.421 **Visual working memory supports configuration, but not maintenance or application, of attentional control settings**

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What mechanism allows people to tune attention to search for pre-specified targets? One possibility is that such "attentional sets" involve the holding of target features in visual working memory (VWM). Alternatively, VWM might support the configuration of attentional set but become less central once configuration is completed. We tested these possibilities by manipulating concurrent VWM load during a classic "contingent attentional capture" task, where non-targets that contain features of a pre-specified target typically capture attention (indexed via response time; Folk et al., 1992). In Experiment 1, participants made speeded judgments about a target (identifying it as either '=' or 'X'); the target was always red for the half the participants and always green for the other half, and it was preceded by a cue that a) either was of the same color as the target or the opposite color, and b) appeared in the same location as the target or in a different location. Each trial occurred during the retention interval of a VWM task, where participants attempted to remember the colors of either two squares (low load) or four squares (high load). Results revealed that cues matching the target color captured attention more robustly than cues of the opposite color (i.e., contingent capture), but that this was unaffected by VWM load. Experiment 2 introduced the need to configure attentional set trial-by-trial, as well as the between-subjects factor of whether VWM load was induced before or after providing information about the target color on each trial. Results revealed no effect of VWM load when information about the target color appeared prior to the induction of VWM load, but there was a significant effect of VWM load when such information was provided afterwards. Thus, VWM appears crucial for the configuration of attentional set but not necessarily for its maintenance or application.

53.422 **Rapid Recovery of Moving Targets Following Task Disruption**

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Tracking tasks, such as monitoring traffic while driving or supervising children on a playground, would seem to require continuous visual attention. In fact, we can track multiple moving objects even through disruptions to the task, such as looking away. How do we do this? We have previously suggested a mechanism that stores information about tracked objects offline during disruption, so the visual system can perform a secondary task, then later resume tracking without complete loss (Horowitz et al., 2006).

Here we studied the timecourse of target recovery following a brief disruption. Participants tracked a set of moving targets among identical moving distractors. During tracking, all objects disappeared simultaneously, then reappeared after a brief gap. Objects continued to move during the gap. At a delay between 0-1280 ms following reappearance, one object was probed. Participants identified the probed object as a target or distractor. In different experiments, we varied the gap duration from 133-507 ms, the tracking load from 1-4 targets, and the set of probe delays. In all experiments, RT decreased over probe delays of roughly 0-50 ms following reappearance, then remained constant.

We assumed that the visual system takes some amount of time to recover the targets following the gap. Under this assumption, RT should decline linearly as a function of probe delay with a slope of -1. Recovery time may be estimated as the probe delay at which RT reaches baseline and stops declining. Recovery time was estimated to be about 45 ms in all experiments, regardless of gap duration or tracking load. These results suggest that recovery of tracked objects following disruption occurs rapidly and in parallel.

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Multisensory processing: Cross-modal perception

Orchid Ballroom, Boards 423–436

Tuesday, May 11, 8:30 - 12:30 pm

53.423 The Contribution of Left and Right Visual Fields to Perceived Orientation

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Vision plays an important role in our ability to orient. A major factor in self orientation is the perceived direction of up. Previous studies involving perceptual upright (PU: the orientation at which objects are best recognized) have demonstrated a consistent leftward bias in a character recognition task. We hypothesized that this leftward bias may be due to unequal visual orientation cue ratings across the visual field. We assessed the perceptual upright using OCHART (Oriented CHAracter Recognition Task) which measures the orientation at which a letter probe is "perceptually upright" (Dyde et al., 2006 Exp Brain Res. 173: 612). The probe was presented in the centre of a background masked down to a circle subtending 35° and divided into two with a vertical black line separating the two halves. Images on each half were photographs of an outdoor scene upright, tilted clockwise or counter-clockwise by 112.5°, or a grey field of equal average luminance. The effects of the two sides were additive in determining the PU with no obvious dominance of one side or the other. However, when the oriented scene was presented only on one side (with the other side grey) the strongest effect on the probe was found when visual cues were tilted in the same direction as the visual field on which they were presented. Our data suggest that orientation cues presented on the left and right sides of space are weighted approximately equally by the brain. The brain integrates the conflicting visual cues on either side of the visual field when determining perceptual upright.

Acknowledgement: Canadian Space Agency, Natural Sciences and Engineering Research Council of Canada

53.424 Perceptual orientation judgements in astronauts: pre-flight results

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Introduction: Bodies in the Space Environment (BISE) is a Canadian Space Agency sponsored experiment currently running onboard the International Space Station. The project examines the effect of long-term exposure to microgravity on perceived object orientation. Methods: Thirteen astronauts were tested using the Oriented Character Recognition Test (OCHART) as part of the pre-flight data collection process. OCHART measures the orientation at which a letter probe is "perceptually upright" (PU) (Dyde et al. 2006 Exp. Brain Res. 173: 612). OCHART was performed while upright and lying right-side-down (rsd). By varying the background orientation and the orientation of the subjects the relative contribution of vision, gravity and the body can be determined. Data from 49 undergraduate students were collected for comparison. Students' data variance was computed and a second pool of 24 student subjects was constructed to match variance in the astronaut subject pool. Results: When in an upright posture the direction of PU was more influenced by a tilted visual background for the complete student group compared to astronauts. Astronauts' PUs had significantly smaller variances than those of the complete student group. Comparing the astronauts with a group of 24 students (matched for variance) showed that there was no difference in the influence of the tilted background on PU between these two groups. When these two groups' data was compared in the rsd posture, the direction of PU was reliably closer to the axis of gravity (and further away from the body centre-line) for the students compared to astronauts. Discussion: Initial data suggest that astronauts rely less on the axis of gravity when performing an orientation measure compared to a student-group matched for variance. Experiments are ongoing with a subject pool age-matched to the astronaut group.

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53.425 Not peripersonal space but the working area of the hand determines the presence and absence of the visual capture of the felt hand location in a mirror along the sagittal plane

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Based on the mirror-box techniques of Ramachandran and colleagues, when normal healthy participants views their left arm in a mirror positioned along the midsagittal plane, the impression of viewing his right hand (virtual right hand) visually captures the felt right hand location and participants rarely notice their unseen real right hand location behind the mirror, which is far from the virtual hand. To investigate the relationship between this illusion and peripersonal space, we evaluated the spatial limit of the illusion along the sagittal plane. Participants put their left hand on the mirror at a fixed position. In each trial, they were required to put their right hand at random position and to tap the mirror six times with all fingers synchronously with both hands , and were required to report whether they felt their right hand behind the mirror was located mirror-inversed position to their left hand or not. Their hand and finger positions were recorded using the infra-red motion-capture system (Library co. ltd.). The plot areas of their wrist position showed that the illusion was seen almost anywhere in the working area of the right hand except at the limit, which suggests that it is not peripersonal space but that the muscle tensions and signals from the subjects' joints may erase this illusion when the arm posture is unnatural. To further test this possibility, we kept the observers' right wrist positions the same as the virtual wrist. Their real right hand was always within their peripersonal space. The participants randomly twisted their right hand along the sagittal plane while keeping their wrist location the same. Again, the illusion disappeared when they twisted their hand to the limit. These results suggest that the strong muscle tensions and signals from joints can overcome visual capture and recalibrate the visual-proprioceptive conflict.

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53.426 Multi-modally perceived direction of self-motion from orthogonally directed visual and vestibular stimulation

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We measured observers' perceived direction of self-motion resulting from the simultaneous presentation of visual and vestibular information, each simulating a different direction of motion. Sakurai et al. (2003, ECVP) reported that when observers experience real leftward/rightward motion while viewing a visual expanding/contracting optic flow pattern consistent with forward/backward self-motion, their perceived motion direction was intermediate to those specified by visual and vestibular information. This experiment extends that study and generalizes those findings, exploring other visual/vestibular combinations. Specifically, we explored more visual patterns including translational optic flow – consistent with upward/downward or leftward/rightward motion as well as our previous patterns of expanding/contracting optic flow, consistent with forward/backward motion. Observers were seated on an oscillating motor-driven swing pro-

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viding real motion, while they viewed optic flow patterns, phase-locked to the swing motion, consisting of sine wave gratings in each of four conditions: 1) forward/backward real motion paired with upward/downward translational oscillatory optic flow (horizontal gratings), 2) forward/backward real motion paired with leftward/rightward translational oscillatory optic flow (vertical gratings), 3) leftward/rightward real motion paired with upward/downward optic flow, 4) leftward/rightward real motion paired with expanding/contracting optic flow. Observers were cued to indicate their perceived direction of self-motion during one half of the swing period, by setting a virtual pointer presented at the center of the head mounted display. In every combination of orthogonally directed visual and vestibular stimulation, observers reported distorted directions intermediate to those specified by visual and vestibular information. For example, reported self-motion directions were forward and downward, backward and upward in condition 1, forward and rightward, backward and leftward in condition 2, leftward and downward, rightward and upward in condition 3, leftward and forward, rightward and backward in condition 4. Observers reported the opposite distortions of perceived self-motions for the complementary stimulus pairs in each condition.

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53.427 **Veridical walking inhibits vection perception**

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Vection (visually-induced self-motion perception) has been investigated for static observers generally. We aimed to investigate effects of walking (body action) on vection perception. Viewpoint motion along a line-of-sight was simulated in a three-dimensional cloud of dots (2 km/h, 1626 dots visible in average), and its optic flow was presented on a 120-inch rear-screen (91 x 75 deg). The direction of simulated motion was forward (expansion) or backward (contraction). Naive participants observed the stimulus during walking forward or backward on a treadmill (2 km/h) at 1.2 m viewing distance for 60 s. All four combinations of 2 optic-flow directions and 2 walking directions were repeated 4 times for each participant, and their vection latency and duration were measured. Vection latency was shorter in the backward vection condition than the forward vection condition. For the forward vection condition, its latency was longer when observers walked forward than backward. For the backward vection condition, its latency was longer when observers walked backward than forward. Thus, the vection perception was inhibited when observers' walking was in the direction of simulated viewpoint motion (direction of optic flow). These results seem to be paradoxical. Since the self-motion perception is a multi-modal perception fusing visual, vestibular, and propriceptive senses with different weights (weak fusion model), we speculated that the weight of visual self-motion (vection) is increased without walking or with incongruent walking (proprioception). On the contrary, the weight of vection is relatively decreased with veridical walking because both visual and proprioceptive information are available and congruent.

Acknowledgement: Supported by Grant-in-Aid for JSPS Fellows MEXT Japan to SO, Nissan Science Foundation to MK, and The Global COE program 'Frontiers of Intelligent Sensing'

53.428 **Visual and Auditory deterministic signals can facilitate tactile sensations**

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We report novel tactile-visual and tactile-auditory interactions in humans, demonstrating that a facilitating sound or visual deterministic signal, that is synchronous with an excitatory tactile deterministic signal presented at the lower leg, increases the peripheral representation of this excitatory signal (deterministic resonance). In a series of experiments we applied a local electrical stimulation and measured the electrical (electromyography or EMG) response of the right calf muscle while the local electrical stimulation was maintained at subthreshold levels (not detected). By introducing the visual or auditory representation of the local electrical signal (facilitation signal) to the central system the signal sensation was recovered and the electrical EMG signal increased. We go further by demonstrating that the neural dynamics of this phenomenon can resemble that of stochastic resonance by showing similar peripheral effects when introducing auditory noise instead of the same deterministic signal. In the last experiment, we show that the paired deterministic stimulations exhibit response functions similar to stochastic resonance.

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53.429 **Kinesthetic information modulates visual motion perception**

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Previously we showed that actively moving a grating pattern disambiguates the perceived direction of visual motion. We demonstrate here that active movement is not necessary, but that kinesthetic signals from passive movement of the hand can disambiguate the perceived motion direction. Eight subjects did 4 active and 4 passive blocks in Experiment 1. In active blocks, subjects slid a dumb-bell shape device (bar connecting two 6" plates) on a tabletop along self-chosen directions for 4000ms. Its position was recorded at 250Hz. Square-wave gratings (2 deg/cycle), rendered on a monitor, were reflected by a mirror onto the plane co-aligned with the top plate and moving at the same velocity as the subjects' hand movement. Subjects viewed the gratings through a 12-degree round aperture and reported the perceived grating motion direction. In passive blocks, the device was mounted on a robot arm, which regenerated the motion recorded in active blocks. Subjects, grasping the bar, were moved by the robot without seeing their arms and performed the same task. Seven subjects' direction judgments showed modulation from the hand movement in both conditions. The weights given to kinesthetic signal were not statistically significant in active and passive conditions (paired t(7)=0.46). In Experiment 2, 8 new subjects did 4 passive and 4 vision-only blocks, in which subjects reported the motion without grasping the bar. Six subjects showed kinesthetic modulation in the passive condition, but none in the vision-only condition, excluding the possibility that subjects used visual cues in judging the true motion direction. The results confirm that kinesthetic information modulates motion perception. That a similar magnitude of perceptual modulation occurred in passive and active conditions indicate that high-level intentional signals about the planned movement direction cannot explain the effect, rather the brain integrates kinesthetic and visual signals when estimating the visual motion direction.

53.430 **Does it feel shiny? Haptic cues affect perceived gloss**

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Human observers combine haptic (touch) and visual cues to estimate object properties such as slant (Ernst, Banks & Buelthoff, 2000) and size (Ernst & Banks, 2002). In the present study we ask whether haptic cues can change a visual percept; specifically, is the perception of gloss influenced by how an object feels? Observers binocularly viewed a single convex shaded bump, either with or without a specular highlight. The specular highlight was either aligned with the diffuse shading, or offset by up to 120°. On visual-only trials observers simply viewed the stimulus and made a 2AFC shiny vs. matte judgement. On visual-haptic trials, observers touched and viewed the stimulus before making their judgement. Stimuli felt either hard and smooth or soft and rubbery. In agreement with previous work (Anderson & Kim, 2009), specular highlights that were closely aligned with the diffuse shading led to shiny percepts. However, as the misalignment increased, the object was increasingly judged as matte. Importantly, when the object felt hard and smooth, observers classed the objects as shiny for larger highlight misalignments. In contrast, when the object felt soft and rubbery, objects appeared matte with smaller offsets between highlight and diffuse shading. We conclude that haptic information can alter observers' visual percepts of material properties.

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53.431 **Effective tactile noise can decrease luminance modulated thresholds**

J.E. Lugo[1](je.lugo.arce@umontreal.ca), R. Doti[1], J. Faubert[1]; [1]Visual Psychophysics and Perception Laboratory, School of Optomety, Université de Montréal

The multisensory FULCRUM principle describes a ubiquitous phenomenon in humans [1,2]. This principle can be interpreted within an energy and frequency model of multisensory neurons' spontaneous activity. In this context, the sensitivity transitions represent the change from spontaneous activity to a firing activity in multisensory neurons. Initially the energy and frequency content of the multisensory neurons' activity (supplied by a weak signal) is not enough to be detected but when the facilitation signal (for example auditory noise or another deterministic signal) enters the brain, it generates a general activation among multisensory neurons of different regions, modifying their original activity. The result is an integrated activation that promotes sensitivity transitions and the signals are then perceived. For instance, by using psychophysical techniques we demonstrate that auditory or tactile noise can enhance the sensitivity of visual system responses to weak signals. Specifically, we show that the effective tactile noise significantly decreased luminance modulated visual thresholds. Because this multisensory facilitation process appears universal and a fundamental property of sensory/perceptual systems, we will call it the multisensory FULCRUM principle. A fulcrum is one that supplies capability for action and we believe that this best describes the fundamental principle at work in these multisensory interactions. [1] Lugo E, Doti R, Faubert J (2008) Ubiquitous Crossmodal Stochastic Resonance in Humans: Auditory Noise Noise Facilitates Tactile, Visual and Proprioceptive Sensations. PLoS ONE 3(8): e2860. doi:10.1371/journal.pone.0002860 [2] Lugo J E, Doti R, Wittich W, Faubert J (2008) Multisensory Integration: Central processing modifies perypheral systems. Psychological Science 19 (10): 989-999.

Acknowledgement: NSERC-Essilor Chair and NSERC

53.432 **Semantic congruency, attention, and fixation position modulate conscious perception when viewing a bistable figure**

Jhih-Yun Hsiao[1](r97227115@ntu.edu.tw), Yi-Chuan Chen[2], Charles Spence[2], Su-Ling Yeh[1]; [1]Department of Psychology, National Taiwan University, [2]Department of Experimental Psychology, University of Oxford

Bistable figures provide a fascinating window through which to explore human visual awareness. This is because a constant visual stimulus induces a dynamic alternation between two distinct percepts over time. Here we provide evidence that a background auditory soundtrack (that was semantically congruent with one or other percept) can modulate people's perception of bistable figures; we then further test whether this factor interacts with the factors of selective attention and fixation position that have previously been shown to influence the perception of bistable figures (Meng & Tong, 2004). The participants viewed the "my wife or my step-mother" figure and reported their dominant percept continuously. In Experiment 1, the participants reported seeing the old woman (young lady) for more of the time when listening to the voice of an old woman (young lady). In Experiment 2, this auditory modulation of bistable figure perception was observed regardless of where the participants were instructed to focus their fixation. In Experiment 3, attending to a specific view was found to dominate the percept of the bistable figure and this factor overrode the modulation of bistable perception by auditory semantic congruency. These results therefore suggest that in the process by which a conscious percept emerges when viewing a bistable figure, the modulation of both semantic congruency and selective attention were independent of the low-level factors of overt fixation position; however, the influence of selective attention is more powerful than that of auditory semantic congruency. These results also imply that the modulation of top-down factors of selective attention and semantic congruency on the formations of visual awareness in ambiguous situations may be weighted differently, such as when comparing bistable figures and binocular rivalry (see Chen, Yeh, & Spence, submitted).

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53.433 **Formal congruency and spatiotemporal proximity in multisensory integration**

Elena Makovac[1](elena.makovac@hotmail.it), Walter Gerbino[1]; [1]Department of Psychology "Gaetano Kanizsa", University of Trieste, Italy

Makovac & Gerbino (2009 a, b) reported increases of the multisensory response enhancement (MRE) when audiovisual AV components of a cross-modal event are (a) formally congruent, like in the takete-maluma phenomenon, and (b) in close spatiotemporal proximity, a necessary condition for multisensory integration by the superior colliculus and other brain areas (Calvert et al. 2000). While previous studies required observers to explicitly evaluate target properties, our MRE effects were obtained by asking observers to detect the occurrence of V targets and to ignore sounds, in either A and AV trials. Data were consistent with general principles of multisensory integration (spatial rule, temporal rule, inverse effectiveness rule). In the present research we utilized a combination of implicit tasks to study three aspects of MRE effects: (1) the interaction between the structural components of cross-modal stimulation, formal congruency and spatiotemporal proximity; (2) the optimal AV asynchrony compatible with low-efficiency stimuli; (3) the relationship between superadditivity and automatic activation as criteria for defining multisensory integration. Formal congruency was manipulated by varying the degree of similarity between the sound intensity profile and the 2D visual shape of short (<100 ms) AV events. The optimal (i.e., inducing a maximum MRE) stimulus onset asynchrony was compared to perceived simultaneity of AV stimuli for each observer, measured in a control condition. Superadditivity was evaluated by comparing the estimates of top performances in unisensory and multisensory sessions. We discuss our results in the context of current psychophysical and fMRI evidence on formal (Gallace & Spence 2006), semantic (Hein et al. 2007), and training-induced (Naumer et al. 2008) congruency effects in AV object representation.

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53.434 **Unusual bilateral referred sensations in a lower limb amputee during mirror therapy: Evidence for a phantom limb within a phantom limb, and cross-hemispheric reorganization**

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Background. Amputees often perceive sensations to be emanating from their missing limbs. Sensations can be evoked by touching an intact body part ("referred sensations", RS) or by creating the visual illusion of an intact limb under volitional control (e.g. using a mirror image of one's intact, moving limb). Current findings suggest that RSs are associated with reorganization of the somatosensory cortex, with the area previously associated with the limb now responding to stimulation of the adjacently mapped body area (Ramachandran, Flor). We report a rare example of bilateral RS that is evoked by mirror stimulation, and that may imply long-range, cross-cortical remapping. Method/Results. Bilateral RSs were elicited from a 50 y/o male above-the-right-knee amputee whenever he viewed his intact leg in a mirror (treatment for phantom limb pain). (1) In the absence of mirror stimulation, he experienced a paralyzed phantom right leg with pain in the toes and no RS. (2) Mirror stimulation elicited movement and tingling sensations, and transient pain suppression. (3) If during mirror stimulation, he was touched on his lower left leg or foot, he felt stimulation at equivalent sites in BOTH limbs. (4) The bilateral effect lasted for up to a minute after removing the mirror. (5) The mirror illusion caused RSs of his right foot and lower right leg on his LEFT knee. That is, touching the back and front of his LEFT knee evoked RSs perceived to emanate from his phantom RIGHT foot and knee. Discussion. These rare phenomena are inconsistent with simple remapping of adjacent cortical areas in this subject. It seems likely that the right somatosensory cortex (which normally controls the left leg) now controls the corresponding left cortex that formerly controlled the right leg. A neuroimaging study could establish if stimulating the left leg activates bilateral cortical areas.

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53.435 **Evaluative model of cross-modal correspondences**

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To date cross-modal correspondences of stimuli from different sensory modalities have been widely demonstrated, although mechanisms that stand behind the phenomenon have not been fully established yet. In previous studies we investigated the role of evaluative meaning (semantic features that people impose to the external world, e.g. pleasant or interesting) in our experience of stimuli from different sensory modalities. The results showed that the elementary evaluative attributes we impose to stimuli from different modalities converge into three basic evaluative factors: affective evaluation (pleasant, positive, relaxing), arousal (impressive, powerful, interesting), and cognitive evaluation (clear, regular, meaningful) (Jankovic, 2000; Markovic, Jankovic, Subotic, 2002). We also demonstrated a significant similarity among obtained factorial structures across different sensory modalities, implying cross-modal nature of evaluative meaning. Following the establishment of a 3-D cross-modal semantic (evaluative) space, stimuli from different sensory modalities that have nothing

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in common (considering explicit, objective features) can now be subjected to the same metrics and compared according to their semantic similarity. In Experiment 1 respondents judged abstract visual patterns and pseudowords on the same set of evaluative attributes. By calculating the distance of stimuli in the 3-D evaluative space we have obtained mutual evaluative similarity of visual and verbal stimuli. In Experiment 2 respondents were asked to make explicit matches between abstract visual patterns and auditory presented pseudowords. The results showed that cross-modal correspondences are mostly predicted by evaluative similarity of visual and verbal stimuli. Affective evaluation appears to be the most important predictor, followed by arousal and cognitive evaluation. In conclusion we propose the model for prediction of cross-modal correspondences based on semantic (evaluative) similarity of stimuli.

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53.436 **Divided Attention and Sensory Integration: The Return of the Race Model**

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The sensory brain processes different features of incoming stimuli in parallel. The combination/integration of features within or across sensory modalities can often improve perception and cognition as expected from probability summation. Interestingly, the literature on divided attention abounds with reports of integration effects that exceed probability summation. In the so-called redundant target paradigm, participants respond as quickly as possible to targets that are defined, for example, by their color (red vs. green) and/or orientation (vertical vs. horizontal). Typically, reaction times to redundant targets defined by both features are faster than to targets defined by a single feature only. In analogy to a higher probability for a "small number" when playing with two rather than one dice, probability summation or race-models can in principle account for a speeding up of reaction times. However, according to the influential race-model-test (Miller, 1982, Divided attention: evidence for coactivation with redundant signals, Cognitive Psychology 14, 247-279), reaction times are even faster and performance is even better than predicted by probability summation. Consequently, race models are rejected and a benefit due to sensory integration is assumed. Here, we critically evaluate the race-model-test and its interpretation. Fifteen observers participated in the experiment described above and we determined cumulative reaction time distributions based on a total of 3000 trials per condition. We show that not only fastest reaction times are faster but also that slowest reaction times are slower than predicted – a finding that is neglected by Miller's test and also in the literature. Importantly, in terms of variance, this result indicates that performance is not better but in fact worse. Hence, race models cannot be rejected. We hypothesize that the increased variance is related to capacity limited decision processes and provide new interpretations for a large variety of studies using the redundant target paradigm.

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Multisensory processing: Synesthesia

Orchid Ballroom, Boards 437–444

Tuesday, May 11, 8:30 - 12:30 pm

53.437 **Color Input into Motion Processing in Grapheme-Color Synesthetes**

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Background: It has been proposed that individuals with grapheme-color synesthesia have increased levels of connectivity, particularly between V4 and Visual Word Form Area (Hubbard and Ramachandran, 2005). To investigate whether increased connectivity may be a widespread phenomenon, we asked whether color and motion interactions are stronger in synesthetes than in controls. To this end, we used a paradigm that indexes the amount of chromatic (red/green) input to motion processing as compared to a benchmark of luminance (light/dark) input to motion processing. Methods: We used a MOT/DET paradigm, which obtains the ratio of contrast threshold for discriminating direction of a moving grating (MOT), to the contrast threshold for detecting that same moving grating (DET). Typical adults exhibit MOT/DET ratios near 1.0 for luminance gratings, but closer to 2.0-4.0 for chromatic gratings, suggesting that chromatic information provides weaker input to motion mechanisms than luminance information. Our stimuli were luminance and chromatic horizontal gratings (1.0cpd, 5.5Hz, subtending 2.0x2.0°). In the MOT task, a grating was presented and participants indicated whether it moved up or down. In the DET task, participants indicated in which of two intervals contained the moving grating. The relative contribution of chromatic versus luminance information for motion processing is calculated as the difference in log MOT/DET ratios for chromatic vs. luminance gratings (Diff-Ratio), with values > 0 indicating weaker chromatic input. If synesthetes have greater-than-normal color-motion interactions: 1) their chromatic MOT/DET ratios should be lower than controls, and 2) their Diff-Ratio should be lower than controls. Results: While both synesthestes (n = 7) and controls (n = 7) showed Diff-Ratios significantly greater than 0 (indicating weaker chromatic vs. luminance input to motion), there were no group differences in Diff-Ratio, nor chromatic MOT/DET. Conclusions: At current, we do not find evidence for increased interactions between color and motion in synesthetes.

53.438 **Determinants of synesthetic color choice for Japanese characters**

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The determinants of synesthetic color choice for Japanese characters were studied in six Japanese synesthetes, who report seeing color for characters, numerals and letters. Four possible determinants were investigated: visual form (script), character frequency, sound, and meaning. Three kinds of Japanese characters were used as stimuli: Hiragana, Katakana, and Kanji. Hiragana and Katakana are both Japanese phonetic characters that represent the same set of syllables although their visual forms are dissimilar. Hiragana characters appear much more frequently in Japanese texts than do Katakana characters. Kanji characters are logographs, which represent a meaning or a concept, like a content word does. There are many homophones among Kanji characters. Also many Kanji characters share the same visual components (radicals) although their sounds and meanings are dissimilar. By using Hiragana, Katakana, and Kanji characters, we could dissociate effects of sound, visual form, character frequency, and meaning in Japanese grapheme-color synesthesia. From a palette of 138 colors, the synesthetes selected a color corresponding to each character. The experimental sessions were repeated three times to assess participants' consistency of color choices. The results for Hiragana and Katakana characters were remarkably consistent. This indicates that color selection depended on character sounds, not on visual form or character frequency. The color selections for Kanji numerals were remarkably consistent with those for Arabic numerals, which had been tested separately. Furthermore, Kanji characters which represent color names and names of objects with high color diagnosticity were represented by the corresponding colors, indicating that meaning was a strong determinant of synesthetic color choice for Kanji characters. These results suggest that sound and higher order processing (i.e., semantics) are involved in Japanese grapheme–color synesthesia.

53.439 **When the Inducing Grapheme Changes and When the Induced Synesthetic Color Changes**

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Background: It has been shown that conscious awareness of an inducing grapheme is necessary for synesthetic color experience (Mattingley et al., 2001; Rich & Mattingley, 2005). However, whether grapheme recognition should precede synesthetic color perception has not been addressed. Using particular grapheme pairs that entail ambiguous recognition when rotated, i.e., W-M or 6-9, we investigated the temporal relationship between grapheme recognition and synesthetic color perception. Experiment 1: In 2 separate blocks of trials, 9 synesthetes observed either the letter W(M) or the digit 6(9) followed by a pattern mask. The presented graphemes were in one of seven different angles between 0 and 180 degrees. Observers responded by pressing one of two keyboard buttons indicating the perceived identity of the grapheme in the grapheme recognition task (e.g., W or M) or the experienced synesthetic color (e.g., purple or green for SK) in the synesthetic color task. For the most synesthetes tested, reaction time(RT) was slower in the synesthetic color task than in the grapheme recognition task.

Experiment 2: In 2 separate blocks of trials, a subset of synesthetes who participated in Experiment 1 observed either the letter or the digit rotating in clockwise or counterclockwise direction. The initial angle of the grapheme was varied. Observers responded by pressing a button indicating the moment the grapheme changes its identity (e.g., from W to M or from M to W) or the moment the experienced synesthetic color changes (e.g., from purple to green or from green to purple for SK). For all the synesthetes tested, the pattern of results shown by perceptual latency in Experiment 2 was parallel to that shown by RT in Experiment 1. To further investigate whether grapheme familiarity influences the microgenesis of synesthetic color experiences, we're now testing Korean synesthetes who see colors on both alphanumeric and Korean characters.

Acknowledgement: This work was supported by Korea Research Foundation- Grant funded by the Korean Government (KRF-2009-332-H00011)

53.440 **Vividness of visual imagery predicts spatial priming in grapheme-color synesthetes**

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Synesthesia is well understood to be an automatic perceptual phenomenon paralleling print color in some ways but also differing in others. Following a study presented previously, we address this juxtaposition by asking whether synesthetic color binds to the location of an invoking grapheme in the same way as print color. We tested 17 grapheme-color synesthetes using stereo glasses to produce the perception of two planes in 3D depth. On each trial, an achromatic letter (prime) appeared for 750 msec on the near or far plane of space and participants named the immediately following color patch (probe) quickly and accurately. The prime and probe appeared in the same line of sight and either on the same or different spatial planes. The probe color was either the same or different to the synesthetic color induced by the prime. Supporting previous work, we found faster responses to name the probe colors congruent with synesthetic colors than incongruent, but synesthetes as a group did not show effects of spatial priming, unlike non-synesthetes who exhibited faster RTs when prime and probe locations were different. However, individual synesthetes showed dramatically different spatial priming effects, exhibiting a positive correlation between their spatial priming scores and mental imagery measures (Marks, 1973). Specifically, synesthetes with more vivid visual imagery were faster to name a color when the prime and probe were on the same plane while those with weaker visual imagery showed the opposite pattern. Results from 17 non-synesthetes primed with colored letters but the same probe task showed that under the current conditions, negative spatial priming is the norm. Thus, synesthetes with strong visual imagery appear to overcome the typical prime/probe conflict, suggesting that synesthetic color may operate through a cortical network that interacts with printed color but exists as a separate feature representation.

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53.441 **New results in neuroscience, behavior, and genetics of synesthesia**

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Synesthesia is a phenomenon in which stimulation of one sense triggers an experience in another sense. The most common forms produce an automatic perception of color in response to a grapheme or a word, although there are many forms involving various sensory associations with smell, taste, and touch. Synesthesia is thought to occur in at least 1% of the population, and the associations are quantifiable by measuring their consistency within subjects over time. Using data from the online Synesthesia Battery (www.synesthete.org; Eagleman et al, 2007), we have analyzed the forms of synesthesia reported by almost 6,000 synesthetes. Our results indicate that synesthesia forms tend to cluster into five main groups, one of which we term colored sequence synesthesia (CSS). This clustering pattern suggests that synesthetes with one colored sequence (e.g. number-color) are likely to have others (e.g. letter-color, weekday-color, month-color) but unlikely to have a form like music-color. In an effort to elucidate the neural activity underlying CSS, we present neuroimaging data collected while showing synesthetes clips of black and white children's television. Our preliminary data indicate that synesthetes and non-synesthetes process color in anatomically distinct regions. Finally, the genetic mechanisms responsible for synesthesia have been widely debated but remain largely unknown. We present data from our ongoing family linkage analysis, collected from 48 individuals in five large families. Each affected synesthete was verified for CSS using the Synesthesia Battery. Our results implicate a 23MB region on chromosome 16. In sum, we combine data from cluster analyses, neuroimaging studies, and genetic linkage analyses to present a coherent picture of the neural basis of synesthesia, an understanding which will serve as a powerful guide to the normal operations of neural cross-talk and perception.

53.442 **10 Color-grapheme synesthetes with highly similar learned associations**

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Recent work on synesthesia has begun to emphasize the role of learning in determining the particular inducer concurrent pairings manifested in synesthesia (Rich et al, 2005; Smilek et al, 2007; Eagleman, 2009). Previously we reported on a female color grapheme synesthete with color letter pairings that closely resembled the colors found in a childhood letter set strongly suggesting that an environmental stimulus can shape the development of synesthesia (Witthoft & Winawer, 2006). Here we extend this case study to a group. We present data from an additional 9 synesthetes (4 female / 5 male) with remarkably similar color-letter associations, 8 of who also recall or are still in possession of the same or a similar Fisher Price childhood letter set. All the synesthetes were raised in the US and are in a similar age group (~27-39 years old). Color matching data and behavioral performance indicative of synesthesia were largely gathered via the synesthete.org website (see Eagleman et al, 2007). Additionally, 5/10 subjects have been tested in the laboratory by ourselves or other researchers (Kim & Blake, 2006; Alvarez & Robertson, 2008). Intersubject correlations for the hues assigned the 24 (I and O are excluded) letters are above 0.99 in some subject pairs, with several subjects choosing almost exactly the same hue for each letter (with all the colors closely matching those in the letter sets). While these data do not comment on the possible importance of genetic factors in determining who will become a synesthete (Ward & Simner, 2002; Barnett et al, 2008; Asher et al, 2009), they do add further support to the idea that, in some people, environmental stimuli can play a strong role in shaping synesthetic associations.

53.443 **Motion induced pitch: a case of visual-auditory synesthesia**

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We report a novel feature-based visual-auditory synesthesia that is more elaborate than the previously reported percepts of synchronized auditory beats induced by visual flashes. CN hears specific pitches and chords when she views different motion patterns including a perfect 5th chord when viewing rotational apparent motion, a tritone chord when the rotation is ambiguous, and complex jarring sounds when viewing dynamic random dots. We discovered that this form of synesthesia builds on simple systematic relationships between visual motion direction and auditory pitch. In the current study, we determined the tuning, the underlying coordinate system, and the sensory impact of this synesthesia. To determine the tuning, we used sinusoidal gratings of 0.12 cycles/deg moving at 22.9 deg/sec, which reliably produced sounds for CN. While viewing a moving sinusoidal grating, CN experiences a 315-Hz sound when the grating moves upward, a 254-Hz sound when it moves horizontally in either direction, and a 217-Hz sound when it moves downward. JNDs were all less than 3-Hz, indicating precise and stable interactions between motion direction and pitch; these relationships were relatively independent of speed. Interestingly, CN experiences no sounds when viewing a square-wave grating, suggesting that the underlying synesthetic interactions are specific to spatial-frequency content as well as direction of motion. We examined the underlying coordinate system of her synesthesia with 90-degree head tilt; the results indicated that CN's synesthesia arises from a head-centered processing of visual motion. Lastly, to demonstrate the sensory impact of the synesthesia, we used a 2IFC motion-coherence detection task. CN reported using synesthetically induced sounds to detect coherent motion. Indeed, her coherence-detection thresholds were lower than those of non-synesthetic control participants. These results suggest that visual processing of motion direction and auditory perception of pitch can maintain surprisingly specific and systematic neural connections.

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53.444 **Electrophysiological Evidence Supporting the Automaticity of Synaesthetic Number-Forms**

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For individuals with Number-Form Synaesthesia, numbers occupy very specific and highly consistent spatial locations. The number-form synaesthete we studied here (L) experiences the numbers 1 to 10 rising vertically from bottom to top, then extending in a horizontal left to right direction from 10-20. Using a spatial cueing paradigm, we empirically confirmed L's subjective reports of her unique number line. Digits 1, 2, 8, or 9 were centrally presented on a computer screen followed by a target square that appeared on the bottom or top of the display. L was reliably faster at detecting targets in synaesthetically cued relative to uncued locations, where controls showed no response time differences. Interestingly, L's cueing effects disappeared once the targets were misaligned with her number-forms (presented on the left and right of the display). Furthermore, L demonstrated the vertical cueing effects even at short stimulus onset asynchronies (150 ms SOAs) between cue and target onsets, suggesting her attention was automatically shifted to the cued location. Here, we used event-related brain potentials (ERPs) to provide converging evidence for L's rapid shifts of attention. Compared to non-synaesthetes, L's brain waves generated an early negative deflection occurring at about 200 ms (N2) in occipital and parietal sites following valid targets, reflecting an early enhancement in attention to validly cued locations. Importantly, this N2 component disappeared once the targets were misaligned with her number-forms (targets appeared on the left and right). Non-synaesthetes showed no ERP differences to detect the targets when presented both vertically and horizontally. These findings substantiate L's behavioural cueing effects for the vertical targets at short SOAs with converging electrophysiological evidence that revealed the emergence of early-evoked potentials to validly cued locations. These findings further strengthen our claim that for this synaesthete (L) digits automatically trigger shifts in spatial attention.

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Temporal processing: Perception of time

Orchid Ballroom, Boards 445–456

Tuesday, May 11, 8:30 - 12:30 pm

53.445 **The effect of luminance signal on adaptation-based duration compression**

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Adapting to high temporal frequency luminance-modulated gratings reduces the apparent duration of a subsequently presented sub-second dynamic stimulus (Johnston, Arnold & Nishida, 2006, Current Biology, 16(5):472-9). Here we investigate the effect of the luminance signal on the strength of this temporal aftereffect using stimuli defined along the equiluminant S-constant axis and elevated with respect to the equiluminance plane of the DKL space (Derrington, Krauskopf & Lennie, 1984, Journal of Physiology, 357:241-65). We first found the individual equiluminance points using the minimum motion technique (Cavanagh, MacLeod & Anstis, 1987, Journal of the Optical Society of America A, 4(8):1428-38) for different temporal frequencies and contrasts. We then eliminated the effect of adaptation on the perceived speed (of a 7Hz test) by using interleaved 5Hz and 10Hz adaptors for different luminance levels (equiluminance and an intermediate (65cd/m²) luminance difference between the magenta and cyan grating phases), separately. Finally, we used these individual ratios, at which no change occurred in the perceived speed of a 7Hz test pattern, in our duration experiments. A standard grating (600ms, 7Hz, 0.5cpd) was always displayed at the adapted location (in half of the trials 5° above, in half of the trials 5° below the fixation point) and a comparison (7Hz, 0.5cpd), presented at the unadapted side, was varied over trials (300ms – 1200ms) to generate a psychometric function. The PSE provided a measure of perceived duration. Both test and adaptor were either isoluminant, or luminance modulated with a 45cd/m² and 90cd/m² luminance difference between the magenta and cyan phases of the chromatic gratings (magenta being darker). We found an apparent temporal compression of the luminance modulated gratings which decreased with a reduction in luminance contrast and was no longer significantly different from zero at equiluminance. This provides further evidence for the involvement of the magnocellular system in adaptation-based compression.

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53.446 **Orientation-specific flicker adaptation dilates static time**

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Adapting to a flickering stimulus makes a subsequently presented static stimulus (in the order of 500-1000 ms) appear longer. This flicker-based time-dilation aftereffect has been thought to be mediated by central mechanisms such as increased arousal and attention. We investigated a potential role of low-level visual adaptation in this aftereffect. If flicker adaptation of low-level visual neurons contributes to subsequent temporal dilation, the aftereffect should be orientation specific, stronger when the orientations of the adaptor and test stimuli are the same than when they are different. The arousal hypothesis predicts no orientation specificity, the attention hypothesis predicts the opposite effect because attention capture by orientation change should make the different-orientation test stimulus appear longer, and contrast adaptation also predicts the opposite effect because the less visible same-orientation test stimulus should appear shorter. We used vertical and horizontal Gabors (4.17° radius, 4.32 cycles/deg) as the adaptor (flickered at 5 Hz or static; lasting 5000 ms) and test (static; lasting from 200 to 800 ms) stimuli. The perceived duration of the test stimulus was measured using a 2AFC temporal bisection task (shorter PSEs indicating temporal dilation). Overall, the test stimulus appeared longer (by 67 ms) when preceded by a flickered adaptor compared to a static adaptor, replicating the previous results. Crucially, the test stimulus appeared even longer (by 31 ms) when the flickered adaptor and the test Gabor had the same orientation than when they were orthogonal. These results suggest that flicker-based adaptation of orientation-tuned visual neurons contributes to temporal dilation over and above any effects of arousal, attention capture, and/or contrast adaptation. This orientation-specific time-dilation aftereffect is distinct from the recently reported location-specific but orientation-independent time shrinkage aftereffect (from rapidly flickering adaptor to flickering test). Time perception thus depends on the adaptive states of low-level visual processes in multiple ways.

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53.447 **Influences of stimulus predictability on its perceived duration**

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Our ability to judge how long a visual stimulus lasts has been proposed to rely on an internal content-dependent clock, which determines apparent duration using a "predict and compare" strategy. For example, a prediction of what the visual world will look like in 100 ms is continuously compared to the sensory input. When the prediction matches the visual input, the system determines that 100 ms have passed and resets the prediction (Johnston, In Attention and Time, edited by Nobre & Coull (OUP, Oxford), In press). If this is true, it is reasonable to expect that the degree of predictability of a stimulus has an influence on its perceived duration. In this experiment, we asked subjects to compare the relative duration of a 10 Hz drifting comparison stimulus (variable duration across trials) with a standard stimulus (fixed duration, 600, 1200 or 2400 ms) with different degrees of predictability in different sessions. The standard could be static, drifting at 10 Hz (these two conditions are highly predictable) or mixed (a combination of static and drifting intervals). In this last condition the degree of predictability of the stimulus was low: a static interval always followed a drifting one, but we assigned a duration between 100 and 200 ms to each subinterval, randomly, within and across trials. For all standard durations, the unpredictable (mixed) stimulus looked significantly compressed (~20% reduction). The drifting and the static stimulus differed from the actual

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duration only for one standard duration in each case (mild expansion for drifting at 2400, compression for static at 1200 as predicted by Brown, 1995, Perception & Psychophysics, 57(1): 105-116). These results support the idea that interfering with the predictability of a stimulus may disrupt the continuity of a "predict and compare" mechanism and therefore, influence its apparent duration.

53.448 Is Subjective Duration a Signature of Coding Efficiency?

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The perceived duration of a stimulus can be modulated by novelty and repetition (Pariyadath & Eagleman, 2007, 2008; Eagleman and Pariyadath, 2009). For example, in a repeated presentation of auditory or visual stimuli, an oddball stimulus of equivalent physical duration appears to last longer, a phenomenon known as the oddball effect. We have proposed that this duration illusion is a reflection of the neural phenomenon of repetition suppression – the diminishment of the neural response to a stimulus that is repeated – suggesting that the illusion reflects not a subjective expansion of the oddball, but rather a contraction of the repeated stimuli. In support of this hypothesis, we show that patient populations with impaired repetition responses, such as in schizophrenia, perceive duration illusions differently from healthy controls. We further present neuroimaging data indicating that repetition suppression in stimulus-specific cortical areas influences subjective duration. Results from our lab and several scattered findings in the literature can be compiled to demonstrate that, in general, any stimulus manipulation that increases response magnitude (such as increasing stimulus size, brightness or predictability) leads to a concurrent increase in the perceived duration of the stimulus (Eagleman and Pariyadath, 2009). We propose the novel hypothesis that the experience of duration is a signature of the amount of energy expended in representing a stimulus—that is, the coding efficiency.

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53.449 Individual differences in time perception indicate different modality-independent mechanisms for different temporal durations

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The ability to estimate elapsed time is fundamental to human behavior, and this ability varies substantially across individuals. Its neural basis remains debated. While some evidence points to a central, modality-independent 'clock' underpinning this ability, other empirical data suggest sensory modality-specific 'clocks'. And whether different brain structures are involved in estimation of shorter and longer temporal intervals remains unclear. Here, we took a new approach to these questions by investigating individual differences in the ability to estimate the duration of stimuli in a large group of healthy observers, and their relationship to brain structure. We examined how well individuals could judge the duration of a stimulus presented for either a short (~2s) or longer (~12s) duration in either visual or auditory sensory modalities. We found substantial variation in accuracy across the group of participants; but while variability in participants' performance was highly consistent across modalities, it was much weaker across different estimation durations. We then examined whether these individual differences in behavioral accuracy were reflected in differences in gray matter density using a voxel based morphometry analysis applied to structural MRI images of our participants' brains. Taken together, our data suggest the existence of different modality-independent mechanisms for judging different temporal durations.

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53.450 Audiovisual integration: the duration of uncertain times

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Despite continual temporal discrepancies between sensory inputs, signals arising from the same event are bound together into a coherent percept. It has been suggested that multiple timekeepers monitor the different sensory streams, producing differences in perceived duration of events. Given this, what is the integration strategy adopted for combining sensory information in the time domain? Specifically, if the brain has information about the duration of an event from more than one source, can the uncertainty of the duration estimate decrease, and can the Maximum Likelihood Estimate (MLE) model predict such a change? Using a 2AFC procedure, participants had to judge which interval was longer (1st or 2nd) for auditory, visual and audiovisual stimuli. Each trial contained 2 intervals: a standard stimulus (sampled from one of three durations), and a comparison interval whose duration changed randomly in relation to standard stimulus duration. The reliability of the auditory stimulus was manipulated to produce the unimodal weighting scheme. Data was fit with a cumulative Gaussian psychometric function from which PSE and JND were extracted.

Results for unimodal trials showed JND changes that depended upon the duration of the standard, according to Weber's law. JND values also decreased with decreases in signal noise. Comparison of the present bimodal results with MLE predictions revealed optimal integration of auditory and visual duration cues. Additionally the results show that the integration of uncertain visual and auditory duration signals is a weighted average of these signals. That is, PSE shifts in perceived duration tended to reflect MLE predictions with shifts following the more reliable unimodal signal. These results are the first to demonstrate 'optimal' integration of sensory information in the time domain and contradict other studies applying MLE to this stimulus feature.

53.451 Spatially Localized Time Shifts in Visual Experience

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The neural encoding of an event must necessarily lag behind its occurrence in the outside world. However, we are not generally conscious of this processing delay. It is also possible to make a distinction between the time at which a neural representation of the event is formed (brain time), and the time at which we experience that event to have occurred (event time). Nevertheless, we expect that temporal relationships that exist in the world should be paralleled in visual experience. Here, we report that two synchronized running clocks appear temporally offset when one is presented in a region of the visual field previously adapted to a sequentially expanding and contracting concentric grating. After 20Hz adaptation, a clock in an adapted region appeared advanced relative to a clock in an unadapted region, whereas there was no such effect after 5Hz adaptation. The time-shift induced by adaptation cannot have been mediated by changes in the perceived speed of the clock, as 20Hz adaptation decreased, and 5Hz adaptation increased, its apparent speed. When comparing the two running clocks, observers were required to divide attention between two locations. However, the same pattern of time-shifts was also evident when observers reported the time on a single clock when exogenously cued by a visual transient. In a final experiment, we found that reaction times on a clock-hand position discrimination task presented in an adapted region did not differ for 5Hz or 20Hz adaptation, showing that the absolute time required for visual information from an adapted region to be accessed was unaffected by adaptation. Altogether, our findings show that it is possible to induce spatially localized time-shifts in visual experience. These shifts are not a result of changes in processing latency. Rather, they indicate a decoupling of visual time representation and the timing of concurrent visual events.

53.452 Does audiovisual temporal recalibration store without stimulation?

Tonja-Katrin Machulla[1](tonja.machulla@tuebingen.mpg.de), Massimiliano Di Luca[1], Marc O. Ernst[1]; [1]Max Planck Institute for Biological Cybernetics, Tuebingen

Recent studies have investigated adaptation to temporal discrepancies between different sensory modalities by first exposing participants to asynchronous multisensory signals, and subsequently assessing the magnitude of the adaptation effect (the size of the shift in subjective simultaneity). Although never reported, there is reason to assume that the strength of the adaptation effect declines during this measurement period. Usually, short re-exposures are interleaved with testing to prevent such declining. In the present study, we show that a decrease in the strength of adaptation still can take place, even when a common re-exposure procedure is used. In a second experiment, we investigated whether the observed decline is due to: (1) a dissipation of adaptation with the passage of time or, (2) a new adapta-

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tion induced by the test stimuli. We find that temporal adaptation does not dissipate with time but is stored until new sensory information, i.e., stimuli that differ from those used during the adaptation procedure, is presented. An alternative explanation, namely that adaptation decays over time but is re-established before the first test trial due to the experimental procedure we chose, is addressed in a control experiment. This finding is discussed in terms of Helson's adaptation level (AL) theory [1947, Adaptation-level as frame of reference for prediction of psychophysical data. The American Journal of Psychology, 60, 1-29], according to which the null point of any perceptual dimension, in our case the perception of simultaneity on the dimension of temporal order, is a summarizing statistic of all stimuli presented in the past. Any single stimulus pulls the AL toward its own value, and any single stimulus is judged as though it was being compared with the current AL.

53.453 **Color-motion asynchrony depends on stimulus repetition**

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Color-motion asynchrony depends on stimulus predictability To craft a useful model of the world, the visual system must combine information about different stimulus features processed at different times in different networks in the brain. This perceptual binding can be fooled by certain types of visual stimuli. For example, when two stimulus attributes (e.g., color and motion) are simultaneously alternated between two states (e.g., red/upward motion and green/downward motion), the color is perceived as changing ~80 ms before the motion direction. Previous investigations into this color/motion asynchrony (CMA) illusion have used a repetitive stimulus which alternates between two colors. In contrast, we here measure perceptual asynchrony using repeated (grey-blue-grey-blue-…) and random (grey-blue-grey-orange-…) color sequences paired with alternating directions of vertical motion. The CMA was found to be 17% smaller in the randomized condition (68 ms) than in the repeated condition (82 ms). This result suggests that the asynchrony illusion is related to, or at least modified by, neural repetition suppression—the phenomenon of a diminishing neural response to a repeated stimulus. Using functional neuroimaging, we measured the BOLD signal amplitude in the posterior fusiform gyrus to be 19.3% smaller in the repeated condition than in the random condition. All reported characteristics of the CMA illusion appear to be explained by a model of perceptual decision-making in which neural evidence for each alternative, defined as the concurrent response of the relevant color and motion populations, is accumulated over time and compared. The alternative with the greater evidence is the end result of the decision. In this model, a change in the relative latencies or firing rates of these signals can lead to a change in the final perceptual decision. Our findings demonstrate that stimulus repetition—and thus the amplitude of neural responses—are important factors in the CMA illusion.

Acknowledgement: NIH RO1 NS053960

53.454 **The spatial selectivity of neural timing mechanisms for tactile events**

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Adaptation studies [Johnston et al. 2006, Burr et al. 2007] suggest that visual events are timed by multiple, spatially selective mechanisms anchored in real-world rather than retinal coordinates [Burr et al. 2007]. To test whether this was a general property of event timing we investigated timing mechanisms for touch, using a paradigm similar to that used in vision [Burr et al. 2007]. Subjects adapted to tactile movement by resting their right index finger on a corrugated grating etched on a wheel moving at 15 cm/sec (45 Hz). After adaptation, subjects compared the duration of a test stimulus (22 Hz moving grating of variable duration) presented to the adapted hand to a probe presented to the index finger of the left hand for 600 ms after a 500 ms pause. Three different conditions were examined: full adaptation, where the test stimulus was presented to the same index finger in the same position as the adaptor; dermotopic adaptation, where the test was presented to the index finger in a different position in space; and spatiotopic adaptation, where the test was presented to the middle finger moved to the same spatial position as the adaptor. Both perceived speed and perceived duration of the tactile stimulus were affected by adaptation. When the speed of the test was adjusted to compensate for the effects of adaptation, the effects of event time in the dermotopic condition were minimal, while the full and spatiotopic adaptation conditions showed large reductions in perceived duration, up to 40%. These results suggest that like visual events, tactile events are timed by neural mechanisms that are spatially selective, not in receptor coordinates but in external or body-centered coordinates. This may be important in constructing and updating a body representation within which tactile events are timed.

53.455 **The curse of inconsistent auditory-visual perceptual asynchronies**

Daniel Linares[1](danilinares@gmail.com), Alex Holcombe[1]; [1]School of Psychology, University of Sydney

Neurophysiological recordings indicate that sensory latencies are shorter for auditory than for visual signals. Whether this processing advantage for sounds causes them to be perceived earlier has been studied using synchrony and temporal order tasks with a click and a flash, but results have been inconsistent across both tasks and individuals. Some or all of the inconsistency may result from temporal attraction and repulsion effects (e.g. temporal ventriloquism) of a click and flash presented close in time. We probed relative perceptual latency in two tasks for which auditory-visual interactions should be smaller or absent. METHODS. In the first, a flash-lag task, participants reported the location of a moving object at the time of a click or a flash. Relative perceptual latency was inferred from the difference in reported positions between the click and the flash conditions. The second task was to judge which of two intervals was longer. A click and a flash were used to bound the intervals, which were several hundreds of milliseconds long to avoid auditory-visual interactions or sensory integration. A shorter perceptual latency for clicks should yield a longer perceived duration for click-flash than for flash-click intervals. RESULTS. Across several individuals, the apparent perceptual latency difference for the flash and the click was inconsistent between our duration and flash-lag tasks, as well as for order and synchrony judgments. CONCLUSION. The absence of a consistent perceptual correlate of neural latency differences is apparently not due solely to sensory interactions between the click and the flash. The temporally extended nature of responses may play a role. Although physically brief, a click and a flash yield sustained neural responses with separate onset and offset transients. Differences in the use of these responses in different tasks and across individuals may result in the large variability in perceptual latencies observed.

Acknowledgement: Supported by an Australian Research Council Discovery Project to AH

53.456 **Visually-evoked but context-dependent distortions in time perception**

Michael Esterman[1,2](esterman@jhu.edu), Leon Gmeindl[1]; [1]Department of Psychological and Brain Sciences, Johns Hopkins University, [2]VA Boston Healthcare System

Previous results indicate that the rate of change within some stimulus dimensions (e.g., luminance) reliably influences subjects' reports of stimulus duration: for example, rapid rates of change result in overestimated event duration. What remains unclear, however, is the degree to which these bottom-up influences on behavior reflect distortion in the perception of time passing, rather than distortion in retrieval from short-term memory (STM). Specifically, when subjects must either compare the durations of successive stimuli or reproduce stimulus duration – two common experimental paradigms – they may need to "replay" stimuli held in STM. Furthermore, replaying stimuli from STM may take longer for more rapidly changing stimuli, resulting in overestimated duration. Two experiments reported here minimized the need for subjects to hold stimulus durations in STM. The results provide evidence for online, visually-evoked distortions in time perception. However, in subsequent studies we found that distortions in time perception were not tied to absolute rates of change; stimuli with identical rates of change were judged to have different subjective durations depending on context and subjects' expectations. These findings indicate that distortions in time perception arise from an interaction between bottom-up and top-down influences.

Development: Early

Vista Ballroom, Boards 501–512

Tuesday, May 11, 8:30 - 12:30 pm

53.501 Perception of the Müller-Lyer illusion in 3- to 8- month old infants

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Developmental studies have examined the perception of the Müller-Lyer illusion mainly in childhood (Predebon, 1985; Gentilucci et al., 2001). However there are no studies of infants' perception of the Müller-Lyer illusion. In the present study we investigated 3-8-month-old infants' perception of the Müller-Lyer illusion by using a familiarization paradigm. A total of 36 Japanese infants aged 3-4, 5-6 and 7-8 months participated in this study. The experiment consisted of three phases, namely the pre-test, the familiarization trial, and the post-familiarization test. In the familiarization trial, two identical Müller-Lyer illusion figures were presented. In the pre-test and the post-familiarisation test, the lines of same length and the lines of different length figures were presented side by side. If infants could perceive the Müller-Lyer illusion, they were expected to show a novelty preference for the lines of same length figure in the post-familiarization test. Results of the familiarization trial showed that all infants habituated to the familiarization display. A preference score was calculated for each infant in the pre-test and post-familiarization test. This was done by dividing the infant's looking time for the lines of same length figure during the two test trials by the total looking time over the two test trials, and then multiplying this ratio by 100. To determine whether infants perceived the Müller-Lyer illusion in the familiarization display, we conducted paired t-tests on the preference score for the lines of same length figure between the pre-test and post-familiarization test. This analysis revealed that 5-6-month-old and 7-8-month-old infants looked significantly longer during post-habituation trials (5-6 months: $t(11) = 3.51$, $p < .01$;7-8 months: $t(11) = 3.85$, $p < .01$). These results suggest that 5-8-month-old infants could perceive the Müller-Lyer illusion. Our study is the first report suggesting the perception of the Müller-Lyer illusion by infants.

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53.502 Lateralization of visual categories in infancy

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How the two hemispheres of the adult brain contribute to categorical processing has been extensively investigated (e.g., Jager & Postma, 2003). However, despite categorization being a pervasive aspect of infant cognition, there is little understanding of how visual categories in infancy are lateralized. Here, we investigate the lateralization of categorical perception of orientation at 5-months. Although orientation is a continuum ranging from 0 to 360°, both adults and infants perceive it categorically. For example, infants dishabituate to a novel orientation when the novel and habituated orientations are from different categories (vertical and oblique) but not when from the same category, even when the degree of difference between novel and habituated stimuli is equated (e.g., Bomba, 1984). To investigate the lateralization of this category effect, a visual search task was used where oriented lines were presented in a ring around a central fixation point. One line (the target), which was presented to left or right visual fields (L/RVF), was a different orientation to the others (the distractors). Targets and distractors were either from the same category (15 and 30°) or from different categories (0 and 15°). Eye-movements were recorded, stimuli were presented only when centrally fixated, and latencies for a direct eye-movement to the target were analyzed. Infants were centrally fixated for the duration of the latency measure, ensuring that targets remained lateralized (Franklin, Drivonikou, Bevis, Regier, Kay & Davies, 2008). Infants were faster at initiating a direct eye-movement to the target amongst different- than same-category distractors, but only for targets in the RVF. As the RVF initially projects to the LH, orientation categories therefore appear to be LH lateralized at 5-months. The findings are contrasted to the lateralization of categorical perception of hue in infancy (Franklin et al., 2008) and are also related to the lateralization of visual categories in adults.

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53.503 Children hear better than they see!

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Several studies measured the development of different aspects of auditory and visual perception separately without the possibility of comparing their rate of maturation. The results of one study that did compare the development of both modalities suggest that temporal processing develops more rapidly for the auditory compared to the visual modality (Droit-Volet, Tourret, & Wearden, 2004). The present study charted and compared the development of sensory responses to basic visual and auditory stimuli. We measured contrast (visual condition) and pure-tone (auditory condition) detection and discrimination for physically similar stimuli. The visual stimuli consisted of luminance modulated sine-wave gratings that had a spatial frequency of 1 and 5 cpd. The auditory stimuli consisted of pure-tones that had a frequency of 500 and 4000 Hz. A control condition equated the amplitude of the auditory and visual stimuli for the frequency discrimination condition. Thresholds were measured with a temporal 2-AFC procedure combined with an adaptive staircase. Participants were children 6, 8, and 10 years of age and adults (n=16 per group). Statistical analyses using a GLM showed that detection thresholds in the auditory modality are mature by 6 and 8 years of age for the lower and higher frequencies, respectively. In contrast, detection thresholds in the visual modality are still immature at 10 years for the low frequency and become mature at 8 years of age for the higher frequency. A similar pattern was found for frequency discrimination. In the auditory modality, it is mature by 8 years for both frequencies, whilst in the visual modality it is mature by 10 years of age for the lower and 8 years for the higher frequency. Together, these results suggest that sensitivity in the auditory modality matures more rapidly during early childhood and achieves adult levels earlier than sensitivity in the visual modality.

Acknowledgement: NSERC to DE

53.504 Infant 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. To investigate this, we asked whether infants' preference for upright vs. inverted faces was greater for "low" vs. "high" SF-filtered faces, using stimuli equated for detectability. Methods: Four-month-old infants (n = 11) 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, we determined the percentage of trials an infant preferred the upright stimulus (>50% indicates an upright preference). Four conditions were presented: 2 stimulus types (faces vs. objects) x 2 SF filters (low: <0.3 c/deg vs. high: > 0.5 c/deg). Stimuli were presented at 3.3x contrast threshold, with threshold for the four conditions obtained in a separate group of infants prior to the upright preference study. Results: For face stimuli, infants showed an upright preference for high SF faces (64.1%, p=0.0035, 1-tailed t-test), but not low SF faces (52.7%, p=NS). Likewise, for objects, infants showed an upright preference for high SF objects (56.5%, p=0.002, 1-tailed t-test), but not low SF objects (49.9%, p=NS). However, the effect for high SF faces was greater than that for high SF objects (p=0.06, MS). Conclusions: The mechanisms underlying upright face preferences in infants appear to be selective for high SFs. The discrepancy with previous findings (de Heering et al. 2007) may be explained by proposing that: 1) previous studies did not control for detectability of low vs. high SFs (i.e., the low SF faces may have been more detectable), or 2) reliance on low vs. high SFs depends on the nature of the face processing measure, which differs between studies.

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53.505 **Chromatic (Red/Green) and Luminance Contrast Sensitivity in Monozygotic and Dizygotic Twin Infants**

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Purpose: To determine the extent to which contrast sensitivity (CS) development is governed by genetic mechanisms vs. environment, we compared CS between pairs of twin infants and pairs of unrelated infants. If genetics have a strong influence on CS, Monozygotic (Mz) twin siblings should be more similar (and more strongly correlated) than Dizygotic (Dz) twin siblings, and both Mz and Dz twins should show greater correlations than unrelated infant pairs. By contrast, if genetics have little influence, correlations should be the same for Dz and Mz twins. In this latter scenario, if both Mz and Dz twins show greater correlations than unrelated infant pairs, this suggests a role of shared environment. The current study measured Luminance (light/dark) and Chromatic (red/green) CS to assess sensitivity of the Magnocellular and Parvocellular pathways, respectively. Methods: Ten and 26 pairs of Mz and Dz twin pairs were tested (mean age = 4.5 ±1.5 mos). Zygosity was assessed using a questionnaire and cheek swab kits. Luminance and Chromatic CS were obtained for sinusoidal gratings using forced-choice preferential looking (~200 trials per infant; 0.27 cycles/degree; 4.2 Hz). Results: Multiple regression was conducted on 100 runs of random Twin-1/Twin-2 orderings. Results indicated that the CS of one twin predicted 35-40% of the variance (p <0.0001) in the CS of the other twin, while controlling for postnatal age, gestational length, and gender. Simulations with randomly-matched twins suggest these findings are not due to chance. Discussion: Results suggest shared environment and/or genes influence both Luminance and Chromatic CS. With more subjects, we will address whether Luminance vs. Chromatic CS is more or less affected by shared genes/environment. Once we have enough data to compare Mz vs. Dz twins, we can ask which factor, genes or environment, is more influential using structural equation modeling (Neale et al, 2002).

Acknowledgement: NIH/NEI

53.506 **Developmental Differences in Attentional Resolution due to Task Complexity**

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Attentional resolution (Cavanagh & Intriligator, 2001) is defined as the smallest region in space that can be selected by visual attention. The size of this region has shown to become more fine-grained during development (Wolf & Pfeiffer, 2009). In the present study, we investigated how the attentional resolution in different age groups (grades 1, 3, 5, and 7 as compared to an adult sample) is influenced by a variation of load. Using a multiple object tracking paradigm, we varied the number of objects to manipulate the load and the distance between target and distractors to assess thresholds of attentional resolution. Results indicate a dissociation between the impact of load on adults' and children's attentional resolution. More specifically, while an increase in object number does not affect the attentional resolution of adults, it certainly does so in children. However, here an interaction could be observed. Increasing the number of objects from one to two only had an effect on the attentional resolution of the smaller children only (grades 1 and 3). For three targets, however, the attentional resolution of the older children (grades 5 and 7) was affected as well. Thus a change in attentional resolution towards a coarser resolution could be observed the more objects were involved and the smaller the children were. Our results thus touch two theoretical positions and possibly resolve their apparent contradiction. It is still an unresolved issue whether attentional resolution can be manipulated by task difficulty (Alvarez & Franconeri, 2007) or whether it is independent of any variation in task demands (Cavanagh & Intriligator, 2001). Our results indicate that attentional resolution is stable as long as the task does not touch the capacity limits of attention. If it does, a compromise between attentional resolution and attentional load has to be made.

53.507 **Visual statistical learning with and without an attention cue in infancy**

Rachel Wu[1](rachelwu2006@gmail.com), Natasha Kirkham[1]; [1]Centre for Brain and Cognitive Development, Birkbeck, University of London

Social cues (i.e., eye gaze, infant-directed speech, head turn) mediate infants' learning of basic linguistic and perceptual events among distractions (e.g., Houston-Price et al., 2006). Here, we demonstrate that social cues (rather than no cues) produce rapid learning of statistically-defined visual events. Fifty-three 9-month-olds were eye-tracked while being familiarized to movies similar to Fiser and Aslin's (2002) complex shape patterns, each composed of 3 differently colored component shapes. Either a single pattern appeared in one of two panels, arranged left and right, in the lower part of the screen (No Distractor conditions), or a target pattern appeared in one panel and a distractor pattern in the other panel (Distractor condition). For each pattern, the movie depicted two component shapes remaining constant while the other component varied (i.e., changed its color and shape). In one of the No Distractor conditions as well as the Distractor condition, a female face appeared in the center of the screen and turned to look down at the target pattern. After these movies, infants were shown expected and unexpected patterns (relative to the target pattern), defined by whether a split in the pattern involved the variable component (expected) or constant components (unexpected). Infants in both Face conditions (with and without distractors; N=35) looked longer to the unexpected split during test trials (p<.05). Infants in the No Face condition (N=18) exhibited only a gradual preference for the expected split (p<.03), even though these infants looked twice as long to the target shape during familiarization compared infants in both Face conditions. Social cues thus bias visual statistical processing, underscoring the impact of social attention cues on learning basic events in a noisy environment. It is possible that these attention cues are even necessary for rapid perceptual learning in infancy.

53.508 **Calibration of the visual by the haptic system during development**

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Cross-sensory calibration of one sense by another is an important multisensory function. Our recent studies suggest that the haptic system is important for calibration of visual judgements of size, particularly during development. If true, on would expect that the calibration should work only for distances within the haptic workspace. We studied size matching in 40 young subjects (6 - 24) of balls (about 5 cm diam) placed at various distances inside and outside the haptic workspace (42, 60, 85 and 120 cm). 6-10 year-old children consistently underestimated object size by 2-3 mm for distances outside their haptic workspace (85 & 120 cm), implying incomplete size-constancy. Adults (20-30 years), on the other hand, showed the opposite trend, overestimating object size by 2 - 4 mm at 85 & 120 cm, thereby exaggerated size-constency. Our results show that both children (as young as 6) and adults have quite good size constancy, but that it is imperfect for distances outside the haptic workspace. Interestingly, the bias in size perception outside the haptic workspace is in different directions for adults and children, suggesting that the mechanisms subserving size constancy are not fully developed even at 10-years of age. In a separte experiment we showed that in adults the size perception bias outside the haptic workspace could be reduced or even eliminated when subjects observed an actor grasping the ball stimulus. This has fascinating implications, suggesting that "calibration" of vision can be achieved by observation of haptic action, possibly implicating the "mirror system".

53.509 **Linking tools and actions in the developing brain**

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In the adult brain, passive looking at tools preferentially activates the medial fusiform gyrus and regions in the dorsal "grasping-circuit". It is surprising that a purely perceptual task that involves no explicit action activates dorsal visuo-motor regions. This has sparked a debate about whether the dorsal preference for tools reflects (1) a functional link between objects and action representations resulting from experience or (2) automatic processing of affordances (object features that afford for action). Investigating how the tool network develops can help to resolve this debate. We present data of an fMRI study in which adults and 6 to 10-year old children performed a passive viewing task with colour photographs of familiar tools and animals. Regions that responded more to tools than animals were the ventral medial fusiform gyrus, and the dorsal areas V3/dLOC, VIP, LIP, AIP and inferior frontal gyrus. Children and adults showed a similar pat-

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tern of cortical regions with a tool preference. A whole-brain group comparison indeed showed that there was no difference across age. Even young children thus activate areas that are part of the dorsal grasping circuit when they passively look at tools. In addition, a behavioural study with the same participants showed that affordances of graspable objects automatically influence actions in an adult-like manner from 6 years onwards. We thus report developmental consistency of the link between tools and actions from early childhood onwards, both in cortical organization and behaviour. These results are consistent with two possible developmental paths: (1) in contrast to the face-network, that keeps on developing until at least 10 years of age, experience before the 6th year of life is sufficient for the tool-network to stabilize into an adult-like organization, or (2) that automatic processing of affordances is present at birth. Future directions will be discussed.

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53.510 **Smooth Pursuit Eye Movements and Depth from Motion Parallax in Infancy**

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Motion parallax (MP) is a kinetic, monocular cue to depth that relies on both retinal image motion and a pursuit eye movement signal. With MP, depth sign is based on the direction of the smooth pursuit eye movement signal: Retinal motion in the same direction as the pursuit signal is perceived nearer than fixation. Retinal motion in the opposite direction is perceived farther away than fixation (M. Nawrot & Joyce, 2006). In previous research to understand the development of MP in infants we (E. Nawrot, Mayo, & M. Nawrot, 2009) used an infant control habituation procedure with an MP stimulus to determine the average age of dishabituation to a depth-reversed test stimulus. Dishabituation to the change in depth sign is evidence for depth discrimination from MP. Now, our goal is to determine when the developing smooth pursuit system has sufficiently matured in infancy and then directly measure pursuit eye movements in relation to a motion parallax task. We presented 12-20 week-old infants with both a depth-from-MP task and a visual tracking task designed to elicit smooth pursuit (SP). The MP stimulus and procedure is identical to previous research (E. Nawrot, Mayo, & M. Nawrot, 2009). Tracking is elicited with a schematic “happy-face” that translates at 10 deg/sec. Eye movements are recorded using a Tobii systems X120 Eye Tracker. We expect to find that SP gain (eye velocity/target velocity) increases across this age range and pursuit maturity will correlate with the onset of sensitivity to MP. Data collected from 16 infants so far supports the hypothesis that depth from MP requires maturation of SP. In general, younger infants demonstrate more saccadic and lower gain eye movements, without MP, while older infants demonstrate more smooth pursuit tracking of the stimulus and MP.

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53.511 **A salience-mapping method for testing infants’ visual working memory for speed vs. luminance**

Erik Blaser[1](erik.blaser@umb.edu), Zsuzsa Kaldy[1], Henry Lo[1], Marisa Biondi[1]; [1]Psychology, UMass Boston

Background. Research on infant cognition has long been concerned with how infants process static vs. moving objects (e.g. Van de Walle & Spelke, 1996; Rakison & Poulin-Dubois, 2002). We are interested in comparing infants’ visual working memory (VWM) for speed and luminance. Here we focus on our revised ‘salience-mapping’ technique (Kaldy & Blaser, 2009) that allows us to generate comparison objects with iso-salient differences from a common baseline object, thereby ensuring fair VWM tests. Methods. Subjects’ age was 5;0-6;30. A Tobii T120 eye-tracker measured infant’ gaze direction. Experiment 1 (ISM): Salience was calibrated in a preferential looking paradigm by pitting a baseline object (a slowly rotating green star) against a range of objects that increased either in luminance or in speed of rotation. Salience functions were obtained for each of the dimensions. We chose speed and luminance values that were at the 75% iso-salience level. In this way we defined three objects that had the following relationship: the salience difference between the baseline and the luminance comparison and the baseline and the speed comparison was equal. Experiment 2 (VWM): In this in-progress experiment, two of the three such defined objects are presented for 3.5 seconds. The two objects disappear for 2 seconds, then reappear, but with one changed in luminance or speed (by the previously calibrated amount) while the other reappears unchanged. Preference, determined from looking time, for the changed (vs. unchanged) object is evidence for memory. Results. Iso-salient differences for luminance and motion were successfully measured in Experiment 1 using our revised salience-mapping technique. While data collection for Experiment 2 is ongoing, we expect better VWM for motion as opposed to luminance. Discussion. In service to VWM experiments, we demonstrated an innovative method for producing psychophysically comparable stimulus differences for infants along the dimensions of speed and luminance.

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53.512 **The neural correlates of imitation in children**

Angie Eunji Huh[1](anghuh@gmail.com), Susan Jones[1], Karin James[1]; [1]Psychological and Brain Sciences, Indiana University Bloomington

This study examines the association between action and perception in the development of the human mirror system (HMS) in children from 4-7 years of age. Imitation is one mechanism that may promote associations between action and perception in the developing brain. Neuroimaging studies on adults have found activation of the same 3 areas in the brain, termed the Human Mirror System, both when participants imitate an action and when they are imitated. Using fMRI, we compared neural activation patterns in children during action production and observation both in isolation and in the context of imitation. We hypothesized that because both perception and action are required for imitation, the HMS will not be recruited during action or perception alone. Results revealed no overlapping activation in the 3 core areas of the HMS during observations and production of the same actions in isolation. In addition, the children’s response pattern during imitation was somewhat different than the pattern previously shown in adults. Unlike adults, children showed no activation in the inferior parietal lobule during imitation tasks, but similar to adults, did recruit the inferior frontal gyrus and the superior temporal sulcus. These results demonstrate that imitation recruits different brain systems in the adult than in the child. We speculate that imitation recruits a temporal-parietal-frontal pathway in adults and a more direct temporal-frontal pathway in the child.

Perception and action: Mechanisms

Vista Ballroom, Boards 513–522

Tuesday, May 11, 8:30 - 12:30 pm

53.513 **Does an auditory distractor allow humans to behave more randomly?**

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It is well known that human beings are poor random generators (Wagenaar, 1972). For example, people have difficulty in creating random number sequences. What underlies this behavioral tendency? In order to examine this, we investigate the kinds of environments that can alter this ability to generate randomness. Subjects selected and mouse-clicked three different buttons in the designated field on the computer display (there are 4X4 square buttons). In each trial, subjects were asked to make the three button combination that they have never created before, that is, “a new combination”. One subject group did the task while listening to the radio, another group without listening to the radio. The degree of randomness was assessed quantitatively. We find that the averaged level of randomness of the subjects group listening to the radio is significantly higher than the group without the radio. Although the achievement of the group with radio was still worse than the pseudo-random combinations generated by a computer, the auditory distractor led to more random combinations. The present results are in accord with previous findings that show that people are poor random generators. At the same time, it suggests that reducing a subject’s concentration on the task enhances the ability to generate randomness or attenuates suppression of more stereotyped behavior. However, to understand the mechanisms underlying this phenomenon, further psychophysical and physiological experiments are required.

Acknowledgement: JSPS Postdoctoral Fellow for Research Abroad

 See page 3 for Abstract Numbering System

53.514 Visual decision making is most influenced by past experience of weak signals

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Visual decision making is regarded as a process in which sensory signals are integrated toward an appropriate action. Decisions are based not only on current sensory signals, but also on statistical knowledge about past incidences. It is naturally thought that the statistical knowledge formed by stronger visual signals more greatly influences decision makings. However, here we have found that very weak signals on previous trials have a greater influence on current decisions than do stronger signals on current decisions. On each trial, subjects were presented with a noisy, oriented stimulus, and asked to report which one of two alternative orientations was presented. The signal-to-noise ratio (0%, 5%, 15%, or 20%) was varied from trial to trial. While 5% signal was too weak to perceive, 15% and 20% signals were conspicuous. One session consisted of 6 runs, with 144 trials per run. In every block of 48 trials, one of three pairs of incidence probabilities (33%/66%, 50%/50%, or 66%/33%) was assigned to the two orientations. Two groups of 10 subjects were employed In the first group, incidence probability was manipulated for the 5%, 15%, and 20% signal trials. In the second group, incidence probability was manipulated for the 15% and 20% signal trials only and the incidence probability for the 5% signal trials was constantly 50%. While the first group showed a significant degree of positive correlation between the past stimulus sequence and current response sequence, the second group showed no correlation. Given that the only difference between two groups was the manipulation of trails with imperceptible 5% signal, the present results indicate that on the contrary to the general thought visual decision making is more influenced by past experience of weak signals than that of stronger signals.

53.515 Consciousness Thresholds of Motivationally Relevant Stimuli: Faces, Dangerous Animals and Mundane Objects

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Motivationally relevant stimuli might reach awareness earlier than objects without such relevance. We used a visual masking paradigm to compare consciousness thresholds for neutral faces, threatening dogs and cups. Here, the subjects were presented with two stimuli—an image from one of the three object categories and its spatially scrambled counterpart—both of which were followed, at a varying stimulus onset asynchrony (SOA), by a spatially overlapping pattern mask containing features of objects from all three categories. Subjects then identified the category and the location of the unscrambled image. We defined the consciousness threshold as the smallest SOA at which the category and location of the masked image was correctly identified at an above chance accuracy. We reasoned that, on the one hand, (a) awareness of potentially dangerous objects might be adaptive for planning evasive behaviors; on the other hand, (b) consciousness might be suppressed due to the negative valence of such stimuli. We predicted that, of the three object categories tested, 1) faces, which are socially significant and more frequently encountered, would have the lowest consciousness threshold; 2) based on alternative (a), threatening dogs should have a consciousness threshold equal to or higher than that for faces but lower than that for motivationally neutral cups; 3) based on alternative (b), threatening dogs should have the highest consciousness threshold. Our results show that (i) faces have a lower consciousness threshold than both cups and threatening dogs, and (ii) supporting alternative (b), threatening dogs have a higher consciousness threshold than both faces and cups. Therefore, the minimal SOA for attaining awareness of stimuli might depend on their social and motivational relevance. Moreover, these results suggest that threatening information may be suppressed from awareness and therefore attain consciousness only when it becomes more visible at longer target-mask SOAs.

53.516 Effects of Movement Observation on Execution Altered by Response Features and Background Images

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Many studies show that if one is asked to produce a motion while observing another's motion, action production is influenced by the overlap in spatial position/direction (spatial congruency) and overlap in type of bodily motion (anatomical congruency) between observed and executed motions. In the present study, we examine this effect more closely by modifying the paradigm established by Brass, Bekkering, & Prinz (2001). We asked whether congruency between the kinematics of observed and executed up/down finger motions produces an anatomical effect even when the executed motions (key pressing and key lifting) involve different object-specific goals than the observed motions (downward or upward finger motions). To isolate spatial and anatomical effects, finger motions were presented with the observed hand in both an upright and inverted orientation. Furthermore, half of our participants saw a uniform gray background behind observed finger motions and half saw a table image below the hand with a blank wall behind (providing a goal object for downward, but not upward motions). We find that only key presses (not lifts) showed main effects of spatial and anatomical congruency. We suggest that when a salient familiar goal state for an alternative action is part of a more novel response sequence (e.g. having a key depressed as the starting position for a lift response), the congruency between observed goals and the novel and familiar goal states of responses yield conflicting facilitatory and inhibitory effects. In addition, congruency effects were influenced by the background presented. Specifically, our results show that when participants initially saw upright finger motions above a table, congruency effects were absent when the motions (and background) were subsequently inverted. However, this was not the case if upright or inverted motions were presented on a gray background or if inverted motions were first presented with a table background.

53.517 Modeling the visual coordination task in de Rugy et al.: It's perception, perception, perception

Geoffrey P. Bingham[1](gbingham@indiana.edu), Winona Snapp-Childs[1], Andrew D. Wilson[2]; [1]Psychological & Brain Sciences, Indiana University, [2]Institute of Membrane & Systems Biology, University of Leeds

Bingham (2001; 2004a,b) proposed a dynamical model of coordinated rhythmic movement that predicted the information used was the relative direction of motion, modified by relative speed. de Rugy et al (2008) tested this prediction by testing the dependence on speed. They reported that movement stability did not depend on relative speed. However, there were limitations that cast doubt on these findings. Among them was the fact that the task used to test the model was not one the model was designed to represent. Snapp-Childs, Wilson and Bingham (submitted) replicated de Rugy et al.'s experiment and obtained results that supported the Bingham information hypothesis in contrast to the finding of de Rugy et al. We now revise the original Bingham model to apply to this new task, and then compare simulated data to the Snapp-Childs et al. data. To adapt the model to the new task, it had to be revised in three respects. First, the visual coordination task entailed uni-directional (not bi-directional) visual coupling. The revised model was used to simulate the switching experiment of Snapp-Childs et al successfully. Uni-directional coupling yielded a less stable system that switched at 1.25Hz rather than 3-4Hz. Second, the task required participants to control and produce specific amplitudes of movement (as well as specific frequencies and relative phases). This entailed another information variable, specifying amplitude, to be incorporated into the dynamical model to control and produce required amplitudes. Third, the task required that participants correct spontaneous deviations from required relative phases. The original Bingham model included perceived relative phase. This was now used to detect departures from required phases and to perform corrections. The resulting model successfully simulated the results replicated in Snapp-Childs et al. illustrating emphatically that perception-action models are required to model performance in coordinated rhythmic movement tasks.

53.518 The stability of rhythmic movement coordination depends on relative speed

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Bingham (2001; 2004a,b) proposed a dynamical model of coordinated rhythmic movement that predicted the information used was the relative direction of motion, modified by relative speed. de Rugy et al (2008) tested this prediction by testing the dependence on speed. They reported that

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movement stability did not depend on relative speed. However, there were limitations that cast doubt on these findings. First, the only reported measure was of stability. It quantified consistency but not accuracy. Second, amplitude, manipulated to alter relative speed, was not reported. Whether required differences in speed were actually generated is unknown. Finally, the task used to test the model was not one the model was designed to represent. We ran the following studies to test Bingham's hypothesis more precisely. Participants used a joystick to coordinate the movement of two dots on a screen, controlled by computer and joystick respectively. First, we tested stability using the 'switching' paradigm. Participants attempted to produce 180° relative phase at frequencies increasing from 0.5Hz to 2.0Hz by 0.25Hz steps. Switching occurred at 1.25Hz. Visual coordination is much less stable than bimanual coordination. Next, we assessed movement stability at 0° and 180° by having participants move at 1.0Hz, 1.25Hz and 1.50Hz. The amplitude of the joystick dot was constant while that of the computer dot was either the same or three times larger. 0° with unequal amplitudes had the same relative speed difference as 180° with equal amplitudes; so, the stability should be comparable and less than 0° with equal amplitudes. Using a measure of both consistency and accuracy, we found that speed differences affected movement stability as predicted by the Bingham hypothesis (even though amplitudes were somewhat different than required). Bingham, Snapp-Childs and Wilson (submitted) revised the model for the new task and successfully captured these results.

53.519 Reduction of the flash-lag effect in active observation depends upon the learning of directional relationship between hand and stimulus movemenets

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In our previous study, we found that observer's active control of the stimulus movement would reduce the illusory flash-lag effect when the upward (downward) movement of the stimulus on the front parallel display is coupled with the forward (backward) mouse movement on the desk, as in most computer operating systems (Ichikawa & Masakura, 2006 Vision Research). In this study, we examined whether the repetitive observation with the directional relationship between the stimulus and hand movements, which is opposite to the one used in most computer operating systems, and therefore unfamiliar to observers, would affect the flash-lag effect. In the active condition, 28.8 arc deg of vertical movement of the stimulus (19.1 x 19.0 arc min) on the display corresponded to about 30.0 cm of the mouse movement on the desk. The upward (downward) movement of the stimulus was coupled with the backward (forward) mouse movement. In the automatic condition, the stimulus moved automatically with a constant velocity which was determined by the average of the stimulus movement in the active condition. A flash stimulus (19.1 x 19.0 arc min) was presented beside the moving stimulus. The vertical position lag between the flash and moving stimuli ranged from -76.0 to 76.0 arc min by 19.0 arc min step (negative value indicates that the position of the flash was behind of the moving stimulus). Observers judged whether the moving stimulus was below or above the flash. We measured the flash-lag effect for the active and automatic conditions before and after 360 training trials with the unfamiliar relationship between mouse and stimulus movements. We found that, after the training trials, the flash-lag effect was reduced only in the active condition. This result suggests that the learning of a specific directional relationship between hand and stimulus movements would reduce the flash-lag effect.

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53.520 The Effectivity of Stroboscopic Training on Anticipation Timing

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Introduction Accurate and consistent anticipation timing (AT) is considered advantageous during dynamic reactive activities such as automobile driving, baseball batting, and basketball passing. Stroboscopic training has gained interest in the athletic community as a means of improving AT. The purpose of this study was to evaluate stroboscopic training effects on AT. Methods Forty-four young adult optometry students served as subjects. Pre-training AT was measured at speeds of 10, 20 and 30 mph using the Bassin Anticipation Timer. Subjects were equally divided into an experimental group that trained with functional stroboscopic eyewear and a control group that trained with non-stroboscopic eyewear. Training consisted of 2 weeks of tennis ball catching: underhand tosses at 12 ft (3.7 m) for 10 min per day. Upon completion of training, subjects were immediately retested on AT and then tested again 24 hrs later. Results Repeated-measures ANOVA revealed that, after training, there was no significant change in AT accuracy for either group, but the experimental group did show significant improvement in consistency at 30 mph, and that the effect was maintained for 24 hrs. Discussion Stroboscopic training did not improve AT accuracy in this study, possibly because of the relatively slow testing speeds used, the simple training activity, and/or the study population. However, it did demonstrate improved AT consistency at the fastest test speed, which was maintained post-training. Future research should consider stroboscopic training effects with speeds and activities more similar to those that an athlete would expect to encounter in his or her sport.

53.521 Performance Affects Perception of Ball Speed in Tennis

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Several studies suggest that action abilities affect spatial perception. For example, a softball appears to be larger when athletes are hitting better (Witt & Proffitt, 2005), and a putting hole appears larger when golfers are playing better (Witt, Linkenauger, Bakdash, & Proffitt, 2008). In the present research, we demonstrate that action abilities in sports, specifically in tennis, affects both spatial perception and perception of ball speed. Students taking tennis lessons estimated the duration of ball travel from a ball machine to the point when it made contact with their racquet by performing an interval reproduction task following each ball return. After successful returns, players estimated the duration of the ball travel to be longer, suggesting that they perceived the ball to travel slower, compared with when they unsuccessfully returned the ball. Our results suggest that there is a bidirectional relationship between performance and perception and that perception of ball speed is scaled in relation to one's performance. This finding is consistent with athletic experiences. For example, in describing her game, a former world number one tennis player, Martina Navratilova said, "when I'm in the zone the ball simply appears to move slower, everything slows down."

53.522 Visual Acuity is Essential for Optimal Visual Performance of NFL Players

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The measurement of static visual acuity (SVA) is an essential element of any vision evaluation because degraded visual acuity can have a detrimental effect on many other aspects of visual performance. Although the expected level of SVA depends on the visual task demands of each sport situation, studies have frequently found better SVA in athletes than in non-athletes. The purpose of this study was to compare performance of visual and visuomotor skills in a population of NFL football players with excellent and reduced SVA. Eighty-two NFL football players received a visual performance evaluation at their team's training center over a span of 2 seasons. Based on the athletes' SVA and refractive error measures, they were identified for a referral to an eye care practitioner for potential remediation. An athlete was identified for a referral if (1) SVA of either or both eyes was worse than 20/17 on a Snellen chart or (2) there was significant hyperopia in either eye (cyl $\geq$ 1.5 diopter). Twenty-eight of the 82 players were identified for a referral. Statistically, the referred and the non-referred population had significantly different SVA ($p<0.001$). Of the visual performance variables measured, the non-referred players were better than the referred players in the following visual and visuomotor skills: contrast sensitivity ($p=0.008$), accommodative facility ($p<0.001$), depth perception ($p=0.017$), reaction time ($p<0.001$), and target acquisition ($p=0.030$). Some of the other skills measured that did not result in statistical significance were perception span, motor response time, anticipation timing, eye-hand coordination, and target following. There is a statistically significant reduction in some measures of visual performance in NFL football players who have SVA worse than 20/17. Excellent SVA contributes to optimal visual performance when central vision factors into success. Professional football players may benefit from refractive compensation to maximize SVA.

Object recognition: Recognition processes

Vista Ballroom, Boards 523–538

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53.523 Object recognition based on hierarchically organized structures of natural objects

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Humans can recognize objects quickly and accurately despite tremendous variations in their appearance. This amazing ability of rapid categorization has motivated several models of natural vision and object recognition. The conclusion of these models is rather far-reaching: humans achieve rapid categorization in a way similar to these models. Since understanding the computations underlying rapid categorization is important for achieving natural vision, we have re-examined several of these models. In particular, we trained the models and tested them with scenes in which the objects to be categorized were replaced with uniform ellipses. We found that the models categorized most of the scenes with ellipses as having the objects. Therefore, these models do not categorize objects but rather the contexts in which the objects are imbedded and thus provide little clue on how humans achieve rapid categorization. Here, we propose a statistical object recognition model based on a large set of hierarchically organized structures of natural objects. First, a large set of hierarchical object structures are obtained from natural objects. At each level of the hierarchy are a set of object structures, each of which consists of a combination of independent components of natural objects. Each object/category is then represented by a subset of these hierarchical structures and the natural variations of the object/category by a probability distribution of the underlying structures. Object recognition/categorization is performed as statistical inference. We tested this model on several large datasets and found that the model achieves a great performance on object recognition/categorization both in isolation and in natural contexts.

53.524 Statistics of natural objects and object recognition

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Natural visual scenes and objects entail highly structured statistics, occurring over the full range of variations in the world. Representing these statistics by populations of neurons is a paramount requirement for natural vision. The function of the visual brain, however, has long been taken to be the representation of scene features. It is thus not clear how representing individual features per se could deal with the enormous feature variations and co-occurrences of other features in the natural environment.

Here, taking object recognition as an example, we explore a novel hypothesis, namely, that, instead of representing features, the visual brain instantiates a large set of hierarchically organized, structured probability distributions (PDs) of natural visual scenes and objects and that the function of visual cortical circuitry is to perform statistical operations on these PDs to generate the full range of percepts of the natural environment for successful behaviors. To explore the merits of this hypothesis, we develop a large set of hierarchically organized, structured PDs of natural objects. First, we find all possible local structures of natural objects. Two object structures are deemed the same if they can be transformed to each other by an affine transform (displacement, rotation, scaling) and smooth nonlinear transforms. For each object structure, we then develop a PD that characterizes the natural variations of the structure. Finally, by applying this procedure at a set of spatial scales, we obtain a large set of object structures, each of which is associated with a PD. Using these object structures and associated PDs, we develop hierarchical, structured probabilistic representations of natural objects. Object recognition is performed as statistical inference. Tests on several large databases of objects show that the performance of this model is comparable to or better than some of the best models of object recognition.

53.525 The role of Weibull image statistics in rapid object detection in natural scenes

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The ability of the human brain to extract meaningful information from complex natural scenes in less amount of time than from simple, artificial stimuli is one of the great mysteries of vision. One prominent example of this ability is that natural scenes containing animals lead to a frontal ERP difference compared to scenes without animals as soon as 150 ms after stimulus-onset (Thorpe et al., 1996). Whereas these findings make clear that the brain is able to very rapidly distinguish these types of images, it is unclear on the basis of what information this distinction is made - in other words, whether early differences in the ERP between natural stimuli are related to low-level or high-level information in natural images. We have shown previously that the early animal vs. non-animal difference is driven by low-level image statistics of local contrast correlations, as captured by two parameters (beta and gamma) of the Weibull fit to the edge histogram of natural images (Scholte et al., 2009). These parameters can be estimated in a physiologically plausible way and explain 85% of the variance in the early ERP. We are currently expanding on this work by investigating to what extent low-level image statistics, as measured by beta and gamma, are involved in determining the latencies of target vs. non-target ERP differences in those cases where other types of stimuli than animals (vehicles) are used and where the specific task the subject is performing is varied (from simple detection to subordinate categorization). Early results confirm our previous findings and expand them to other types of stimuli and tasks.

Thorpe et al., (1996). Speed of processing in the human visual system. Nature, 381(6582):520-2.

Scholte et al., (2009). Visual gist of natural scenes derived from image statistics parameters [Abstract]. Journal of Vision, 9(8):1039, 1039a.

53.526 Influence of Local Noise Structure on Object Recognition

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Psychophysical experiments frequently use random pixel noise to study the coding mechanisms of the visual system. However, interactions in natural scenes occur among elements of larger articulated structures than pixels. We examined how structure in noise influences the ability to recognize objects with a novel coherence paradigm for object recognition. Grayscale images of 200 everyday objects from 40 categories were analyzed with a multi-scale bank of Gabor-wavelet filters whose responses defined the positions, orientations and phases of signal Gabor patches that were used to reconstruct the original image. The proportion of signal to random noise Gabors was varied using a staircase procedure to determine a threshold supporting object recognition on 75% trials. The noise structure was controlled to produce Gabor chains of varying length (1, 2, 3, or 6 elements) and local orientation, forming straight, smoothly or irregularly curved contours. Each trial, nineteen naïve subjects assigned the reconstructed image to one of four categories, randomly selected from all categories. Object recognition thresholds were invariant to the nature of the underlying local orientation structure of the noise. Increasing the length of the noise contours from 1 to 2 elements increased thresholds ($p<0.001$), but not for longer contours, suggesting that object identification is based on grouping local contour fragments, but only over very local areas. The invariance of performance with respect to feature type suggests that object recognition relies upon prior knowledge of object form, and that such a top-down mechanism allows the visual system to discount variation in local noise. Sensitivity to the number of elements suggests that assembling descriptions that can support the top-down mechanisms depend on the complexity of the distractors.

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53.527 A computational model for material recognition

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We have previously shown that observers can recognize high-level material categories (e.g. paper, fabric, plastic etc.) in complex, real world images even in 40 millisecond exposures (Sharan et al., VSS 2009). This rapid perception of materials is different from object or texture recognition, and is fairly robust to low-level image degradations such as blurring or contrast inversion. We now turn to computational models and ask if machines can mimic this human performance. Recent work has shown that simple image features based on luminance statistics (Sharan et al.. 2008), or based on 5x5 pixel patches (Varma and Zisserman, 2009) are sufficient for some texture and material recognition tasks. We tested state-of-art models based on these features on the stimuli that our observers viewed. The performance was poor (Categorization rate: Varma-Zisserman = 20%, observers = 90%, chance = 11%). Our stimuli, a diverse collection of photographs derived from Flickr.com, are undoubtedly more challenging than state-of-art benchmarks (Dana et al., 1999). We have developed a model that combines low and mid-level image features, based on color, texture, micro-geometry, outline shape and reflectance properties, in a Bayesian framework. This model achieves significant improvement over state-of-art on our stimuli (Categorization rate: 41%) though it lags human performance by a large margin. Individual features such as color (28%) or texture (37%) or outline shape (28%) are also useful. Interestingly, when we ask human observers to categorize materials based on these features alone (e.g. by converting our stimuli to line drawings that convey shape information, or scrambling them to emphasize textures), observer performance is similar to that of the model (20-35%). Taken together, our findings suggest that isolated cues (e.g. color or texture) or simple image features based on these cues, are not sufficient for real world material recognition.

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53.528 **The role of feedback projections in a biologically realistic, high performance model of object recognition**

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Neurons in successive areas along the ventral visual pathway exhibit increasingly complex response properties that facilitate the robust recognition of objects at multiple locations, scales, and orientations in the visual world. Previous biological models of object recognition have focused on leveraging these response properties to build up transformation invariant representations through a series of feedforward projections. In addition to feedforward projections, feedback projections are abundant throughout visual cortex, yet relatively little is known about their function in vision. Here, we present a model of object recognition that shows how feedback projections can produce considerably robust recognition performance in visual noise. The model is capable of transformation invariant recognition of 100 different categories of three-dimensional objects and can generalize recognition to novel exemplars with greater than 90% accuracy. When the objects are embedded in spatially correlated visual noise, our model exhibits substantially greater robustness during recognition (a 50% accuracy difference in some cases) compared to a feedforward backpropogation model. Thus, the top-down flow of activation via feedback projections can help to resolve uncertainty due to noise based on learned visual knowledge. Finally, in contrast with other biological models of object recognition, our model develops all of its critical transformation invariant representations through general-purpose learning mechanisms that operate via the feedforward and feedback projections. Thus, our model demonstrates how a biologically realistic architecture that supports generic cortical learning is successful at solving the difficult problem of invariant object recognition.

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53.529 **GPGPU-based real-time object detection and recognition system**

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Many neuroscience inspired vision algorithms have been proposed over the past few decades. However, it is difficult to easily compare the various algorithms that have been proposed by investigators. Many are very computationally intensive and are thus hard to run at or near real time. This makes it difficult to rapidly compare different algorithms. Further, it makes it difficult to tweak existing algorithms and to design new algorithms due to the training and testing framework that must be constructed around it. With the advent of GPGPU computing significant speedups on the order of 10-50 times are achievable if the computations are intensive, local, and massively parallel. Many object recognition systems fit this description, so the GPGPU provides an attractive platform. We describe an implemented GPGPU-based system that uses saliency (Itti, Koch, 1998) to detect interesting regions of a scene, and a generic backend that can run various object recognition systems such as HMAX (Riesenhuber, Poggio 1999) or SIFT (Lowe, 2004). The less intensive front end system only achieved a speed up of 2x, but HMAX was sped up by 10x (Chikkerur, 2008). We believe that this framework will allow rapid testing and improvement of novel recognition algorithms.

53.530 **Top-Down Processes of Model Verification Facilitate Visual Object Categorization under Impoverished Viewing Conditions after 200 ms**

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While objects seen under optimal visual conditions are rapidly categorized, categorizing objects under impoverished viewing conditions (e.g., unusual views, in fog, occlusion) requires more time and may depend more on top-down processing, as hypothesized by object model verification theory. Object categorization involves matching the incoming perceptual information to a stored visuostructural representation in long-term memory. Functional magnetic resonance imaging (fMRI) work found evidence for model verification theory, and implicated ventrolateral prefrontal cortex (VLPFC) and parietal lobe in top-down modulation of posterior visual processes during the categorization of impoverished images of objects. We replicated the fMRI study with event-related potentials (ERPs) to time model verification processes. The two-state interactive account of visual object knowledge predicts that top-down processes of model verification modulate object model selection processes supporting categorization during a frontopolar N350, and later categorization processes during a parietal late positive complex (LPC), but not earlier feedforward processes of perceptual categorization during a P150-N170 complex. 24 participants categorized fragmented line drawings of known objects. Impoverishment was defined by a median split of response time with slower times defining more impoverished (MI) and faster times defining less impoverished (LI) objects. As predicted, after 200 ms, the N350 was larger for MI than LI objects, whereas the LPC was smaller for MI than LI objects. Consistent with the two-state interactive account, object model selection processes supporting categorization occur after 200 ms and can be modulated by top-down processes of model verification implemented in VLPFC-parietal networks to facilitate object constancy under impoverished viewing conditions.

53.531 **The Speed of Categorization: A Priority for People?**

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Objects are typically categorized fastest at the basic level ("dog") relative to more superordinate ("animal") or subordinate ("labrador retriever") levels (Rosch et al., 1976). A traditional explanation for this basic-level advantage is that an initial stage of processing first categorizes objects at the basic level (Grill-Spector & Kanwisher, 2005; Jolicoeur, Gluck, & Kosslyn, 1984), but this has been challenged by more recent findings (e.g., Bowers & Jones, 2008; Mace et al., 2009; Mack et al., 2008, 2009; Rogers & Patterson, 2007). In the current study, we explored whether there is temporal priority in processing people by measuring the time course of categorization and evaluating behavioral data using a computational model of perceptual decision making (Ratcliff, 1978). We contrasted speeded categorization of people versus speeded categorization of dogs, manipulating the similarity between the targets and distractors (similar distractors were other animals and dissimilar distractors were nonliving objects) and the homogeneity of the set of distractors (two versus ten object categories). Participants were more accurate and faster for both people and dogs when distractors were dissimilar to the targets and the homogeneity of distractors did not have an effect on performance. But critically, we found a temporal advantage for categorizing people both in overall reaction times and in measures of minimal processing time for successful categorization. Not only were peo-

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ple categorized faster than dogs, they were also categorized earlier. Model predictions suggested that a temporal advantage for categorizing people arises from both a priority in perceptual encoding and a faster accumulation of evidence for a decision. The current study significantly extends recent work by further characterizing the time course of categorization at different levels and for different kinds of objects and investigating the underlying mechanisms within a computational framework.

53.532 **Top-down models explain key aspects of a Speed-of-Sight character recognition task**

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Object recognition is very rapid, typically reaching completion within 150 msec following image onset, consistent with intersaccade intervals in humans. In Speed-of-Sight tasks, recognition can be interrupted by masks presented at a given delay—termed the Stimulus Onset Asynchrony (SOA). Featureless images (black, white, grey or white noise) are minimally effective as masks, even at very short SOAs (e.g. 20 ms). Optimal masks can significantly compromise object identification at SOAs of 60-80 ms or more. We conducted a 2AFC experiment in which subjects reported the location (left/right) of targets presented next to distractors, with both images quickly replaced by identical masks. To limit image parameters while allowing task difficulty to be varied, images were depicted on a 7-segment LED-like display. Targets were always a specific digit (e.g. "2" or "4"). Masks and distractors consisted of digits, letters or non-semantic symbols composed from the same 7 segments. To account for the observed variability in mask efficacy for different target-mask combinations, we constructed a model that combined dynamical variables representing feed-forward feature detectors—corresponding to the 7 image segments—with high-level pattern detectors for targets, masks and distractors. Masking was most dependent on feature level competition: the numeral 8 was an effective universal mask whereas the numeral 1 was a poor mask, allowing many targets to be reliably detected after a 20 msec SOA. Accounting for mask effectiveness required postulating top-down or feedback influences from pattern detectors to modulate the confidence or persistence of low-level feature detectors. Our results suggest that masking occurs at the level of low-level features and is strongly modulated by top-down or feedback processes, inconsistent with purely feedforward models often proposed to account for Speed-of-Sight results.

Acknowledgement: NSF PetaApps program

53.533 **Comparing Speed-of-Sight studies using rendered vs. natural images**

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Viewpoint invariant object recognition is both an essential capability of biological vision and a key goal of computer vision systems. A critical parameter in biological vision is the amount of time required to recognize an object. This time scale yields information about the algorithm used by the brain to detect objects. Studies that probe this time scale (speed-of-sight studies) performed with natural images are often limited because image content is determined by the photographer. These studies rarely contain systematic variations of scale, orientation and position of the target object within the image. Semi-realistic three-dimensional rendering of objects and scenes enables more systematic studies, allowing the isolation of specific parameters important for object recognition. To date, a computer vision algorithm that can distinguish between cats and dogs has yet to be developed and the specific cortical mechanisms that enable biological visual systems to make such distinctions are unknown. We perform a systematic speed-of-sight study as a step towards developing such an algorithm by enabling a better understanding of the corresponding biological processing strategies. In our study, participants are given the task of reporting whether or not a cat is present in an image ('cat / no cat' task). The object image is displayed briefly, followed by a mask image. As a mask, we use images of dogs as well as 1/f noise. We perform studies with natural images and with rendered images and compare the results.

53.534 **Electrophysiological evidence for early visual categorisation at 80 MS**

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Objective: Using surface ERPs, it has been shown that the processing of natural scenes could be done in 150 ms. Here, we use intracerebral recordings during a visual Go-Nogo categorisation paradigm to investigate the earliest cerebral effects associated with this task. Methods: CF is a 35 year-old woman who underwent intracerebral investigation for presurgical evaluation of intractable epilepsy. 12 depth electrodes, containing from 10 to 15 contacts, were implanted. CF performed a Go-Nogo task in which she had to press a button each time she saw a human face among animal faces. Instructions were then reversed. Stimuli were natural scenes in which targets were close-ups of a large variety of faces. Both categories of stimuli were matched for mean contrast, luminance and spatial frequency. CF also underwent different control tasks. Results: Mean accuracy was 95% correct responses. A focal negative ERP peaking around 80 ms was recorded in the right calcarine fissure anterior to the junction with the parieto-occipital fissure. The maximum amplitude of this ERP was larger for targets (human or animal). With human faces as targets, the ERP peaked at 80 ms with an amplitude of -85 mV while it showed lower amplitude for non-target animal faces (-71 mV; $p<0.01$). When animal faces were targets, the associated ERP peaked at 85 ms with an amplitude of -76 mV whereas it peaked at a lower amplitude on non-target human faces (-57 mV; $p<0.01$). Discussion: These results show that differential electrophysiological effects associated with visual categorisation can be seen as early as 80 ms post-stimulus onset when meaningful stimuli such as animal or human faces are used. Such data imply that features of complex natural scene have been processed within this time.

53.535 **Temporal Interference in Object Recognition**

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The limited processing capacity of the visual system is evident in situations when many objects must be recognized in a brief time period, which typically results in perceptual impairments or delays. The difficulty in recognizing an object when accompanied by temporally or spatially adjacent items may reflect a competition for limited perceptual resources. However, the locus and mechanisms of such interference is still unclear. Here, we measured the extent to which temporally and spatially adjacent items can interfere with recognition processes of a foveated object. Subjects determined which one of two pre-specified face targets was embedded in a rapid serial visual presentation (RSVP) sequence of distractor faces. In addition to the centrally presented sequence, two non-task relevant, horizontally adjacent RSVP sequences were also displayed. The central sequence was presented at varying presentation rates around discrimination thresholds (~6-10 items/s) while the rate of the flanking sequences spanned a much wider range (~2-15 items/s). Performance was poorest overall when the rate of the flanker items was ~8 items/s and was better at slower presentation rates and perhaps more interestingly, also better for fastest rates (15 items/s), in conditions in which more visual information was displayed and could potentially interfere. This pattern was not observed when flanker faces were inverted, suggesting that some aspects of perceptual interference may be unique to processing upright faces. These findings help to describe the relative effects of temporal and spatial interference and suggest that an accurate representation of an object may require a minimum period of uninterrupted processing. When faces are presented too rapidly, they may not be processed at the same level that face identity is represented or perhaps rely on other processing mechanisms and therefore, do not compete for face resources. Further study will assess the reliability and magnitude of these preliminary effects.

53.536 **Top-down processes modulate occipitotemporal cortex to facilitate cognitive decisions with visually impoverished objects after 200 ms: Evidence from neural repetition effects**

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A series of neuroimaging and event-related potential (ERP) studies investigated the brain dynamics of the visual constancy of cognitive decisions about objects. Model verification theory proposes top-down processes of model prediction and testing in ventrolateral prefrontal cortex (VLPFC) and ventrocaudal intraparietal sulcus (vcIPS) regions implicated in mental rotation modulate occipitotemporal cortex to enable cognitive decisions with highly impoverished objects, such as unusual views. Regarding timing, a two-state interactive account proposes that, after the initial bottom-up pass, these brain regions interact to support cognitive decisions about visual objects during a frontal N3 complex. These accounts and multiple memory systems and transfer appropriate processing theories of memory predict the largest repetition effects for same unusual views in these brain areas during the N3 complex because model verification processes are recruited during both study and memory test only in this condition. To test these ideas, repetition effects were compared to objects in unusual and canonical (best) views seen before from the same or the other view during categorization and recognition. Neuroimaging results showed that same unusual views show (a) the most suppression on both tasks in model testing regions in caudal VLPFC (BA 44/6), vcIPS, and dorsal occipitotemporal cortex, and (b) more suppression on categorization than recognition in model prediction regions of mid-VLPFC, lateral occipital, and fusiform cortex. ERP results showed that a frontopolar N350 subcomponent of the N3 complex exhibits the task-general pattern seen in model testing regions, whereas a centrofrontal N390 subcomponent exhibits the categorization-specific pattern seen in the model prediction regions. Altogether, these findings implicate top-down processes between 200 and 500 ms in the visual constancy of cognitive decisions about objects and implicit memory, and indicate that vision and memory theories combined best explain the human brain dynamics for visual object cognition.

53.537 **Comparison between discrimination and identification processes using line-drawing stimuli**

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In object recognition, some cognitive processes, such as detection, discrimination, identification and categorization are involved. We have no adequate knowledge about what kind of properties in stimuli are involved in these processes and how these processes are associated with each other. By focusing on the processes of discrimination and identification, the present study aimed to exhibit the difference between these processes. Two experiments were conducted, one about the discrimination task, and the other about the identification task. In the discrimination task, two stimuli of line-drawings objects were briefly presented (200ms) at the center of the screen and observers were asked to judge whether the objects are the same or not. The procedure of the identification task was almost the same except that the target was assigned by a word before two stimuli were presented and observers were asked to choose one of them as the target. Eight objects were selected from Snodgrass and Vanderwart (1980) as stimuli. The background of stimuli was masked by black-and-white random-noise. The stimuli (black line-drawing objects) were also masked probabilistically by random-noise. We analyzed the accuracy and RT on the discrimination and identification tasks and examined the correlation between these values and intrinsic information of line-drawing objects in order to investigate which information is involved in the discrimination and identification processes. The results of both task showed that there is no clear relationship between accuracy and local information in stimuli. However, the difference in holistic complexity has some influences on the discrimination of line-drawing object. On the other hand, identification was related to the contour's factor of object (such as feature points and complexity of object component). Therefore, we assume that the discrimination process involves the comparison of holistic shapes and the identification process involves using strong features of the object as cues.

53.538 **The interaction of structural and conceptual information determines object confusability**

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The current study examines the impact of conceptual information on competition from shared structural features during an object recall task. Previous studies with category specific visual agnosia (CSVA) patient ELM show that structural dimensions such as tapering and pinching are stored in a distributed fashion, and that integration of these dimensions can fail during recall due to competition from objects that share values on these dimensions (Dixon, Bub & Arguin, 1997). Visual similarity is therefore determined not only by proximity among distributed diagnostic structural dimensions, but also by the number of values shared by objects within a category. Importantly, ELM was able to use distinctive conceptual information to resolve structural competition during recall. This interaction between structural similarity and conceptual relatedness was replicated in normal recall of newly learned attributes to known objects (Bukach et al., 2004). However, it is difficult to define the relevant diagnostic features of real objects. In the current study, we use novel stimuli to manipulate both the number of shared features and conceptual relatedness of objects while controlling for similarity due to proximity. Participants associated either conceptually related or unrelated labels to object sets that shared few or many values on diagnostic structural dimensions. Participants in the conceptually related and shared structural values condition made more errors than any other group. These results are consistent with the pattern of errors from CSVA patient ELM and provide strong evidence for the influence of conceptual information on resolution of competition from shared values on structural dimensions during normal recall.

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Face perception: Disorders

Vista Ballroom, Boards 539–552

Tuesday, May 11, 8:30 - 12:30 pm

53.539 **Face detection in acquired prosopagnosia**

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Detection of faces in visual scenes has received extensive attention in machine vision, but limited research has addressed face detection in humans. Here we assess face detection in six participants with acquired prosopagnosia resulting from a variety of lesions to better understand the processes and neural areas contributing to face detection and the relation of detection to other stages of face recognition. All six participants showed severe impairments on tests of facial identity recognition, confirming prosopagnosia, and participants were also extensively tested for perceptual discrimination of faces. We used structural MRI to delineate the lesions and functional MRI to show the status of the core regions of the face-processing network (OFA, FFA, STS). Two tasks requiring visual search for the presence of a face among distractor stimuli assessed detection in the patients and 12 age-matched controls. Two participants, R-AT2 and B-AT1, performed normally on both tasks. These patients had anterior temporal lesions that did not affect their core face-processing network. Two participants, R-AT1 and R-IOT4, had severe detection impairments while the performance of R-IOT1 and B-AT/IOT1 was borderline. These four subjects all showed difficulty on perceptual tasks requiring discrimination of facial identity. Except for R-AT1, all subjects had lesions to right inferior occipitotemporal cortex, with loss of the FFA and OFA in R-IOT1 and B-AT/IOT1 and loss of the FFA alone in R-IOT4. Furthermore, DTI analysis in R-AT1 suggested reduced fractional anisotropy in the region of the FFA and OFA. The association between detection and identity perception suggests that these abilities may be supported by the same processes. Impairment in these abilities correlates with damage to the core face-processing network

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in the right hemisphere. Face detection deficits in R-IOT4 despite preservation of the right and left OFA indicates that these regions are not sufficient on their own to support detection.

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53.540 **The right anterior temporal and right fusiform variants of acquired prosopagnosia**

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Subtypes of acquired prosopagnosia have long been proposed, including apperceptive, associative and amnestic variants. The relation of functional subtype to underlying variations in lesion anatomy is an area of study. The recent development of fMRI localizers that reliably identify regions of the core face-processing network (FFA, OFA, and STS) in single subjects allows us to transform structure-function questions into investigations of the relation between behaviour and the status of face networks. Here we describe two paradigmatic patients with acquired prosopagnosia:

BP had had herpes encephalitis causing a right anterior temporal lesion, with fMRI showing an intact core network, but most likely loss of aIT. Neuropsychological testing showed sparing of other perceptual and memory functions, with deficits on the face component of the Warrington Recognition Test and the Cambridge Face Memory Test. She was impaired on the Famous Faces test, but had normal semantic knowledge of people. She was normal on many face perception tasks, including face detection, gender perception, expression perception, discrimination of facial features and configuration, and view-invariant face discrimination. She was impaired on face imagery, however.

RG had a right medial occipitotemporal stroke that destroyed the FFA but spared OFA and STS. Neuropsychological tests showed sparing of other perceptual and memory functions, and he too was impaired on the Famous Faces test, but had normal semantic knowledge of people. Unlike BP, RG showed widespread impairments on many face perception tests, including face detection, gender perception, discrimination of facial features and configuration, and view-invariant face discrimination. Imagery of global facial properties was normal, in contrast to BP.

We conclude that BP has an amnestic variant of prosopagnosia associated with right anterior temporal damage, likely including aIT, but sparing OFA and FFA, and that RG has an apperceptive variant, from right fusiform damage and loss of the FFA.

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53.541 **Residual face-selectivity of the N170 and M170 is related to the status of the occipital and fusiform face areas in acquired prosopagnosia**

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Event-related potentials (ERP) using scalp EEG recordings demonstrate that a difference between the perception of face and non-face object stimuli is evident in the N170 potential, usually larger over the posterior regions of the right hemisphere. A similar phenomenon is noted in the M170 potential in magnetoencephalography (MEG). The anatomic origins of this face-selective N170 remain uncertain, with proposals that it may reflect contributions from the FFA, STS or both. To investigate this, we studied the face-selective N170 using ERP and M170 using MEG in patients with acquired prosopagnosia. Significance of face/object contrasts in single-subject ERP were based on nonparametric bootstrap confidence intervals. All patients had undergone extensive neuropsychological and behavioural testing, as well as structural and functional MRI with a dynamic face localizer (Fox et al, Human Brain Mapping 2009) to characterize the post-lesion status of their core face-processing network, namely the FFA, STS and OFA. Two patients had right or bilateral anterior temporal damage from herpes encephalitis, sparing all components of the core network. The ERP data showed that, despite their prosopagnosia, they still showed a significant difference between faces and objects in the N170 over the right occipitotemporal regions, which was confirmed in the M170 using MEG in one patient. Three patients had occipitotemporal damage, two with loss of the FFA alone and one with loss of the FFA and OFA. Two of these subjects showed no difference between faces and objects in either the N170 or M170; however one subject with loss of the FFA alone did show a residual face-selective N170. We conclude that STS survival is insufficient on its own to generate a face-selective N170 in some patients, but on the other hand loss of the FFA alone does not always eliminate this electrophysiological phenomenon.

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53.542 **Non-identity based facial information processing in developmental prosopagnosia**

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Certain models of face processing (Bruce and Young , 1986) postulate that certain types of non-identity based facial information can be processed independently of face identity recognition. Developmental prosopagnosia is characterized by a severe deficit in face-identity recognition. The status of non-identity based face information in this condition would be useful in understanding how face processing happens normally and also in individuals with developmental prosopagnosia. Developmental prosopagnosics generally report no subjective deficits in the perception of age, gender or attractiveness.By looking at associations and dissociations of non-identity facial information like age , gender and attractiveness from face-based identity recognition, the issues of parallel streams of information extraction can be evaluated. Also, the kinds of facial information that are compromised along with face-based identity recognition will speak to the organization of these information processing streams by understanding what deficits go together and what do not. Phenotype differences may also exist in developmental prosopagnosia in the nature of the associations and dissociations – information from individual differences is important in this regard.Correlations of attractiveness judgements by developmental prosopagnosics with those of the control population are discussed. Tests were developed to assess attractiveness, age, gender perception.By testing 16 developmental prosopagnosics, we show that normal age and gender processing can exist in many such cases in spite of face-identity recognition deficits.

53.543 **Recognition of static versus dynamic faces in prosopagnosia**

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A striking finding in the face recognition literature is that motion improves recognition accuracy only when viewing conditions are poor. This may be due to parallel (separate) neural processing of the invariant (identity) information in the fusiform gyrus and changeable (social communication) information in the superior temporal sulcus (pSTS) (Haxby et al., 2000). The pSTS may serve as a secondary "back-up" route for the recognition of faces from identity-specific facial dynamics (O'Toole et al., 2002). This predicts that prosopagnosics with an intact pSTS may be able to recognize faces when they are presented in motion. We compared face recognition for prosopagnosics with intact STS (n=2) and neurologically intact controls (n=19). In our experiment, we used static and dynamic (speaking/expressing) faces, tested in identical and "changed" stimulus conditions (e.g., different video with hair change, etc.). Participants learned 40 faces: half from dynamic videos and half from multiple static images extracted from the videos. At test, participants made "old/new" judgments to identical and changed stimuli from the learning session and to novel faces. As expected, controls showed equivalent accuracy for static and dynamic conditions, with better performance for identical than for changed stimuli. Using the same procedure, we tested two prosopagnosic patients: MR, who has a lesion that destroyed the right OFA and FFA, and BP, who has a right anterior temporal lesion sparing these areas. For identical stimuli, MR and BP performed marginally better on static faces than on dynamic faces. For the more challenging problem of recognizing people from changed stimuli, both MR and BP performed substantially better on the dynamic faces. The motion advantage seen for MR and BP in the changed stimulus condition is consistent with the hypothesis that patients with a preserved pSTS may show better face recognition for moving faces.

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53.544 **Neural differences between developmental prosopagnosics and super-recognizers**

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Developmental prosopagnosia (DP) is a condition marked by very poor face recognition ability despite normal vision and absence of brain damage. At the opposite end of the face recognition spectrum, super-recognizers are people who are exceptionally good at recognizing faces (Russell, Duchaine & Nakayama 2009). In previous fMRI studies, subjects with DP showed patterns of brain activity similar to normal subjects. Here we extended the range of face recognition ability by comparing fMRI activity in DPs versus super-recognizers. Test stimuli included 1) standard localizers for face-selective activity (face vs. place images), and 2) faces of normal versus reversed contrast polarity. In normal subjects, reversal of contrast polarity produces a deficit in both facial recognition and face-selective brain activity (George, et al, 1999; Gilad, Meng, Sinha, 2009). The results indicate that: 1) DPs had smaller Fusiform Face Areas (FFAs) than the super-recognizers, 2) super-recognizers showed higher face selectivity in FFA, compared to DPs; 3) super-recognizers had stronger responses to faces in FFA, compared to DPs; 3) In FFA, both groups showed a larger response to faces of normal contrast polarity, compared to faces of reversed contrast polarity; 5) in FFA, super-recognizers did not show a larger contrast polarity bias, compared to DPs. However, 6) super-recognizers did show a larger contrast polarity bias in the anterior temporal lobe, bilaterally. These results support previous evidence that some aspects of mid-level face processing (e.g. contrast polarity sensitivity in FFA) are automatic and bottom-up in nature, and do not differ as a function of facial recognition. Other aspects of our data (in FFA and the anterior temporal face region) may well be related to the facial recognition differences in these two populations.

53.545 **Impaired face recognition despite normal face-space coding and holistic processing: Evidence from a developmental prosopagnosic**

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It has long been presumed that face-space coding and holistic processing are primary determinants of successful face recognition. Here, however, we present a case of a severe developmental prosopagnosic who showed normal face-space coding and holistic processing. Subject SP (a 23 year-old female) demonstrated severe face perception and face memory deficits, scoring 2.24 – 6.87 SD below the mean on the Cambridge Face Perception Test, the Cambridge Face Memory Test, and the MACCS Famous Face Test 2008. Her deficits appeared to be face-specific: performance was well within the normal range on a general intellectual test (Raven), a word memory task, the Birmingham Object Recognition Battery, and the Cambridge Car Recognition Test. To investigate SP's face-space coding, we used a wide range of face adaptation aftereffect experiments. Compared to controls, SP showed normal eye-height, expanded/contracted, and identity aftereffects for faces; she also showed normal expanded/contracted aftereffects for side-views of horses. Importantly, we ruled out the interpretation that SP's normal face aftereffects arose from object-general representations: exactly like controls (Susilo, McKone, & Edwards, VSS 2009), SP showed weak transfer of aftereffects between a vertically-distorted T-shape and test faces varied in eye-height. To investigate holistic processing, SP completed three composite tasks (one naming, two same/different) with three different sets of faces. She demonstrated normal composite effects for upright faces. Crucially, she showed no composite effect for inverted faces, ruling out the possibility that the upright effect was driven by a general global attentional bias. The case of SP suggests that face-space coding and holistic processing alone may not be sufficient to explain face recognition, and speaks to the possibility of other important determinants behind successful face recognition performance.

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53.546 **Holistic perception of facial expression in congenital prosopagnosia**

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People with developmental or congenital prosopagnosia (CP) have never learned to adequately recognise faces, despite intact sensory and intellectual functioning. Recent research suggests these individuals can have a deficit restricted to recognising facial identity, with no apparent difficulties recognising facial expressions. These findings are currently being used to infer dissociable cognitive systems underlying facial identity and facial expression recognition. However, this logic only holds if the intact facial processes are achieved via the same mechanisms as controls, rather than compensatory strategies developed to overcome deficits. At present, this is yet to be established. The aim of this project was to determine whether CPs with apparently intact facial expression recognition abilities were using "normal" mechanisms to process this non-identity information from faces, or whether they were using atypical compensatory mechanisms. We assessed the facial expression recognition abilities of a group of adult CPs and a group of age- and sex- matched controls. All of the CPs demonstrated "spared" facial expression recognition abilities on a sensitive battery of facial expression tasks. Given this, we assessed whether the CPs would also show evidence of holistic facial expression perception in a composite task. Composite facial expressions were composed by aligning the top half of one expression (e.g., anger) with the bottom half of another (e.g., happiness). Control participants were slower to identify the expressions in one half of the face when they were aligned rather than misaligned; that is a "composite effect". Results suggest that the group of CPs also displayed a composite effect for expression. This indicates that CPs and controls use similar mechanisms to perceive facial expressions, and thus that facial identity and facial expression recognition might indeed be dissociable in developmental disorders of face recognition.

53.547 **Are deficits in emotional face processing preventing perception of the Thatcher illusion in a case of prosopagnosia?**

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Behavioural studies using the Thatcher illusion are usually assumed to demonstrate configurality in upright face processing. Previously, we have reported on PHD, an individual with prosopagnosia, could not discriminate Thatcherized faces but showed some evidence for residual face processing (VSS, 08). Recent functional imaging data suggests a role for emotional expression perception in discriminating Thatcherized from neutral faces (Donnelly & Hadjikhani, in preparation). Here we report on a series of emotion perception tasks were conducted on PHD and control participants. Results for PHD revealed: (1) specific deficits for distinguishing magnitude of anger and disgust; (2) poor sensitivity when discriminating faces as one of two given emotions; (3) a within category deficit for intensity, but no intensity deficit between emotions unless disgust was present; (4) a different solution for PHD relative to controls in respect of a multidimensional scaling study for sameness judgements of faces varying in emotion identity and intensity. We consider possible relationships between PHDs emotion perception and his ability to discriminate Thatcherised from normal faces.

Acknowledgement: ESRC

Tuesday AM

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53.548 Acquired prosopagnosia as a face-specific disorder: Ruling out the visual similarity hypothesis

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The understanding of the nature of prosopagnosia – classically defined as a disorder of visual recognition specific to faces following brain damage – can inform about how visual face recognition is performed in the normal human brain. However, according to a long-standing alternative view of prosopagnosia, the prosopagnosic impairment would rather reflect a general difficulty for fine-grained discrimination in visually homogenous object categories (Faust, 1955; Damasio et al., 1982; Gauthier et al., 1999). We tested this hypothesis stringently with a well-known brain-damaged prosopagnosic patient (PS, Rossion et al., 2003), in three delayed matching experiments in which the visual similarity between the target and distractor was manipulated parametrically. We used 3 kinds of stimuli: novel 3D geometric shapes manipulated on single or multiple dimensions, morphed common objects (Hahn et al., 2009), and morphed photographs of a highly homogenous familiar category (cars). In every experiment, there was no evidence of a steeper increase of error rates and RTs with increasing levels of visual similarity for the patient, relative to normal observers. These data categorically rule out an account of acquired prosopagnosia in terms of a general problem of fine-grained discrimination in a visually homogenous category. Finally, a fourth experiment with faces showed that, compared to normal observers, the patient's impairment with morphed faces was best revealed at the easiest levels of discrimination, i.e. when individual faces differ clearly in global shape rather than in fine-grained details. Overall, these observations indicate that the alternative view of prosopagnosia as a more general impairment for fine-grained discrimination in visually homogeneous object categories does not hold.

53.549 Typical and atypical development of a mid-band spatial frequency bias in face recognition

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Previous research has found that adults rely on middle spatial frequencies for face recognition. The objectives of the present study were to follow the development of the mid-band bias in the typical population from early childhood and to compare this development in autism and Williams syndrome. The current paradigm was adapted from the adult literature to use across development and involved masking different spatial frequency bands in face images. Poorer performance when a particular band was masked would imply that this band was being used during face recognition. Thirty-six typically developing controls (TD), eighteen children with high-functioning autism (HFA) and fourteen children with Williams syndrome (WS) between 7- and 15-years-old learned to recognise two faces and then determined which face had been masked during presentation in a 2AFC task. Masks covered the face images at either 8 (LSF), 16 (MSF) or 32 (HSF) cycles per image. The use of each spatial frequency was plotted over developmental time for the three groups. In the TD group, 7-year-olds relied significantly more on HSF information than 15-year-olds, while the use of LSFs and MSFs were not significantly predicted by age. An adult-like bias towards the mid-band was evident by the age of 15. Interestingly, the HFA group followed an almost identical pattern. The WS group, however, demonstrated no change in the use of HSFs with age, but a decrease in the use of LSFs between 7- and 15- years-old. Both disorder groups displayed the adult-like mid-band bias found in typical development by the end of the age range studied. These data suggest that the mid-band bias emerges over an extended period of time during childhood. They also confirm the importance of comparing syndromes across a wide age range, demonstrating that the same adult outcome can be achieved through different developmental processes.

Acknowledgement: UK Medical Research Council, Grant G0701484 ID: 85031

53.550 Configural and Feature-based Processing of Human Faces and Their Relation to Autistic Tendencies

Scott Reed[1](sreed@uoregon.edu), Paul Dassonville[2]; [1]Department of Psychology, University of Oregon, [2]Department of Psychology, Institute of Neuroscience, University of Oregon

The developmental disorder of autism has been associated with impairments in the ability to process the spatial configuration of facial features (Davies et al., 1994). Configural processing impairments have therefore been hypothesized to underlie the deficits in emotion recognition and abnormal face processing strategies that are observed in this population (Teunisse & de Gelder, 2001). However, in examining the visual scan patterns of faces in those with autism, results have been inconsistent across studies due to the variability of symptoms that are displayed across small autistic samples. An alternative method that avoids the confound of variant symptoms is to measure autistic tendencies in neuro-typical individuals and examine how visual scan patterns of faces may be modulated by these tendencies. In addition, by disrupting configural processing in neuro-typical individuals through the inversion of faces, we can examine how configural impairments may interact with autistic tendencies to produce deficits in emotion recognition. Subjects (n = 112) completed the Autism, Empathizing, and Systemizing Quotient (AQ, EQ, and SQ) questionnaires and judged the emotional expression in upright and inverted faces while visual scan patterns were recorded. The EQ was negatively associated with the fixation time of the mouth in upright faces, but this did not translate directly into changes in accuracy of emotion recognition. Surprisingly, the SQ was found to be positively associated with the magnitude of the inversion effect on accuracy, with high systemizing tendencies associated with greater impairments in processing facial affect when configural processing was further disrupted through inversion of the faces. Because individuals with autism exhibit even more extreme levels of systemizing than in our neuro-typical participants, the difficulties that clinical populations demonstrate in recognizing emotion in upright faces may be due to this relationship with systemizing tendencies.

53.551 Relationships Among Emotion Categories: Emotion Aftereffects In High-Functioning Adults with Autism

M.D. Rutherford[1](rutherm@mcmaster.ca); [1]Psychology, Neuroscience & Behaviour, McMaster University

Visual aftereffects have been used to determine psychological relationships between perceived emotional facial expressions (Rutherford, Chattha & Krysko, 2007). Findings indicate that there is an asymmetrical relationship among perceived emotion categories: numerous negative emotions oppose few positive emotions. People with autism spectrum disorders (ASD) are believed to have atypical perception of emotional facial expressions (e.g. Rutherford & McIntosh, 2007). Two experiments use visual aftereffects to probe the psychological relationships among emotion categories in those with ASD. Experiment 1 was designed to test whether adults with ASD experienced aftereffects when viewing emotional facial expressions. Happy or Sad faces were the adapting image and a neutral image of the same model was the probe image. 19 ASD and 19 control participants saw the adapting image for 45s and the probe image for 800ms. Observers chose a label in a 4 AFC paradigm to describe the image. Clear evidence of aftereffects resulted. Experiment 2 was designed to probe relationships among the 6 basic emotions. Adapting images were the 6 basic emotions (one per trial) and the probe image was a neutral image of the same model. Response was obtained via 6 AFC task in which observers chose one of the six basic emotion labels to describe the probe image. The control group replicated previous findings. The ASD group showed evidence of afterimages, but different patterns of opposition: although happy opposed sad and sad opposed happy, the opposite of anger, fear and disgust was sad, whereas it was happy for the control group. Also, the opposite of surprise was predominantly disgust, for this group. This study is the first demonstration that we know of of visual aftereffects in a group with ASD. It also provides evidence that aftereffects can be used as a tool to reveal idiosyncratic organization of perceptual categories in special populations.

Acknowledgement: Social Sciences and Humanities Research Council

Tuesday AM

53.552 **The Let's Face It! Program: The assessment and treatment of face processing deficits in children with autism spectrum disorder**

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Although it has been well established that individuals with autism exhibit difficulties in their face recognition abilities, it has been debated whether the deficit reflects a category-specific impairment of faces or a perceptual bias toward local level information. To address this question, the Let's Face It! Skills Battery was administered to children diagnosed with autism spectrum disorder (ASD) and IQ- and age-matched typical developing children. The main finding was that children with ASD were selectively impaired in their ability to recognize faces across changes in orientation and expression. Children with ASD exhibited preserved featural and configural discrimination in the mouth region, but compromised featural and configural discrimination in the eye region. Critically, for non-face objects, children with autism showed normal recognition of automobiles and a superior ability to discriminate featural and configural information in houses. These findings indicate that the face processing deficits in ASD are not due to a local processing bias, but reflect face-specific impairments, characterized by a failure to form view-invariant face representations and impaired perception of information in the eyes. Can the face processing deficits of ASD be remediated through perceptual training? In a randomized clinical trial, children (N = 42) received 20 hours of face training with the Let's Face It! (LFI!) computer-based intervention. The LFI! program is comprised of seven interactive computer games that target the specific face impairments of autism. The main finding was that relative to the waitlist ASD group (N = 37), children in the active treatment training group demonstrated significant gains on the parts/wholes test. The treatment group showed improved analytic recognition of the mouth features and holistic recognition of the eyes. These results indicate that a relatively short-term intervention program can produce measurable improvements in the face processing skills of children with autism.

Acknowledgement: James S. McDonnell Foundation, the National Science Foundation (#SBE-0542013) and the National Science and Engineering Research Councils of Canada

Tuesday AM

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Memory: Encoding and retrieval

Tuesday, May 11, 2:45 - 4:15 pm
Talk Session, Royal Ballroom 1-3
Moderator: Scott Murray

54.11, *2:45 pm*

Evidence For a Fixed Capacity Limit in Visual Selection

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Recent studies suggest that visual working memory (VWM) is best described by a model that enables the storage of a discrete number of items with limited precision. Motivated by known similarities between neural mechanisms of visual selection and working memory, we asked whether performance on an attention-demanding selection task could be described by a similar model. Observers were cued to monitor a variable number of locations in a masked visual display and discriminate the orientation of a single target. Performance on this task was well-described by a model assuming that observers may select a fixed number of spatial locations with limited precision, while encoding no information from other locations (R2 = .94). In contrast, a shared resource model that assumes no fixed selection limit and an inverse relationship between the number of selected locations and the precision of information that can be extracted from any one location provided a relatively poor fit to the observed data (R2 = .46). Furthermore, selection capacity estimates obtained in this task were strongly predictive of VWM capacity estimates obtained in a memory-limited task that employed the same stimulus set. Finally, a cue-evoked N2pc (an ERP component thought to reflect the selection and individuation of objects) was strongly predictive of the number of locations that observers could successfully monitor. This predictive relationship suggests that behavior in this task was limited by the selection of multiple positions rather than the subsequent encoding or storage of information at these locations. Together, these findings suggest that visual selection and VWM storage depend on a common fixed capacity system that enables the selection or storage of a discrete set of positions or items.

Acknowledgement: NIH R01MH087214

54.12, *3:00 pm*

Spatial working memory is limited by fixed resolution representations of location

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Is spatial working memory (SWM) capacity limited by the resolution with which locations are coded in memory? To address this question, we compared the spatial resolution of location representations in two nearly identical tasks typically characterized by different capacity limits. In particular, we first replicated previous work demonstrating that SWM span is reduced when subjects must recall items in a specific serial order (SO) compared to when they may recall in any order (AO). In a follow up experiment we considered whether the different capacity limits in these tasks result from differences in the resolution of position representations. Specifically, standard span trials were intermingled with trials wherein a single target was absent, compared to memory displays, and participants were required to localize the missing target. Resolution was operationally defined as localization precision. Surprisingly, we found no significant resolution differences in SO compared to AO trials. This suggests that SO processing relies on a categorically non-spatial resource, and that it degrades SWM by dual task interference, not by degrading spatial working memory, per se. Importantly, we found no load effect on resolution in the AO condition for target loads within an individual's capacity limit; even a post-hoc comparison for one compared to five targets revealed no significant resolution difference. In other words, there were no per-item costs associated with successfully remembering more targets, revealing that representations are coded at a fixed resolution regardless of load. Perhaps most interestingly, resolution did vary participant-by-participant, and these differences were positively and significantly correlated with individual SWM spans. Participants with greater location resolution could remember more targets. Taken together these results suggest that while, within an individual, objects are always encoded into memory with a fixed spatial resolution, person-by-person, differences in resolution may determine differences in capacity.

54.13, *3:15 pm*

Encoding of a scene into memory is enhanced at behaviorally relevant points in time

Jeffrey Lin[1](jytlin@u.washington.edu), Amanda Pype[1], Scott Murray[1], Geoffrey Boynton[1]; [1]University of Washington

Considerable evidence suggests that the encoding of visual input into memory is strongly affected by attention. For example, encoding of a scene is reduced if spatial attention is drawn away by a demanding rapid-serial-visual-presentation (RSVP) task at fixation. However, encoding under such conditions of divided attention is improved if a scene is particularly salient or novel. Here, we show that the encoding of a scene is also enhanced at behaviorally relevant points in time, regardless of the content of the scene and the focus of spatial attention.

In Experiment 1, after being familiarized with a set of scenes, participants were presented with 16 scenes in a RSVP and were surprisingly unable to recognize whether a specific test scene had appeared in the previous sequence of scenes. In Experiment 2, the same set of scenes was presented, but attention was directed to a demanding task at fixation where the goal was to identify a white target letter among a stream of black distractor letters. As before, one scene was presented for a recognition test immediately after each sequence. Surprisingly, recognition performance was at chance except when the test scenes had been presented concurrently with the white target letters. When interviewed, subjects were unaware of their enhanced memories for these target-concurrent scenes. In Experiment 3, enhanced encoding of visual scenes was also found at the specific time of an auditory target.

Results suggest that at behaviorally relevant points in time, visual traces of the visual field are automatically encoded into memory regardless of the spatial focus of attention. It is as though the visual system is performing a 'screen capture' at the time of target identification; such a screen capture mechanism may play an important role in the retrospective analysis of important events.

Acknowledgement: National Institute of Health (NIH) EY 12925 to GMB.

54.14, *3:30 pm*

Magnetic stimulation of frontal brain areas: visual working memory suffers, other forms of visual short-term memory not

Ilja G. Sligte[1](I.G.Sligte@uva.nl), H. Steven Scholte[1], Victor A.F. Lamme[1]; [1]Cognitive Neuroscience Group, Psychology, University of Amsterdam

To guide our behavior in successful ways, we often need to rely on information that is no longer in view, but maintained in visual short-term memory (VSTM). According to recent insights, maintenance of information in VSTM can happen at multiple levels in the neural hierarchy; either low in primary visual cortex (iconic memory), intermediate in extrastriate visual cortex (fragile VSTM), or high in parietal and frontal cortex (working memory). Previously, we1 have shown that both iconic memory and fragile VSTM can be disrupted, while leaving working memory intact (by showing respectively light masks and pattern masks). Now, by delivering transcranial magnetic stimulation at the right dorsolateral prefrontal cortex (DLPFC) during stimulus maintenance, we show that working memory capacity can be reduced, while leaving fragile VSTM intact. This implies that VSTM stores at different levels of the neural hierarchy operate relatively independently from each other.

1Sligte, I.G., Scholte, H.S., & Lamme, V.A.F. (2008). Are there multiple visual short-term memory stores? PLoS ONE 3, e1699.

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54.15, *3:45 pm*

Selective Remembering: Multivoxel Pattern Analysis of Cortical Reactivation During Retrieval of Visual Images

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Episodic retrieval is thought to involve reactivation of cortical regions that support encoding. The fidelity of our memories is putatively related to how well target memories are selectively reactivated during retrieval attempts. The present study employed multivoxel pattern analysis (MVPA) of fMRI data from a visual memory task to assess how neural measures of cortical reactivation relate to episodic retrieval. We used a paradigm in which individual cue words (nouns) were associated with photographs of well-known faces and/or scenes. Cue words were associated with either a face, scene, or both. Subjects were then presented with the cue word alone and attempted to retrieve the most recently studied photograph associated with each word. Competition—and the demand for selective retrieval—existed whenever a cue word was associated with multiple images. Behavioral results indicated high levels of overall retrieval success, but competitive retrieval was associated with lower recall rates and lower levels of retrieval detail. Pattern classification analyses indicated that patterns of activity in ventral temporal cortex that were elicited during encoding were robustly reactivated during retrieval—that is, classification of the category of retrieved items (face vs. scene) was well above chance. Indeed, the degree of reactivation revealed by pattern analysis increased as a function of retrieval detail that subjects reported, suggesting a link between reactivation and the phenomenology of visual remembering. Moreover, high levels of retrieval detail were associated with increased activation in the hippocampus, suggesting a role for the hippocampus in supporting detailed retrieval and cortical reactivation. Finally, the behavioral costs associated with competition between images were also reflected in neural measures of ventral temporal reactivation, as classification success was poorer when cue words were associated with multiple images. These results demonstrate a tight link between the subjective experience of visual remembering and neural evidence of perceptual reactivation.

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54.16, *4:00 pm*

Object features limit the precision of working memory

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An influential theory (Luck & Vogel, 1997) suggests that objects, rather than individual object features, are the fundamental units that limit our capacity to temporarily store visual information. This conclusion was drawn from paradigms in which the observer must detect whether a change occurred between a sample and a probe array when the arrays are separated by a short retention interval. Such 'change detection' paradigms reveal that increasing the number of objects, but not the number of distinct features, affects working memory performance (Luck & Vogel, 1997; Olson & Jiang, 2002). Using instead a paradigm that independently estimates the number and precision of items stored in working memory (Zhang & Luck, 2008), here we show that the storage of object features is indeed costly. We collected estimates of the precision and guess rate of working memory responses as participants had to remember the color, orientation, or both the color and orientation of isosceles triangles. We found that while the quantity of stored objects is largely unaffected by increasing the number of features per object (no change in guess rate), the fidelity of these representations dramatically decreased. Moreover, selective costs in precision depended on multiple features being contained within the same objects, as effects on both guess rate and fidelity were obtained when the orientation and color features were presented in distinct objects. Thus, in addition to providing evidence against cost-free conjunctions, our results demonstrate that storage of objects and features both limit visual working memory capacity. We argue that previous reports of cost-free conjunctions were due to the insensitivity of the tasks to changes in representational precision. Consistent with this interpretation, we found, using a change detection task, that manipulations of feature load do affect performance when the task places demands on the precision of the stored visual representations.

Attention: Models and mechanisms of search

Tuesday, May 11, 2:45 - 4:15 pm
Talk Session, Royal Ballroom 4-5
Moderator: Arni Kristjansson

54.21, *2:45 pm*

Is object recognition serial or parallel?

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Can one recognize multiple objects in parallel, as if they were simple features? Or does one "read" objects one-by-one, as if they were words? We consider three models of divided attention: a standard serial model, an unlimited-capacity, parallel model, and a fixed-capacity, parallel model. The standard serial model analyzes objects one-by-one. The unlimited-capacity, parallel model analyzes objects independently and simultaneously. The fixed-capacity, parallel model analyzes objects simultaneously, but acquires information at a fixed rate. Methods: For stimuli, we used images of similar animal categories (e.g., bear, wolf, fox). Observers searched a brief display of animal images for target categories. This set of stimuli minimized low-level differences between categories, such as object textures and spatial-frequency spectra. For the experiment, we used several variations on the simultaneous-sequential paradigm to distinguish among the three models. Previously, this paradigm has shown that simple features are processed by an unlimited-capacity, parallel model and words are processed by a standard serial model. Results: Current results for objects favor the fixed-capacity, parallel model over the standard serial model. And, more decisively, the results reject the unlimited-capacity, parallel model.

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54.22, *3:00 pm*

Attention and Uncertainty Limit Visual Search in Noisy Conditions

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Signal detection theory- (SDT; 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 have found strong effects of attention: precuing improves accuracy, especially when the target is embedded in a high level of external noise (Lu & Dosher, 1998; Dosher & Lu, 2000). In this research, we attempt to resolve the apparent contradictory conclusions from these two major lines of inquiry in spatial attention. We hypothesize that the conditions in which an effect of spatially-cued attention is substantial correspond to conditions in which attention effects over and above uncertainty occur in visual search. Our analysis suggests that many of the classical visual search experiments have been carried out using stimulus conditions where attention effects on perception are least likely to be found. We studied visual search in a range of external noise and contrast conditions for low and high template overlap (target-distractor similarity). We found that set size effects in high external noise conditions are larger than expected by decision uncertainty alone: log-log slopes increase sharply in increasing external noise levels, especially in high-precision judgments, showing improved external noise exclusion at smaller set sizes. Additional effects occur in low noise. All these results are well accounted by a visual model that uses the elaborated perceptual template model (ePTM; Jeon, Lu & Dosher, 2009), the attention mechanisms developed in the PTM framework (Lu & Dosher, 1998, Dosher & Lu, 2000), 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.

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54.23, *3:15 pm*

Selective attention to transparent motion is by blocking and not by attenuation

John Palmer[1](jpalmer@uw.edu), Victor D. Nguyen[1], Cathleen M. Moore[2]; [1]Department of Psychology, University of Washington, [2]Department of Psychology, University of Iowa

A filtering paradigm was used to study selection by feature-based attention in transparent motion displays. Observers viewed a single field of dynamic random dots with net motion in several possible directions. The task was to discriminate between relevant directions of motion while ignoring irrelevant directions of motion. For example, one might discriminate between leftward and rightward motion while ignoring diagonal motions. By manipulating the motion strength in both relevant and irrelevant directions, one can test for selection by blocking versus selection by attenuation. With blocking, withdrawing attention prevents detection of even a strong stimulus; with attenuation, withdrawing attention can be overcome by a sufficiently strong stimulus. The results were consistent with blocking and not attenuation. They rule out models of attenuation such as a motion analog to the contrast gain model of contrast detection. Possible models of blocking include attention switching, response gain, or a selection process in decision rather than perception.

54.24, *3:30 pm*

There are no attentional costs when selecting multiple movement goals

Donatas Jonikaitis[1](djonikaitis@googlemail.com), Heiner Deubel[1]; [1]Ludwid Maximilians University

Strong dual task costs are observed when people perform two tasks at the same time, and these costs appear in different tasks, effectors and modalities. Reaction time is commonly used to measure dual task costs, and inferences about underlying cognitive factors leading to dual task competition are made based on shorter or longer reaction times. Based on reaction times it has been suggested that movement goal selection is a major factor leading to dual task costs when making multiple goal directed movements at the same time. To investigate this, we asked participants to point and look at two different locations while we varied the time between the cues to start eye and hand movements. Like in previous studies, we observed that participants were slower to start their eye or hand movement if they were planning another movement at that time. Identical results were observed when participants were planning bimanual movements. Second, we measured whether spatial attention caused these observed dual task costs. Movements might have been delayed, because participants were not able to select multiple movement locations in parallel. We measured attention allocation by presenting short attentional probes at different stages of movement planning. In strong contrast to the dual task cost observed in movement latencies, participants allocated their attention to eye and hand movement goals in parallel and without any cost. The same pattern of results was evident for bimanual movements. These results demonstrate that observed dual task costs in goal directed movements do not arise from movement goal selection. The results also suggest a dissociation between movement latencies and movement goal selection, in that longer movement latencies do not equate to delayed movement goal selection.

54.25, *3:45 pm*

How Does Reflexive Visuospatial Attention Speed Target Processing?

Naseem Al-Aidroos[1](naseem.al.aidroos@utoronto.ca), Maha Adamo[1], Jacky Tam[1], Susanne Ferber[1,2], Jay Pratt[1]; [1]University of Toronto, [2]Rotman Research Institute

Irrelevant transient stimuli can speed responses to visual targets that appear soon after at the same location (relative to other locations). How do these stimuli speed target processing? Traditionally, they are thought to act as cues that reflexively capture visuospatial attention, a mechanism that provides processing priority to specific regions of the visual field. Here we report behavioral and electrophysiological evidence of the limits of this explanation. In the first experiment we show that while targets are identified faster at a cues locations (the classic cueing effect), this effect is increased when the cue and target are visually similar. Thus, the reflexive cueing effect is not a general attentional enhancement of all visual processing within a region of space; rather, some component of the effect is related to the identity of the cue. In a second experiment we used attentional control settings to manipulate whether cues captured attention or not and measured event-related potentials. Cues that captured attention produced a posterior contralateral positivity between 200 to 400 ms after their onset that was absent when they did not capture attention. This component resembles the Ptc, which has been associated with the resolution of perceptual competition between proximal stimuli. More importantly, a similar component was observed time-locked to the target onset, except when the target appeared at a cued location. Thus cues may speed target processing by inducing competition resolution, making this process unnecessary when the target subsequently appears at that location. These results do not fit well with the notion that reflexive attention is a mechanism deployed to enhance visual processing within regions of space. Instead, the present results suggest that transient stimuli initiate perceptual processing, and subsequent targets can exploit these ongoing processes if, for example, they appear at the same location or are visually similar.

Acknowledgement: Natural Sciences and Engineering Research Council of Canada

54.26, *4:00 pm*

“Reversals of fortune” in visual search: Fast modulatory effects of financial reward upon visual search performance

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Rewards have long been known to modulate overt behavior. Less is known of their effect upon attentional and perceptual processes. Here we investigated whether the (changeable) monetary reward-level associated with two different ‘pop-out’ targets might affect color-singleton visual search and the phenomena of ‘priming of pop-out’, i.e. repetition priming for one target type versus the other. Our observers searched for a target diamond-shape with a singleton color among distractor diamond-shapes of another color (e.g. green among red, or vice-versa), then judged whether the target had a notch at top or bottom. Correct judgments led to monetary reward, with symbolic feedback indicating this immediately, while actual financial rewards accumulated for receipt at study end. One particular target color led to higher (10:1) reward for 75% of its correct judgments, while the other singleton target color (counterbalanced over participants) received the higher reward on only 25% of trials. These reward schedules led not only to faster performance overall for the more rewarding target color, but also increased trial-to-trial priming of pop-out for targets of that color. The actual level of reward received on the preceding trial affected this, as did (orthogonally) the likely level of reward. When reward schedules were reversed within blocks, without explicit instruction, a corresponding reversal of the effect upon search performance emerged significantly within around six trials, asymptoting at around fifteen trials, without observers’ explicit knowledge of the contingency. These results establish that not only pop-out search but even priming of pop-out can be influenced by target reward levels, with search performance and priming effects dynamically tracking changes in reward contingencies.

Acknowledgement: University of Iceland Research Fund

Spatial vision: Crowding and mechanisms

Tuesday, May 11, 5:15 - 7:00 pm
Talk Session, Royal Ballroom 1-3
Moderator: Jeremy Freeman

55.11, *5:15 pm*

Crowding and metamerism in the ventral stream

Jeremy Freeman[1](freeman@cns.nyu.edu), Eero Simoncelli[1,2]; [1]Center for Neural Science, New York University, [2]Howard Hughes Medical Institute, New York University

Vision is degraded in the periphery. The phenomenon of “crowding” provides a striking example: objects closer together than half their eccentricity are unrecognizable. Crowding has been described as statistical or textural averaging of features over spatial regions (Parkes et al., 2001), and recently Balas et al. (2009) showed that applying a texture analysis-synthesis model (Portilla & Simoncelli, 2000) to crowded stimuli simulates crowding effects. We develop this hypothesis with an explicit model of extrastriate ventral stream processing that performs eccentricity-dependent pooling across the entire visual field. Images are decomposed with V1-like filters, followed by simple and complex-cell-like nonlinearities. Pairwise products among V1

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outputs are averaged within overlapping spatial regions that grow with eccentricity according to a single scaling parameter (ratio of size-to-eccentricity). If this model captures the information available to human observers, then two properly fixated images with identical model responses should be metamers. We perform experiments to determine the scaling parameter that produces metameric images. Given a natural image, we generate images that have identical model responses, but are otherwise as random as possible. We measure discriminability between such synthetic images as a function of scaling. When images are statistically matched within small pooling regions, performance is at chance (50%), despite substantial differences in the periphery. With larger pooling regions, peripheral differences increase, and discriminability approaches 100%. We fit the psychometric function to estimate the pooling regions (scaling) over which the observer estimates statistics. The result is consistent with the known eccentricity-dependence of crowding, and also with receptive field sizes in macaque mid-ventral areas, particularly V2. Finally, we show that metamers synthesized from classic crowding stimuli (e.g., groups of letters) yield images with jumbled, unidentifiable objects. Thus, the model associates the spatial extent of crowding with mid-ventral receptive field sizes, and provides specific hypotheses for the computations performed by underlying neural populations.

Acknowledgement: NSF Graduate Student Fellowship (J.F.)

55.12, *5:30 pm*

Reduced Neural Activity with Crowding is Independent of Attention and Task Difficulty

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Form vision in peripheral fields is limited by crowding, the impaired identification of a target object when surrounded by other items. Crowding is thought to reflect a failure in feature selection and integration, due to limited spatial resolution of attention or maladapted low-level receptive field properties related to lateral interactions. We investigated the top-down influences of task-difficulty and attention on the neuronal response to crowded and non-crowded letter triplets in the periphery using fMRI. In our first experiment, we changed the distance between target and flanking letters, and measured BOLD response while subjects identified the target letter. In a second experiment, we added conditions identical to the non-crowded stimuli but partially scrambled the target letter to increase task difficulty. We found that decrease in target-flanker separation was associated with decrease in BOLD in V2 through V4 for both experiments, but degrading the target in the non-crowded condition did not cause any such decrease. Therefore, the reduced BOLD signal observed in the crowded condition was not due to increased task difficulty per se or any related differences in attention demands. To further determine any interaction between attention and crowding, we measured BOLD signal induced by peripherally presented crowded and non-crowded letter triplets, while subjects' attention was directed to an unrelated task at fixation. Two conditions were added where only the flankers were displayed, without the center letter. We found that in the non-crowded condition, adding the center letter increased BOLD signal, while in the crowded condition the center letter produced no signal increase, consistent with the interpretation that crowding suppressed signal from the center letter. Together, these results show that the low-level neural response correlated with crowding is independent of task difficulty and attention, indicative of a bottom-up input-driven cause of crowding.

Acknowledgement: NIH/NEI R03EY016391, R01EY017707

55.13, *5:45 pm*

Crowding and cortical reorganization at and around the PRL: model and predictions

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Visual crowding is a ubiquitous phenomenon in peripheral vision and manifests itself as the marked inability to identify shapes when targets are flanked by other objects. It presents a fundamental bottleneck to object recognition for patients with central vision loss. Such patients typically use a stable location in their peripheral retina for fixation for a given task. This location is usually very close to the central scotoma and is known as the preferred retinal locus (PRL). Preliminary studies (Chung & Lin, 2008, ARVO) have shown that the crowding zone measured at the PRL does not exhibit the marked anisotropy that is a hallmark of crowding in the normal periphery (Toet & Levi, 1992). This suggests that there is a process of cortical reorganization that reshapes the crowding zone at the PRL. However, little is known about the underlying causes and the temporal trajectory of the reorganization process. Recently we have proposed a computational model that explains crowding as a consequence of inappropriate image statistics that drive the lateral (long-range horizontal) connections underlying the normal peripheral visual field (Nandy & Tjan, 2009, SfN). The temporal overlap of spatial attention and subsequent fovea-centric saccadic eye movements distort the image statistics to produce the radial anisotropy. By adding to our model the central scotoma and the PRL measured from a patient, we show that the altered image statistics due to the temporal overlap of spatial attention and PRL-centric eye movements would drive the crowding zone at the PRL to being isotropic. We also delineate the developmental time course from pre-scotoma anisotropy to post-scotoma isotropy as a function of exposure to the post-scotoma statistics. Further, our model predicts that the crowding zone at an intact non-PRL location would also undergo reorganization from anisotropy pointing toward the fovea (pre-scotoma) to anisotropy pointing toward the PRL (post-scotoma).

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55.14, *6:00 pm*

Crowding combines

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Visual crowding provides a window into object recognition: observers fail to recognize objects in clutter. Here we ask, what do they see instead? We analyze observers' errors to show that crowding necessarily reflects the combination of information across multiple complex objects, rather than the mislocalization (or substitution) of one object for another. First, we presented single letters, randomly chosen, in noise in the periphery and tabulated a confusion matrix based on observers' (n=3) reports. We then tested the same observers in a classic crowding task, in which they viewed a triplet (target and two flankers) of closely spaced letters in the periphery (10 deg) and reported the identity of the middle target. For each observer, we tailored the triplets based on that observer's single-letter confusion matrix. One flanker was chosen to be a letter that was most confused with (most "similar" to) to the target, and the other was chosen to be a letter that was least confused (least similar). Consistent with the literature, when mistaken, observers tend to report the flankers. The crucial issue, however, is which of the two flankers observers report on these trials. Blind substitution predicts that the two flankers (similar and dissimilar) are equally likely to be reported. Instead, we find that observers are more likely to report the similar flanker (70%) than the dissimilar flanker (30%). The effect of similarity on erroneous responses proves that the response combines information from both the target and the reported flanker. By systematically tailoring the stimuli, we induced a bias in the reports that reveals a pooled, "mongrel-like," underlying percept. Our method, applicable to any object, generalizes the evidence for "compulsory pooling" from the narrow domain of grating orientation (Parkes et al., 2001) to complex, everyday objects.

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55.15, *6:15 pm*

Saccade-distorted image statistics explain target-flanker and flanker-flanker interactions in crowding

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The ability to identify an object in peripheral vision can be severely impaired by clutter. This phenomenon of crowding is ubiquitous and is thought to be a key limitation of form vision in the periphery. The interactions between target and flankers are complex, and no single model can account for the myriad of results. Recently we have argued that crowding is due to the improper encoding of image statistics in peripheral V1 (Nandy & Tjan, 2009 SfN). We hypothesize that image statistics are distorted due to a temporal overlap between spatial attention, which gates the acquisition of image statistics, and the subsequent saccadic eye movement it elicits. In terms of mutual information between edge orientations at neighboring positions,

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the distortion turns smooth continuation into repetition. By fixing all but one parameter in the model using well-known anatomical and eye-movement data unrelated to crowding, we found that the spatial extent of the distortion in orientation statistics precisely reproduces the spatial extent of crowding, with all its tell-tale characteristics: Bouma's Law, radial-tangential anisotropy, and inward-outward asymmetry. The reproduction is robust in the sole free parameter of the model (the hypothesized temporal overlap between attention and saccade). Here, we extended the model to quantify the effects of crowding on orientation discrimination with a Gabor target and different flanker configurations. We proceeded from first principles by using the saccade-distorted image statistics as priors in a Bayesian formulation of a simultaneous segmentation and estimation task within the computational framework of a random field. This model can account for the recent finding of Levi and Carney (2009, Curr. Biol.) that more flankers can cause less crowding. It can also match ordinally the varying levels of crowding induced by the different flanker configurations used in Livne and Sagi (in-press, JOV).

Acknowledgement: NIH R01EY016093, R01EY017707

55.16, *6:30 pm*

Crowded by drifting Gabors: Is crowding based on physical or perceived stimulus position?

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In crowding a stimulus in the periphery (the target) becomes hard to recognize when other stimuli (crowders) are presented nearby. Crowding depends on the distance of the crowders to the target (Bouma, 1970). If the position of the crowders is misperceived, which position matters for the degree of crowding, the physical or the perceived position? In the present experiment the crowders were drifting Gabor gratings whose position appeared as shifted in the direction of motion (DeValois & DeValois, 1991). Six gratings, either drifting inward or outward, surrounded a peripheral target grating at systematically varied distances. Observers judged the orientation of the target grating, that could be tilted 2 deg clockwise or counter-clockwise. Observers performed worse, i.e., they experienced more crowding, when gratings were drifting towards the target and thus perceived in a position closer to the target. The difference in performance between inward and outward drifting crowders corresponds to the difference in perceived positions, as determined in a separate psychophysical assessment of the size of the mislocalization illusion. The extent of crowding was fully determined by the perceived position, which in the present case is only available after the integration of motion information. Arguably, feedback from motion-sensitive extra-striate areas is involved in the motion mislocalization illusion. If so, the results demonstrate that crowding is not based solely on spatial interactions in the feed-forward stream. Furthermore, the present results indicate that the influence of motion on position perception occurs early, before low-level features such as orientation can be perceptually judged.

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55.17, *6:45 pm*

Letter crowding increases with flanker complexity

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Crowding refers to the deleterious influence of nearby contours on visual discrimination. A popular theory for crowding is that it arises as the consequence of inappropriate feature integration. This theory predicts that the effect of crowding increases with the number of features in close proximity to the target. We tested this prediction by examining how letter crowding depends on the perimetric complexity of flanking letters, a measurement that correlates with the number of features. We analyzed a total of 96000 trials in which 16 observers (6000 trials per observer) identified the middle (target) letter of sequences of three crowded lowercase letters (center-to-center separation = 0.8x the x-height) presented at 10° in the inferior visual field. Each letter was randomly drawn from the 26 letters of the Roman alphabet. Eight observers were tested with the Times-Roman font and the other eight with the Courier font. The perimetric complexity (perimeter squared/"ink" area) was determined for each letter and the sum was calculated for the pair of flankers on each trial. We binned the perimetric complexity of the flankers into 10 groups. In general, the error rate of identifying the target letter increased linearly with the perimetric complexity of the flankers, for both Times-Roman ($r = 0.98$) and Courier ($r = 0.99$) fonts. However, the increase of the error rate of identifying the target letter with flanker complexity depends on the target letter complexity such that target letters of low complexity are more susceptible to the flanker complexity, while target letters of high complexity are less susceptible to the flanker complexity. These findings are consistent with the prediction based on the inappropriate feature integration account of crowding, and strongly support the speculation that feature integration is a competitive process that depends on the relative proportion of features between the target and flankers.

Acknowledgement: Supported by NIH grant R01-EY012810

Perceptual learning: Plasticity and adaptation

Tuesday, May 11, 5:15 - 7:00 pm
Talk Session, Royal Ballroom 4-5
Moderator: Sara Mednick

55.21, *5:15 pm*

Adaptation to low signal to noise decreases visual sensitivity

Stephen Engel[1](engel@umn.edu), Peng Zhang[1], Min Bao[1]; [1]Psychology, University of Minnesota

Some neurons in sensory systems will be relatively noisy in a given environment or for a given task. Reducing spiking in such neurons could allow more accurate perception and save limited metabolic resources. Whether the nervous system automatically limits responses of noisy neurons, however, remains unknown. To test this possibility, we measured how subjects' visual sensitivity changed when they adapted to a lowered signal to noise ratio at a specified orientation in the visual environment. Eight subjects viewed the world through an "altered reality" system, comprised of a head mounted gray-scale video camera fed into a laptop computer that drove a head-mounted display (HMD). Vertical information about the world was removed from the video images prior to their display, while keeping overall vertical energy constant. This was performed in real time by randomizing the phases of all vertical Fourier components of the image. Viewing the vertically randomized video images through the HMD, subjects performed everyday tasks, such as playing games, and watching movies in an environment where vertical signals were distracting noise. Prior to and following four hours of adaptation to this environment, contrast detection thresholds were measured for vertical and horizontal sinusoidal patterns (6 deg diameter, 1 cpd, presented 8 deg in the periphery). Following adaptation, vertical thresholds increased by more than 15% relative to horizontal thresholds. A second experiment found a reliable reduction in the apparent contrast of suprathreshold patterns at the noisy orientation following only one hour of adaptation. Sensitivity for simple patterns has been linked to responses of orientation selective neurons in early visual cortex. Exposure to low signal to noise may have caused these neurons to decrease their gain. Such decreases could improve perception in tasks that pool across orientations, and save limited metabolic resources for neurons that signal orientations with higher information content.

55.22, *5:30 pm*

Learning enhances fMRI pattern-based selectivity for visual forms in the human brain

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Previous neurophysiological experiments have shown that learning shapes the neural representation of low-level stimulus features (e.g., orientation). However, much less is known about the neural mechanisms that mediate learning to discriminate global forms. Here, we combine psychophysical and high-resolution fMRI measurements to investigate learning-dependent changes in the neural representation of forms across the human visual cortex. We employed Glass pattern stimuli defined by dot dipoles and generated by linear morphing between radial and concentric patterns. Observers were trained to perform a categorization task (i.e. judged whether each stimulus was similar to a radial or concentric pattern). Observers were trained (2400 trials) with stimuli presented in noise (40% signal) and were tested in the scanner before and after training while performing the same task. Our behavioural results showed that performance in the discrimination of visual forms was significantly improved after training. Multi-voxel pattern classification analysis (MVPA) showed that stimulus discrimination from fMRI responses was enhanced after training in higher occipito-temporal areas (V3a, V7, V3B/KO, and LOC) but not early visual areas. To reliably decode stimuli from fMRI responses, we derived pattern-based tuning curves by ranking the voxel-based preferences for each stimulus condition and fitting the MVPA results with a Gaussian function. We observed significant learning-dependent decreases in the width but not the amplitude of the tuning curves in higher occipito-temporal areas. This finding was replicated by a control experiment, during which observers were scanned while performing a dot-density discrimination task that controlled for differences in task difficulty across stimulus conditions. These findings suggest that learning shapes the fine-tuned representation of global forms related to neural selectivity in higher visual areas rather than simply the overall fMRI responsiveness related to attentional gain processes.

Acknowledgement: This work was supported by grants from the Biotechnology and Biological Sciences Research Council to ZK [D52199X, E027436]

55.23, *5:45 pm*

REM sleep prevents interference in the texture discrimination task

Sara Mednick[1](smednick@ucsd.edu); [1]Department of Psychiatry, School of Medicine, UCSD

Improvement in the texture discrimination task (TDT) depends on sleep, shows feature and retinotopic specificity, varies with stimulus exposure, and is vulnerable to interference. Using a classic interference paradigm, Yotsumoto et al (2009) showed that two-part training on competing background orientations blocked learning of the initial stimulus set. We examined the role of sleep in perceptual interference on a short version of the TDT (to avoid deterioration effects). Interference was tested using two-part training with vertical or horizontal background orientations, which were presented in either the same or different retinotopic locations (lower left and upper right). We examined three nap conditions: naps (with and without rapid eye movement (REM) sleep) compared with quiet rest. We found that quiet rest showed no improvement in the interference condition, whereas naps with REM sleep eliminated interference effects. In fact, REM naps showed more than double the magnitude of learning in the interference condition compared with the non-interference condition. Learning in the interference condition was significantly correlated with the amount of REM sleep in the nap, no other sleep stage was related to performance changes. Interestingly, quiet rest produced perceptual learning to the same degree as sleep in the non-interference conditions. In conclusion, when the brain is serially presented with competing information, such as discriminating a target embedded within two different background orientations, REM sleep appears to enhance memory for information presented first. Thus, the memory trace becomes resilient to interference from subsequent competing targets. Furthermore, although prior studies have compared sleep to active waking controls, we find that quiet rest maybe as effective for learning as REM sleep.

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55.24, *6:00 pm*

Transfer in perceptual learning as extrapolation

C. Shawn Green[1,2](csgreen@umn.edu), Daniel Kersten[1,2], Paul Schrater[1,2,3]; [1]Department of Psychology, University of Minnesota, [2]Center for Cognitive Sciences, University of Minnesota, [3]Department of Computer Science, University of Minnesota

Given appropriate training, humans will demonstrate improvement on virtually any perceptual task. However, the learning that occurs is typically highly specific to the training task and stimuli. In the language of machine learning, such specificity is indicative of what is known as policy learning. Policies can be thought of simply as lookup tables that map states onto actions (i.e.-"what to do"). Importantly, policies are specific to a given goal; if the goal is changed, knowing what was previously the right thing to do provides no information regarding what is currently the right thing to do. As an example, in a typical orientation discrimination task ("Was the gabor tilted clockwise or counterclockwise from a reference angle?"), the optimal policy relies on a discriminate. If the current "state" lies on one side of the discriminate, press 'A', otherwise, press 'B'. Given this, it is clear why transfer is not observed – this policy completely inapplicable when the reference angle is rotated by 90°. If perceptual learning is analogous to policy learning, we hypothesized that in order to observe transfer, the training task must promote the development of a policy that can be extrapolated from and will be appropriate for new orientations. To this end, rather than a discrimination task, which promotes the development of an untransferable policy, an orientation estimation task was employed. Subjects were asked to indicate (by rotating a single line) the exact orientation of a quickly flashed gabor (+/-15° from 45°). The policy that should be learned in this task is a continuous function of orientation and thus it should be possible to extrapolate to previously unseen orientations. As predicted, full transfer was observed when the stimuli were rotated by 90°. These results and overall framework provide a novel way of approaching the field of perceptual learning.

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55.25, *6:15 pm*

Uniformative trials are more effective than informative trials in learning a long term perceptual bias

Sarah J. Harrison[1](sharrison@sunyopt.edu), Benjamin T. Backus[1]; [1]SUNY College of Optometry

A Bayesian account of perceptual learning predicts that learning should occur only when stimuli are informative about statistical contingencies in the environment (e.g. Kersten, O'Toole, Sereno, Knill & Andersen, 1987). Alternatively, learning could occur in the absence of informative cues to appearance, through practice of the perceptual decision itself. We assessed these two possibilities using a perceptually ambiguous Necker cube stimulus: Cue recruitment studies have shown the perceived rotation direction can be trained to be contingent on the stimulus' retinal location (Backus & Haijiang, 2007; Harrison & Backus, 2009). One group viewed only informative presentations, with the direction of cube rotation disambiguated by disparity and occlusion depth cues. Another group viewed uninformative, ambiguous, cubes for more than 96% of presentations. The remaining, informative, trials were sufficient to prime stabilization of the percept (Brascamp, Knapen, Kanai, Noest, van Ee & van den Berg, 2008; Klink, van Ee, Nijs, Brouwer, Noest & van Wezel, 2008), such that the two groups experienced equivalent pairing of perceived rotation direction with retinal location on Day 1. The long-term influence of perceptual experience on Day 1 was assessed on Day 2 by presenting subjects with a 50:50 mix of informative and uninformative stimuli. Informative stimuli had the reverse rotation-location contingency to that experienced the previous day. Those subjects whose perceptual experience on Day 1 had been elicited by the uninformative stimuli were affected very little by the reverse-contingency informative presentations on Day 2, and instead perceived ambiguous cubes as rotating in the same direction as Day 1. In contrast, subjects whose perceptual experience on Day 1 had been elicited by informative stimuli were more likely to perceive opposite rotation on Day 2. Hence, contrary to Bayesian prediction, long-term learning of perceptual appearance was largely driven by "practice", perhaps of the decisional process, while informative presentations played a smaller role.

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55.26, *6:30 pm*

Recovery of stereopsis in human adults with strabismus through perceptual learning

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Stereopsis, the process leading to the sensation of depth from retinal disparity, is compromised or absent in strabismus and/or amblypia. Here we provide the first evidence for the recovery of stereopsis in human adults through perceptual learning - the repetitive practice of a demanding visual task with a feedback. Three strabismic adult observers (23-28 year old) without stereopsis but with normal visual acuity participated in the training. Before stereo training, the three observers failed the Randot circle test (≤ 400 arcsec), and also failed to detect a large binocular disparity (≤ 1320 arcsec) in stereoscopic sinewave gratings. Training trials began with a dichoptic cross and a binocular surrounding frame. By decreasing the contrast of the dominant eye's frame until both frames were visible, and adjusting the vertical and horizontal positions of the two frames separately, observers were able to achieve binocular fusion and alignment. Once fusion was achieved, a pair of sinewave gratings, one above the other with identical contrast and spatial frequency, was presented to the two eyes stereoscopically. The lower grating was presented in the same plane as the

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surround (zero disparity), and the upper grating was presented with a binocular disparity. The observer's task was to judge the relative depth of the top grating (i.e., closer or farther than the bottom grating). Feedback was provided after each trial. Following the training (thousands of trials), all three observers recovered stereopsis, achieving 40-140 arcsec stereoacuity with the Randot circle test, and were able to detect disparities of 70-280 arcsec with stereoscopic sinewave gratings which were jittered in horizontal position to avoid monocular cues. However, even after recovery of local stereopsis, our observers were unable to detect depth in random dot stereograms. We conclude that perceptual learning may be a useful clinical tool for treating stereoblindness.

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55.27, *6:45 pm*

Feedback inhibits untrained motion directions in perceptual learning

Jonathan Dobres[1](jmd@bu.edu), Takeo Watanabe[1]; [1]Boston University Vision Sciences Laboratory

Feedback regarding the correctness of subjects' responses has been shown to have beneficial effects on perceptual learning. It has been shown that feedback can increase the rate of learning (Herzog & Fahle, 1999) or make it possible for an observer to learn with stimuli that would be too difficult to learn in the absence of feedback (Seitz et al 2006). Given the powerful effects of feedback, it would be worthwhile to examine its deeper characteristics, such as specificity and transfer, but these aspects remain largely unexamined in the literature. To examine the nature of these effects, this study examines feedback in concurrence with coherent motion stimuli. Subjects were trained in a 2IFC random dot motion detection task in which two coherent motion directions (coherence = 10%) were interleaved within training sessions. One direction was always paired with trial feedback, and the other, separated from the first by 90º, had no feedback associated with it. Subjects participated in seven such training sessions, each of which was conducted on a different day. One day before and after the training stage, subjects completed pretest and post-test sessions in which they detected motion directions that included the trained directions as well as 16 other directions in a range of ±48º around the directions of training. Results indicate that during training performance steadily increased for the trained directions with and without feedback. To our surprise, results of the test stages are totally different between the two directions; while the observers' detection sensitivity improved only for the direction that had been paired with feedback and its vicinity, performance improvement occurs evenly around the direction that had been paired with no feedback. These results suggest that feedback plays role in inhibiting directions that are not trained.

Acknowledgement: NIH-NEI R21 EY018925 NIH-NEI R01 EY015980-04A2 NIH-NEI R01 EY019466

Tuesday Afternoon Posters

Binocular vision: Stereopsis

Royal Ballroom 6-8, Boards 301–316

Tuesday, May 11, 2:45 - 6:45 pm

56.301 Stereopsis in People with Eyes of Different Lengths: Adaptation via Receptor Geometry or Post-receptoral Mechanisms?

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Stereopsis in normal observers is most sensitive when the objects presented to the two eyes are the same size. People with different refractive errors in the two eyes (anisometropes) usually have one eye longer than the other, so the retinal images differ in size for equal-sized objects. We asked whether stereopsis is best in anisometropes when the retinal images or objects are the same. We measured stereo sensitivity for different object size ratios. Observers discriminated the orientation of a disparity-defined corrugation. Disparity noise was added to determine coherence thresholds. Threshold was best when object sizes were the same despite the differing eye lengths. Two mechanisms could account for this result. First, the retina may expand in proportion to eye length such that the number of cones sampling a given visual angle in the two eyes remains unchanged; this is the receptor hypothesis. Second, post-receptoral mechanisms may adjust for the differences in retinal-image size; this is the post-receptor hypothesis. To determine which hypothesis is a better account, we used an adaptive optics (AO) ophthalmoscope to measure linear and angular cone density in the anisometropes tested psychophysically. AO imaging was done with infrared light and dynamic wavefront correction. Images of the cone mosaic were stabilized and averaged, and individual cones identified. We could resolve cones to within ~0.25 deg of the foveal center. Axial length, corneal curvature, and anterior chamber depth were measured using ultrasound, and those parameters were used to calculate retinal-image sizes. Angular cone density was generally higher in the longer eye. Thus, objects of the same size cover more cones in the long than the short eye, which is inconsistent with the retinal hypothesis. We conclude that anisometropes maintain fine stereopsis, despite having eyes of different lengths, via post-receptoral adaptation of the representation of the retinal images.

Acknowledgement: NIH

56.302 Do People of Different Heights have Different Horopters?

Emily A. Cooper[1](emilycooper@berkeley.edu), Johannes Burge[2], Martin S. Banks[1,3,4]; [1]Helen Wills Neuroscience Institute, University of California, Berkeley, [2]Center for Perceptual Systems, University of Texas, Austin, [3]School of Optometry, University of California, Berkeley, [4]Department of Psychology, University of California, Berkeley

Accurate perception of depth with respect to the ground is critical for walking. The most precise visual cue to depth is binocular disparity. Depth estimates from disparity are most precise for stimuli near corresponding points, pairs of retinal loci that yield the same perceived direction when stimulated. Rays from corresponding points projected into space intersect at the horopter. It would be adaptive if an upright observer's horopter lay in or near the ground. Interestingly, corresponding points deviate systematically near the retinas' vertical meridians: above the left and right foveas they are shifted rightward and leftward, respectively; below the foveas, the shift is opposite. Because of this horizontal shear, the horopter is pitched top-back. Helmholtz noted that this places the horopter near the ground for an upright observer and thereby could optimize depth perception with respect to the ground.

We asked whether people with different eye heights and separations have different shear angles, and whether those angles place the horopter in the ground for each individual. We used a dichoptic apparent-motion paradigm to measure the positions of corresponding points at different retinal eccentricities. We also measured cyclovergence to control for eye torsion and determined the effect of a structured stimulus like the natural environment on cyclovergence. We found a statistically significant, but modest, correlation between predicted and observed shear angles in 28 observers with heights ranging from 4.3 to 7 feet. Thus, corresponding points in most people place the horopter near the ground when they are standing. However, some observers' data were inconsistent with linear shear; their corresponding points yielded curved horopters that cannot be co-planar with the ground.

Acknowledgement: NIH Research Grant R01 EY012851, National Defense Science and Engineering Graduate Fellowship, and UC Berkeley Neuroscience Graduate Program

56.303 The effect of local matching on perceived slant in stereopsis

Rui Ni[1](rui.ni@wichita.edu); [1]Department of Psychology, Wichita State University

The difference between two monocular views of a horizontal line can result in either a complete matching or an incomplete matching. The complete matching is consistent with the perception of a line slanted in depth while the incomplete matching is consistent with the perception of a partially occluded line. Without other cues both complete and incomplete matching are possible resulting in an ambiguous perception of the line which could be either slanted in depth or partially occluded. This study investigated whether a complete matching of local features would affect the matching of horizontal lines in stereopsis and disambiguate the perception. A CrystalEyes 3 Workstation was used to produce the stereo images on a ViewSonic CRT monitor, 140Hz in refresh rate and 1024*768 in resolution. In the experimental displays, horizontal lines were presented to each eye with interocular differences that are consistent with both slant perception and occlusion perception. Vertical lines were presented in between the horizontal lines which specified a unique local matching. In Experiment 1, the vertical lines were presented followed by the presentation of the horizontal lines. In Experiment 2, the vertical lines were presented simultaneously with the horizontal lines. In both Experiments, the vertical lines were manipulated such that they were presented either in a fronto-parallel plane or in a plane slanted in depth. The subjects were asked to judge the perceived slant of the horizontal lines. The results showed that the matching of vertical lines is propagated by the visual system to that of horizontal lines. The matching of local features determined whether slanted lines or partially occluded lines should be perceived from the differences between the left and right views of horizontal lines.

56.304 Effects of orientation and noise on the detection of cyclopean form

Lisa O'Kane[1](lisa.okane@stir.ac.uk), Ross Goutcher[1]; [1]University of Stirling

We present two experiments investigating effects of local orientation and different types of noise on observers' perception of cyclopean form. Observers were presented with a stimulus containing line elements distributed randomly across a surface, consistent with a disparity-defined square wave, oriented at either ±45deg. The observer's task was to determine whether the stimulus was at a clockwise or counter-clockwise orientation. Each stimulus was comprised of either horizontal or vertical line elements. Line elements had the same local orientation within each trial. Different forms of noise were added to these stimuli, in order to obtain 75% performance thresholds for correctly discriminating the orientation of the square wave. In the first experiment, noise was added via the random repositioning of lines in each eye (decorrelation noise). In the second experiment, noise was added by distorting the z positions of the lines in each eye (disparity noise). Thresholds were measured for varying line length (11 – 33 arcmin) and stimulus densities (5 – 50%). We find effects of both line element orientation and noise type. In the first experiment, decorrelation noise thresholds were lower for stimuli comprised of vertical line elements, indicating enhanced performance compared to horizontal line stimuli. In the second experiment, horizontal line stimuli showed improved performance compared to vertical line stimuli when lines were short (11 arcmin). However, performance with horizontal line stimuli reduced markedly with increasing line length to a much greater extent than vertical line stimuli. These results point to effects of noise occurring at multiple levels of processing. Results obtained

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using decorrelation noise are consistent with cross correlation as a method of disparity estimation, however, the effects obtained using disparity noise are consistent with disruption at the level of cyclopean form processing.

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56.305 **Multiple Planes in Stereo-Transparency**

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In the typical Julesz display, subjects view random-dot stereograms in which dots in each depth plane are adjacent. However, Tsirlin, Allison, &Wilcox (JOV/8/5/5) intermingled dots with different disparities to create transparent, overlaid, depth planes. With free viewing and unlimited time to search and re-fixate, their subjects could distinguish up to six such depth planes. We now report that naïve subjects achieve this by scanning the display, noting only two or three planes at a time. However, after many hours of practice, experienced subjects can, in optimal conditions, accurately distinguish six to eight depth planes in a random display within 400 ms. (We provide unlimited exposure to just the first and last planes, to facilitate fusion, before completing the display for the specified time.) The new result supports theories of stereopsis in which the simultaneous analysis of multiple depth planes is possible, even without spatial adjacency.

56.306 **A Neural Model of Binocular Transparent Depth Perception**

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Problem. Humans can segregate binocularly viewed textured surfaces with different disparities, forming a percept of binocular transparency. Most models of stereoscopic perception cannot successfully explain the robust computation of stereoscopic depth for transparent as well as opaque surfaces. Building on a recent model of motion transparency perception (Raudies & Neumann, J.Physiol.Paris 2009, http://dx.doi.org/10.1016/j.jphysparis.2009.11.010) we propose a model of binocular stereo processing that can segregate transparent surfaces at different depths and also handle surfaces that are slanted with respect to the observer's line of sight.

Methods. Spatial correlations among model V1 orientation tuned cells calculate initial disparity estimates, which are passed to model area V2, which integrates V1 activations. Center-surround competition of disparity signals and divisive normalization of activities leads to attraction of similar disparities, a repulsion of nearby disparities and co-existence of distant disparities along a line-of-sight. Modulatory feedback helps to integrate consistent disparity estimates while dissolving local ambiguities and multiple matches at the same location.

Results and Conclusion. The model has been probed by synthetically rendered scenes with transparent slanted planes separated in depth. Such planes can be segregated in depth once disparity differences exceed a small threshold. The model can also successfully integrate smooth depth gradients. The model has been tested on stereo pairs from the Middlebury dataset (http://vision.middlebury.edu/stereo) and robustly processes opaque surfaces. When one eye's view of a region is occluded, disparity estimates are filled in from nearby positions of that region that are visible to both eyes by a feedback loop between areas V1 and V2. The model proposes how disparity sensitive V2 cells, their lateral interactions, and feedback can segregate opaque and transparent surfaces that are slanted in depth. Center-surround interactions in the disparity domain lead to fusion for binocularly matching regions and repulsion of disparity layers that are closely spaced in depth.

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56.307 **Crossed-line stereograms and the processing of stereo transparency**

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The perception of overlapping surfaces in depth (stereo transparency) presents a challenge to disparity measurement mechanisms, since multiple disparities must be encoded within a single area of the visual field. Here we use stimuli comprised of sets of randomly positioned crossed horizontal and vertical lines to examine how the visual system integrates information over space. Disparity was added to these crossed-line stimuli in two ways. First, horizontal and vertical lines in each cross could be given the same disparities by adding shifts of identical magnitude and direction to both lines (same shift stimuli). Alternatively, horizontal and vertical lines could be given different disparities by adding opposite shifts to each line (opposing shift stimuli). Both methods were used to create stereograms depicting transparent surfaces in depth, with the proportion of same shift crosses varied systematically. Observers were presented with two intervals, one containing a crossed-line transparency stimulus, the other containing a crossed-line stimulus depicting a single plane at fixation. Signal-to-noise ratio was varied by randomly repositioning a proportion of crossed lines independently in each image. Signal-to-noise ratios were always identical between intervals. Observers' task was to determine the interval containing the transparent stimulus. 75% correct thresholds were obtained, indicating the signal-to-noise ratio required to successfully determine the interval containing stereo transparency. Thresholds changed with a change in the proportion of same shift crosses, although the direction of change was not consistent across all observers. These results suggest that difficulties in the processing of stereo transparency exist both at the level of disparity measurement, where opposing shifts limit the effectiveness of spatial integration, and at the level of cyclopean surface interpolation, where, in the case of same shift stimuli, evidence for the presence of two disparities in the same area of the visual field is reduced.

Acknowledgement: Research supported by BBSRC Grant # BB/G004803/1 and RCUK Fellowship # EP/E500722/1.

56.308 **Binocular Capture: The effects of mismatched Spatial frequency and opposite contrast polarity**

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Background: Binocular capture occurs when the perceived positions of monocular targets are biased by the cyclopean visual direction of surrounding binocular targets. This effect is larger when the vertical separation between monocular targets exceed the spatial period of its carrier frequency. In an attempt to further elucidate the underlying mechanism mediating this effect, we measured the effects of mismatched spatial frequency targets and opposite contrast targets on the magnitude of binocular capture. Methods: Relative alignment thresholds and bias were measured separately for a pair of vertically separated (8, 30, 60 arcmin.) monocular (4′ X 66′) Vernier spatial frequency (SF) ribbons and a pair of monocular (4′ X 66′) Gaussian bars presented across a cyclopean random dot depth edge (10 arcmin. relative horizontal disparity). Each ribbon of the pair comprised carrier frequencies that were either matched (8 cpd and 1 cpd) or mismatched (top ribbon 1 cpd, bottom ribbon 8 cpd, and vice versa). The Gaussian bars were presented with either matched contrast (bright/bright) or opposite polarity (bright/dark) contrast. Gaussian bars were presented at approximately 3.4 times their contrast detection thresholds. Results: Capture magnitudes increased significantly with vertical separation for the matched 8cpd and mismatched SF ribbons, however, the matched 1 cpd ribbons failed to show a significant effect of separation on capture magnitude. Both matched and opposite polarity Gaussian bars produced increasing capture with increasing vertical separation, however the magnitude of capture was significantly larger for the opposite polarity bars. Capture magnitudes exhibited a strong linear dependence on the alignment thresholds for all conditions, but a weak dependence on the alignment thresholds for the matched 1 cpd condition. Conclusions: Stimuli that favor the recruitment of non-linear position mechanisms exhibit greater susceptibility to binocular capture. In these cases the magnitude of capture is strongly dependent on the precision of relative alignment.

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56.309 **Interactions between monocular occlusions and binocular disparity in the perceived depth of illusory surfaces**

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Monocular occlusions play an important role in stereoscopic depth perception. They signal depth discontinuities and, in certain configurations, create percepts of illusory occluding surfaces. Previous research showed that in these configurations the visual system not only infers the depth sign of the illusory occluder but also the depth magnitude. It is believed that quantitative depth percepts from occlusion arrangements are based on the constraints imposed by the viewing geometry. That is, the minimum (or maximum) possible depth of the illusory occluder is constrained by the line of sight from the eye in which the feature is hidden. This information is used by the visual system to estimate depth even in arrangements where the maximum (or minimum) possible depth is unconstrained. Here we have evaluated the effects of binocular disparity on the localization in depth of illusory occluders for several different stimuli. In each of the stimuli, the presence of monocular occlusions induced the percept of an illusory occluder at a different depth than the occluded object. In a series of psychophysical experiments we measured the perceived depth of the occluder as we manipulated 1) the occlusion geometry and 2) the disparity of a binocular feature placed next to the illusory surface. Subjects used a disparity probe to match the perceived depth in the stimuli. Our results show that the disparity of binocular features biases the perceived depth of the illusory occluders in the direction unconstrained by the viewing geometry. We argue that the extent to which binocular disparity influences depth percepts from occlusions can serve as a litmus test of the contribution of monocular information to quantitative depth percepts.

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56.310 **Relative disparity computation underlies the effects of surround area binocular correlation on depth perception**

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Human subjects perceive depth when viewing binocularly correlated stereograms. Binocular anti-correlation of an entire stereogram abolishes depth perception, while anti-correlation only of the center part of the stimulus accompanied by a correlated surrounding area reverses the direction of perceived depth. Here we developed a computational model which explains the effects of the surround on depth perception. The model consisted of input units responding to disparity in either the center or surround of the stimuli. Anti-correlation of the stimuli inverted the disparity tuning curves of the input units, mimicking V1 neurons. Integration of the input units' responses with threshold operation resulted in relative disparity selective units. The model output was the difference between the responses of two relative disparity selective units preferring either near or far disparity. The model reproduced the effects of surround area binocular correlation on depth perception. We tested the model with psychophysical experiments using random dot stereograms consisting of center and surround areas. In each trial, all dots in the center had the same disparity (-0.32 or +0.32 deg). Dots in the surround were divided into two groups. Different disparities of equal magnitude but opposite sign were assigned for dots in each group (0, ±0.1, …, or ±1.0 deg). Each area was either binocularly correlated or anti-correlated. Four human subjects discriminated the depth of the center against the surround. When both the center and the surround were correlated, subjects reported the depth based on the minimum relative disparity between the center and the surround. Stimuli with correlated center and anti-correlated surround caused reversed depth when the magnitudes of the surround disparities were small (0.2 deg). The results were agreement with our model. We suggest that relative disparity computation between the center and surround is crucial for the effects of surround area binocular correlation on depth perception.

56.311 **The effects of binocular disparity on the detection of curved trajectories are independent of motion direction**

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Pierce, Bian & Andersen (VSS 2009) found that binocular information was important for the detection of curved trajectories. In the current study we examined whether this effect was due to the direction of the motion path. On each trial subjects viewed two computer generated displays. In one display, a sphere followed a straight trajectory; in the other, another sphere moved along either a concave or a convex curved trajectory relative to the x-axis. We used a two-alternative forced choice procedure (2AFC) without feedback and participants were instructed to indicate which display simulated a curved trajectory. Thresholds for curved path discrimination from 16 participants were assessed by varying the curvature of the curved trajectories with an adaptive staircase. We manipulated three independent variables, viewing condition (binocular vs. monocular) curve type (concave vs. convex), and direction of the motion direction path (approaching vs. receding). Each of the 8 combinations was run in a separate block, and the order of blocks was counterbalanced across participants with a Partial Latin Square design. We found thresholds were lower in the binocular condition (M = 6.10 * 10-5) than in the monocular condition (M = 8.55 * 10-5). This difference was greater for concave arcs (M difference = 3.70 * 10-5) than for convex arcs (M difference = 1.19 * 10-5). Whereas the effects for receding objects tend to be weaker than for approaching objects, there was no significant difference between conditions related to motion direction. These results were consistent with our previous finding in support of the importance of the binocular disparity in detecting curved trajectories.

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56.312 **A Comparison of Stereoacuity at 6m of Collegiate Baseball Players in Primary Gaze and Batting Stance**

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Introduction Accurate discrimination of distance information and judgments of spatial localization may be advantageous during baseball batting. Stereopsis is traditionally measured in primary gaze, however a baseball batter's eyes are typically in a lateral gaze direction during batting. The purpose of this study was to compare stereopsis performance at far in primary gaze and in preferred batting stance in a population of collegiate baseball players. Methods Measurements of 6m stereoacuity were conducted as part of a visual performance assessment for the Pacific University men's baseball team (NCAA Division III) from 2004 to 2009. The athletes were 18-24 years of age (N=149), and only measurements taken during their first season's participation were used for analysis in returning athletes. Threshold stereoacuity was measured using a 2-forced choice paradigm at pre-set rod separations with a Howard-Dolman device. Threshold stereoacuity was subsequently measured with the athlete in preferred batting stance. Results The mean threshold stereoacuity in primary gaze was significantly better than in batting stance (p<0.001). The difference in the mean thresholds (8.38 vs 9.92 arc sec) was not considered clinically significant due to the magnitude of the stereoacuity intervals measured. The majority (59%) of athletes maintained the same stereoacuity threshold in both primary gaze and batting stance. A significant number of athletes (32%) performed worse in batting stance compared to primary gaze, while a small number performed better in batting stance (9%). Discussion There is a statistically significant reduction in 6m stereoacuity when measuring collegiate baseball players in batting stance compared to primary gaze position. Many athletes maintain the same stereoacuity threshold in batting stance, however a significant number demonstrated a reduction in depth sensitivity to real-space depth targets. To determine if depth sensitivity may affect baseball batting, depth perception should be assessed in both primary gaze and batting stance.

56.313 **A Comparison of Self-Reported and Measured Autostereogram Skills with Clinical Indicators of Vergence Ability**

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Failure to perceive the disparity-defined form in autostereograms by those with clinically normal stereoacuity can occur when achieving or maintaining the precise vergence angle required to place the intended left and right images on corresponding areas of the two retinas is difficult. Since vergence and accommodation must be maintained at different depth planes to permit sensory fusion of an autostereogram, poor autostereogram skill has been suggested by different investigators to be related either to the presence of a binocular vision anomaly (i.e., a poorly-tuned binocular system) or to a binocular system that is well- coordinated. To clarify the relationship between binocular visual performance and autostereogram skill, we asked subjects with equal visual acuity OU at near and no manifest misalignment of the visual axes to rate their own autostereogram skill. We then compared common clinical indicators of vergence ability (near point phoria, near point of convergence, vergence ranges, vergence facility, stereoacuity, and a symptom survey) with both their self-reported and measured autostereogram skills. Our results indicate that subjects with poor self-assessed and/or measured autostereogram skill have significantly poorer vergence facility (p = 0.012 for self-assessed; p<0.001 for measured), smaller prism base-out vergence break point (p = 0.05 for self-assessed; p = 0.02 for measured), greater exophoria (measured only, p = 0.02), and poorer TNO stereoacuity (self-assessed, p = 0.02 for crossed disparities; measured, p = 0.03 for crossed disparities, p = 0.05 for uncrossed disparities) than do subjects

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with good self-assessed or measured autostereogram skill. After practice significant differences between those with poor versus good measured autostereogram skill remained only for vergence facility (p = 0.05), near phoria (p = 0.02), and TNO stereoacuity (p = 0.01 for crossed disparities, p = 0.003 for uncrossed disparities). Binocular visual symptoms at near were not significantly different for the two groups.

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56.314 **Long distance disparity processing in the human visual cortex: an EEG source imaging study**

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We estimated the relative disparity response of neural populations in different visual areas in human cortex with visual evoked potentials and source localization methods. Using dense dynamic random dot patterns, we modulated the disparity of a central disk (4°diameter) from 0 to 12.6′ uncrossed disparity at 2 Hz. The disk was surrounded by a static annulus (16° outside diameter) presented in the fixation plane. We varied the gap separating the disk from the annulus parametrically from 0 to 5.5 degrees in six separate conditions. We compared the response amplitudes as a function of gap size to responses to the disk alone within fMRI-defined ROI's across the visual cortex. Based on the average signal-to-noise ratio (6 subjects) for the first harmonic (2Hz), we found that there was no change in response amplitude for small separations (<0.5 deg) in all visual areas. At larger separations, the amplitudes in V2 and V3 ROIs decreased to levels comparable to those obtained in the absence of a surround. However, in the V3A ROI, the amplitude remained constant until the gap size exceeded 4° and then fell to the level observed for the no-surround condition. To determine whether this effect was due to the decreasing size of the annular surround, we performed a control experiment, using two annuli of vastly different areas, but separated from the disk by the same gap width (0.5 deg); the responses were identical for these two surrounds. Altogether, these results suggest that area V3A possesses neurons responsive to relative disparity whose receptive fields allow a robust estimation of relative depth even for disparities separated by up to 4 degrees.

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56.315 **Responses of disparity-sensitive V3/V3A neurons to anti-correlated random-dot stereograms**

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Correlated random-dot stereograms (cRDSs) are often used to study depth perception. Depth perception is lost or reversed when using anti-correlated random-dot stereograms (aRDSs), in which the luminance contrast of dots is reversed between the two-eye images (Cumming et al, 1998; Tanabe et al, 2008). Single-unit recordings in monkey visual cortex have revealed that while most neurons in V1 retain disparity modulation for aRDSs, their disparity tuning curves are inverted compared to those for cRDSs (Cumming & Parker, 1997). Additionally, it has been observed that higher level inferior temporal cortex neurons are not disparity-selective for aRDSs (Janssen et al, 2003) and that V4 neurons greatly attenuate this selectivity (Tanabe et al, 2004). Unlike these regions, however, little is known about the responses of neurons in V3/V3A, an intermediate stage between V1 and V4, to aRDSs. Here we examined these responses by recording extracellular activity from 87 visually responsive neurons in two awake, fixating monkeys. Of these, seventy one showed significant selectivity for binocular disparity embedded in cRDSs (Kruskal-Wallis; p<0.05). The percentage of V3/V3A neurons selective for aRDSs (32%; 23/71) approximately equaled that in V4 (37%) (Tanabe et al, 2004). We fitted Gabor functions to the disparity tuning curves in order to calculate the ratio of disparity modulation amplitudes between aRDSs and cRDSs. The ratio for V3/V3A neurons (median, 0.25) was lower than that of V1 neurons (median, 0.39; Cumming & Parker, 1997) (Mann-Whitney test; p=0.0005), but comparable to that of V4 neurons (median, 0.24; Tanabe et al, 2004) (p=0.74). The results suggest that V3/V3A is involved in computations that eliminate any false-match responses elicited in V1.

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56.316 **Developmental Differences in Stereoscopic Discrimination: Is perceptual grouping responsible for depth discrimination deficits in adults?**

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In a recent developmental study we found that adult depth discrimination was consistently poorer than that of a group of 4-6 year olds. This surprising result was obtained when two grey-scale test stimuli were presented simultaneously in opposite directions in depth, above and below a fixation point (Giaschi et. al., 2008). The present set of experiments investigates the poor performance in otherwise visually normal adult observers. Specifically, we evaluate the hypothesis that this deficit is caused by a perceptual grouping mechanism that integrates disparity signals across space and disparity like that identified by McKee (1983). We measured depth identification in adults (18-33) using a large range of disparities (1 min to 3.5 deg). The stimuli were the same characters used in our original study; we manipulated their number (two or one), their appearance (via phase scrambling), and their alignment and location relative to fixation. On each trial, observers were ask to indicate which of two targets was closer, or when only one stimulus was presented, whether the target was closer or further away than a reference frame. In all conditions we measured proportion correct. We found that adult performance remained poor in all conditions in which two stimuli, offset in opposite directions, were presented. Depth identification was not improved by changing configural or spatial aspects of the stimulus. However, performance improved markedly when the two targets were offset in the same direction, or only one stimulus was presented.

If the adult's poor performance is due to perceptual grouping, our data suggests that it may be involuntary because all tasks could have been performed using one of the stimuli. Further research is required to determine if the absence of this effect in young children reflects developmental changes in perceptual organization.

Motion: Flow, depth, and spin

Royal Ballroom 6-8, Boards 317–331

Tuesday, May 11, 2:45 - 6:45 pm

56.317 **Segmentation of action streams: comparison between human and statistically optimal performance**

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Natural body movements arise in form of temporal sequences of individual actions. In order to realize a visual analysis of these actions, the visual system must accomplish a temporal segmentation of such action sequences. Previous work has studied in detail the segmentation of sequences of piecewise linear movements in the two-dimensional plane [1,2] In our study, we tried to compare statistical approaches for segmentation of human full-body movement with human responses. Video sequences were generated by synthesized sequences of natural actions based on motion capture, using appropriate methods for motion blending. Human segmentation was assessed by an interactive adjustment paradigm, where participants had to indicate segmentation points by selection of the relevant frames. This psychophysical data was compared against different segmentation algorithms, which were based: (1) on the available 3D joint trajectories that were used for the synthesis of the motion stimuli; (2) on the two-dimensional optic flow computed from the videos. This computation exploited a physiologically-inspired neural algorithm for optic flow estimation [3]. Simple segmentation methods, e.g. based on discontinuities in path direction or speed, were compared with an optimal Bayesian action segmentation approach from machine learning. This method is based on a generative classifier (naive Bayesian or HMM). Transitions between classes (types of actions) were modeled by resetting the class priors at the change points. Change point configurations were modeled by Bayesian binning [4]. Applying optimization within a Bayesian framework, number and the length of individual action segments were determined automatically. Performance of these different algorithmic methods was compared with human performance.

[1] Shipley et al., JOV, 4(8), 2004.

[2] Agam & Sekuler JOV, 8(1), 2008.

[3] Bayerl & Neumann, IEEE PAMI 29(2), 2007.

[4] Endres et al., NIPS 20, 2008.

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56.318 **Apparent size biases the perception of speed in rotational motion**

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Velocity constancy is the ability to equate physical speeds of objects placed at different depths, despite object's angular speeds on the retina changes proportionally with depth. Multiple studies have shown that size cues play a central role in the achievement of velocity constancy. On the other hand, some studies have provided evidence showing that depth cues are unnecessary for velocity constancy. However, since retinal size is linearly related to depth, it is reasonable to hypothesize that both cues should affect the perception of speed. We present here results of two experiments in which we measure the bias of perceived speed and size as a function of depth for rotational motion. We use this type of motion to avoid the effect of the frame on the perceived speed since the reference in rotational motion is its own center. We introduce binocular disparity to produce depth perception. The stimulus consisted of 16 dots (0.15 deg size) located 2 deg away from the center of rotation, undergoing rotational motion. 6 observers, the authors and 3 others naives as to the purpose of this study took part in the experiment. Results show that observers overestimate dot speed and pattern size of further stimuli but perceiving angular velocity as invariant. This result shows that the visual system would re-scale dot speed when the apparent radius increases so as to maintain angular velocity constant. However, the bias in perceived size is much larger than that of speed, which suggests that such re-scaling is not linear.

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56.319 **Discriminating between upward and downward 3-D motion from projected velocity**

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The direction of motion of an object in a 3-D scene can be ambiguous if only the projected motion path is considered. Specifically, downward motion in the projection can represent either upward or downward motion in the scene. The aim of this study was to determine whether observers could discriminate upward from downward 3-D motion from the projected velocity function alone. The displays consisted of a ball moving towards the observer, below eye level, either against a 3-D scene background or against a uniform background. The projected path of the ball was always downward and was identical across conditions. The average projected speed was also identical across conditions. The projected size changes corresponded to those that would occur for a level path in 3-D, regardless of whether upward or downward motion was simulated. Only the velocity function varied according to the simulated 3-D motion. Two displays, one simulating upward motion and one simulating downward motion, were presented successively in a paired comparison design. The independent variables were the angle between the upward and downward 3-D paths and the type of background–full scene or blank field. To avoid having the ball appear to start from a position on the ground, a cylinder was inserted in the scene and served as a platform from which the ball began its motion. We found that observers were able to discriminate upward from downward 3-D motion with projected trajectories all showing the same downward motion paths. For each background condition, accuracy was determined by the angle between the simulated upward and downward 3-D paths. Accuracy was higher with a scene background than with a uniform background. These results indicate that the projected velocity function is sufficient for discrimination of direction of 3-D motion even with motion paths that are identical in the 2-D projection.

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56.320 **The aperture problem in three dimensions**

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The classic aperture problem describes the ambiguity inherent to the motion of a frontoparallel (2D) contour (such as a line or an edge) viewed through a circular aperture. Despite a continuum of 2D velocities consistent with the apertured view, observers consistently perceive the direction of motion as orthogonal to the contour. Here we present an analogous 3D version where observers judged the 3D direction of motion of a slanted planar surface defined by a moving random dot stereogram presented behind a circular aperture. If the surface is specified by single frame dot lifetimes, the only potential factors influencing the perceived motion direction of the surface are the change in binocular disparity across time and 3D surface orientation. Provided observers use a similar heuristic in the 2D and 3D cases, such a surface should be perceived as traveling normal to its 3D orientation.

In separate sessions, observers judged either the perceived surface slant or direction of motion of the surface using a bird's-eye-view matching paradigm. We varied the surface slant, the lifetime of individual dots, and the 3D motion direction specified by the dots.

Slant judgments were close to veridical in all conditions. When dot lifetimes were more than one frame, and thus unambiguously specified surface motion, motion judgments were consistent with previously reported biases in the perception of 3D motion, and relatively close to veridical.

However, when the surface was specified by single frame dot lifetimes, motion was always perceived as moving directly towards or away from the observer. Thus, in the 3D version of the aperture problem, the perception of surface motion was heavily biased as moving along the line of sight, and not towards the perceived surface normal. These results suggest that the visual system might resolve perceptual ambiguity distinctly in 2D and 3D motion processing.

56.321 **Use of optic flow and visual direction in steering toward a target**

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Previous studies have shown that humans use both optic flow and the target visual direction in active control of self-motion. Here we develop a methodology that allows a more sensitive measurement of the observer's separate reliance on these cues to steer toward a target. Three observers were asked to use a joystick to steer toward a target with three types of displays, an empty screen with only a target visible, a textured ground plane, and a textured ground with reference posts. To tease apart the observer's use of optic flow and target visual direction cues, we perturbed both heading (Yh) and the simulated gaze direction (Yg) in the display using independent sums of seven harmonically unrelated sinusoids (0.1-2.18 Hz and 0.11-2.21 Hz). The former shifted heading from the target while the latter kept heading intact but shifted the target visual direction on the screen. Observers had control of their heading but not their simulated gaze direction (i.e., Yh is a closed-loop task while Yg is an open-loop task). Ninety-second time series of heading error, gaze direction, and joystick displacement were Fourier analyzed and averaged across six trials. For all three observers, as displays contained more optic flow information, the heading RMS error decreased (mean error: 5.99°, 4.50°, and 4.33° for the empty, the textured ground, and the textured ground with posts displays respectively), and observers increasingly controlled heading compared to gaze disturbance (mean ratio of control power correlation: 0.82, 1.08, and 1.40, respectively). Furthermore, Bode plots (frequency response plots) revealed a significant decrease of sensitivity to gaze disturbance (mean control gain: 5.53, -1.03, and -3.76 dB respectively). These findings show that with enriched optic flow displays observers rely more on heading and less on visual direction to steer toward a target.

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56.322 **Global and local influence of form information on human heading perception**

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We have previously reported that the static focus of expansion (FOE) in a radial Glass pattern influences human heading perception (Cheng, Khuu, & Li, VSS, 2008). Here we investigate the underlying mechanism. In Experiment 1, we presented observers with an integrated form and motion display in which the dot pairs in a radial Glass patterns were oriented toward one direction on the screen (the form FOE) while moving toward a different direction in depth (the motion FOE) and a non-integrated display in which a static radial Glass pattern was superimposed on a regular optic-flow stimulus. Heading judgments were strongly biased towards the form FOE for the integrated but not the non-integrated display (form weight: 0.78 vs. 0.27), indicating that the form influence on heading perception is not a decision bias. In Experiment 2, we manipulated the global form information in the radial Glass pattern by randomly orienting some dot pairs. The heading bias towards the form FOE decreased as the global form signal was degraded, suggesting that the bias is mediated by the global form percept. In Experiment 3, we examined whether observers combined the form and motion FOEs for heading perception in a statistically optimal way. The motion FOE was weighted less than its variance warranted, suggesting that the local orientation of each dot pair in the radial Glass pattern disturbed its perceived motion direction, thus affecting the reliability of the estimated motion FOE in optic flow. By approximating the level of motion direction noise for which integration would be optimal, we found that the strength of the effect of local dot-pair orientation on its perceived motion direction was at about 50%. We draw the conclusion that the influence of the form FOE on heading perception is due to both global and local interactions between form and motion signals.

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56.323 **Rotation is used to perceive path curvature from optic flow**

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Previous studies have found that observers can reliably judge their future trajectory along a circular path from optic flow. However, observers have difficulty distinguishing straight and circular paths in some conditions, suggesting insensitivity to optical acceleration. How are observers able to account for path curvature when judging a future circular path? One explanation is that instantaneous rotation is used as a cue for curvature. In many situations, such as driving, the body rotates in sync with change in heading direction, so rotation provides a reliable cue. The purpose of this study was to test whether the visual system relies on rotation to perceive path curvature from optic flow. Stimuli simulated travel along a circular path on a random dot ground plane, with speeds of 2 m/s and curvature (yaw) of 2°/s. Two conditions differed in simulated view rotation. In the rotating view condition, view direction rotated in sync with heading direction, as in previous studies. In the fixed view condition, displays simulated travel along the same circular paths but without change in view direction. In Experiment 1, observers indicated their perceived future path at various distances by adjusting the horizontal position of a pole. Judgments were consistent with curved paths in the rotating view condition, while in the fixed view condition, judgments were consistent with straight paths. In Experiment 2, observers reported whether their perceived path was straight, curved leftward, or curved rightward. Judgments were highly accurate in the rotating view condition, while in the fixed view condition, curved paths were often reported to be straight, and observers did not reliably distinguish the sign of curvature. In both experiments, observers had difficulty perceiving path curvature from optic flow when it was not accompanied by view rotation, consistent with use of rotation as a perceptual cue to curvature.

56.324 **A Visuomotor Aftereffect Requires Effort To Self Locomote Paired With A Mismatch of Optic Flow**

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When riding in a car, we experience a mismatch between optic flow and self-produced locomotor activity. In this circumstance, we do not experience a subsequent visuomotor adaptation, perhaps due to the absence of locomotor movement. Note, however, that a mismatch produced by pairing locomotion with an absence of optic flow – in this case, caused by wearing a blindfold – does induce and aftereffect (Durgin & Pelah, 1999). The present research investigated what sort of action / optic flow pairings are required to evoke a visuomotor adaptation. The study employed a 2 x 4 design in which one half of the participants experienced optic flow at 3 mph, and one half of the participants experienced zero optic flow. During this time, participants performed one of 4 actions: walking on a treadmill at 3 mph, walking in place, riding a stationary bicycle, or standing still. For each participant, we obtained pre- and post- measures of forward drift during a blind marching in place task. We found that pairing zero optical flow with treadmill walking was the only condition evoking a reliable visual motor adaptation. We conclude that effort to self locomote, coupled with a mismatch of optic flow, is required in order to establish a visuomotor aftereffect.

56.325 **Improving Driver Ability to Avoid Collisions when Following a Snowplow**

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Low luminance contrast occurring with fog or snow under photopic conditions creates extremely dangerous situations when driving, especially when following other vehicles. In these situations, detecting motion of the lead vehicle is greatly reduced due to low contrast sensitivity. In particular, the expansion information necessary for detecting potential collisions may be poorly integrated. We created a driving simulation framework to test alternative lighting configurations on snowplows to improve detection of approach in low luminance contrast situations, reducing the time to respond in a realistic, driving simulation study. We compared errors and reaction times in a simulated driving task over virtual 3D roadways in which participants judged whether the lead snowplow vehicle was approaching or withdrawing. We compared lighting that was similar to that used in current snowplows to ones in which vertical non-flashing bars were added to the outer edges of a snowplow and to a condition in which bright corners were added. We found a significant drop in response time to information for impending collision when non-flashing vertical bars positioned at the left and right sides of the vehicle were added to a baseline display that had only normal flashing lights. The average response time for the flashing condition was 1.96 seconds, while the reaction time for the vertical bar condition was 1.84 seconds. We also found that when the lights on the corners were added to the vertical bars average performance again improved to 1.79 seconds. Ability to detect information for approach under dense fog or snowing conditions can be substantially improved if lighting on the lead vehicle is altered to optimize the light positioning and orientation. These transformations raise the optical expansion information over threshold for subjects in a driving simulation study. Other lighting designs may be even more effective in improving the safety of drivers.

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56.326 **Perception of apparent motion relies on postdictive interpolation**

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Ever since Wertheimer discovered apparent motion (AM), controversy about its mechanism (i.e., interpolation vs. extrapolation, postdictive vs. predictive) still lingers. In this series of experiments, we addressed both questions by presenting subjects an AM stimulus starting from the middle of the screen (phase 1) and terminating at either left or right (phase 2) unpredictably. The subjects perceived both motions effortlessly, regardless of the apparent direction. Thus, the motion illusion must have been constructed in the brain only after phase 2, which determined the direction of motion. In the same experiment, we also flashed two targets simultaneously, during phase 2, at various spatial locations and asked subjects to report the temporal order of these targets. We found that almost all subjects perceived the two targets sequentially, between the two AM phases in time, when they were flashed between the AM stimuli. No sequential effect was detected on targets outside of the AM trajectory. These results are consistent with the interpolation hypothesis. In a second experiment, we studied the dependency of sequential effect on different spatiotemporal configurations of targets. We introduced a marker to help subjects to disambiguate the order of intermediate targets and asked them to judge the co-occurrence of the marker with either target while the target configuration was varied. We applied two types of AM sequences, a "predictive" when targets were presented before the AM, and a "postdictive" when targets were presented after the AM. According to the results, the marker helped subjects to perceive the correct temporal order under the predictive condition but not under the postdictive condition. We concluded that apparent motion perception is postdictive, that it relies on interpolation, and that the postdictive interpolation has a sequential masking/delaying effect on the perception of intermediate targets. The neuronal mechanism of this masking is yet to be determined.

Acknowledgement: JST.ERATO Shimojo Implicit Bran Function Project

56.327 **Curved apparent motion induced by amodal completion and the launching effect**

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Many aspects of amodal completion in static scenes have been studied, but relatively little is known about how completion interacts with moving structures in dynamic scenes. We examined whether amodal completion can bias an apparent motion path towards longer curved paths behind an occluder, which would violate the well-established principle that apparent motion follows the shortest possible path. In a series of experiments, observers viewed motion sequences of two alternating rectangular targets positioned at the ends of a semicircular "tube," with varying inter-stimulus intervals (ISI: 100-500 ms). With short ISIs, observers tended to report simple straight path motion, i.e. outside the tube. But with longer ISIs, they became increasingly likely to report a curved motion path occluded by the tube. Subjects also reported that at longer ISIs straight motion became jerker while curved motion became smoother. In the next experiment, we varied the shape of the occluder, and found similar results with no effect of occluder shape. Other experiments investigated whether the motion path could be influenced by a Michotte-style "launch" at the initiation of motion. We added two more small objects which appeared to collide with the motion tokens at offset, in the direction of either the straight path or the curved path. Subjects in these experiments almost exclusively perceived a motion path in the direction of the launch, regardless of ISI, suggesting a very strong bias in the direction of perceived momentum. In sum, our results suggest that (1) The amodal representation of a fully hidden object behind an occluder can bridge the gap between two token locations via a curved motion trajectory, (2) amodal completion in space-time can make curved motion appear relatively smooth and continuous, and (3) the launching effect strongly induces a motion path in the direction of launching.

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56.328 **Planar configuration rather than depth adjacency determines the strength of induced motion**

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A moving object can induce an opposite direction of motion in a neighboring target, a phenomenon called induced motion. It has been suggested that motion induction is due to target-inducer interactions that are local in visual space. According to this view, increasing the distance between inducer and target should weaken induced motion. Alternatively, separation in depth per se may not determine whether one object can affect the motion of another. Currently available data supports either viewpoint. In particular, Gogel and Mac Cracken (1979) observed a strong weakening of induced motion as the target's location in depth moves farther than the inducer, whereas Di Vita and Rock (1997) noted that depth separation did not exert a strong influence. We noticed that the former study employed stimuli whose motion covered a constant visual angle across depth, whereas the second study employed a constant extent of motion on the stimulus display. Here we report the results of psychophysical experiments which leverage on this difference to resolve the discrepancy in the two results and show that disparity-based depth is insufficient to determine the strength of induced motion. Participants rated the effect of a horizontally oscillating inducer frame on a vertically oscillating target dot presented at different disparities in an otherwise dark environment. In the constant visual angle condition (similar to Gogel and Mac Cracken (1979)), induced motion decreased with depth separation. In the constant extent condition (similar to Di Vita and Rock (1997)), induced motion was constant across depth. These results imply that factors related to the target velocity or extent of motion, more than depth, determine the magnitude of motion induction. AY and JL are supported in part by CELEST, an NSF Science of Learning Center (NSF SBE-0354378). JL is also supported in part by the SyNAPSE program of DARPA (HR001109-03-0001, HR001-09-C-0011).

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56.329 **From Motion to Object: How Visual Cortex Does Motion Vector Decomposition to Create Object-Centered Reference Frames**

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How do spatially disjoint and ambiguous local motion signals in multiple directions generate coherent and unambiguous representations of object motion? Various motion percepts have been shown to obey a rule of vector decomposition, where global motion appears to be subtracted from the true motion path of localized stimulus components (Johansson, 1950). This results in striking percepts wherein objects and their parts are seen as moving relative to a common reference frame. While vector decomposition has been amply confirmed in a variety of experiments, no neural model has explained how it may occur in neural circuits. The current model shows how vector decomposition results from multiple-scale and multiple-depth interactions within and between the form and motion processing streams in V1-V2 and V1-MT. These interactions include form-to-motion interactions from V2 to MT which ensure that precise representations of object motion-in-depth can be computed, as demonstrated by the 3D Formotion model (e.g., Grossberg, Mingolla and Viswanathan, 2001, Vis. Res.; Berzhanskaya, Grossberg and Mingolla, 2007, Vis. Res.) and supported by recent neurophysiological data of Ponce, Lomber, & Born, 2008, Nat. Neurosci.). The present work shows how these interactions also cause vector decomposition of moving targets, notably how form grouping, form-to-motion capture, and figure-ground separation mechanisms may work together to simulate classical Duncker (1929) and Johansson (1950) percepts of vector decomposition and coherent object motion in a frame of reference. Supported in part by CELEST, an NSF Science of Learning Center (SBE-0354378) and the SyNAPSE program of DARPA (HR001109-03-0001, HR001-09-C-0011).

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56.330 **Visual discrimination of arrival times: Troublesome effects of stimuli and experimental regime**

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Discrimination thresholds for visually perceiving which of two objects, approaching head-on at constant velocity, will arrive earlier at one's station point, have been reported to range between 0.016 and 0.250 (Oberfeld & Hecht, 2008; Regan & Hamstra, 1993; Simpson, 1988; Todd, 1981). Values for lateral motion are typically in the lower range (Bootsma & Oudejans, 1993), and values for recession, moment of passage, and complex scenarios, in the higher range (Kaiser & Mowafy, 1993; Kim & Grocki, 2006). We compared Todd's (1981) original stimuli and his experimental regime with modified ones. Todd had presented outlines of two virtual squares, optically specified by 24 dots each, in 2AFC with a constant standard. We, in addition, used dot clouds with the same number of dots as Todd's squares, and a standard-free procedure. We also used narrower ranges of object sizes, velocities, and arrival-time differences, fewer trials, and naïve instead of trained observers. We obtained a minor effect of stimulus type and a large one of experimental regime. As verified by detailed analyses by conditions and levels of variables, huge differences in object size and velocity distract from the task. The weak effect of stimulus type is consistent with Simpson's (1988) contention that unspecialized optic-flow analyzers suffice for extracting temporal information; on the other hand, it might also mirror the flexibility of dedicated "looming detectors" – not requiring contours or outlined shapes for proper functioning (cf. Beverley & Regan, 1980; Koenderink, 1985). We observed excessive individual differences with Weber fractions ranging between 0.017 and 0.123. For 32 % of sessions, no psycho-

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metric functions could be fitted. We are currently extending our present work to include different trajectories, objects, and contexts, and also control measures of plain motion sensitivity, in order to test the generality of our findings and to better understand differences in performance.

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56.331 **Looking off effect – shift of face direction caused by a rotating object**

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[Purpose] Motion influences the perceived position of stationary objects in certain conditions. We found a similar phenomenon, where rotation signals in depth influence the direction of a briefly presented face image (looking off effect). When a rotating object is replaced by a face image, the face direction appears to shift in the rotation direction of the moving object. We examined whether the phenomenon is a variation of the 2D motion effect, whether it is local effect and whether it is face specific phenomenon.

[Experiment] The rotating inducer was a 3D human head and the test stimulus was a 2D cartoon face or a wired object. In a trial, the inducer rotated around the vertical axis from one side to the other. When the inducer directed to the center (facing to the observer), a test stimulus replaced it briefly. The direction of the test stimulus varied between -4° and 4° and the observer responded the direction of the test (left or right). With in the method of constant stimuli, we measured the direction of the test object that appeared to be in straight ahead.

[Results] The perceived straight direction of the test image was shifted in the direction of the inducer rotation. The effect was the larger for the face (2.0°) than for the wired object (1.2°). When an upside down face was used, the amount of the shift reduced (1.7°). Using the depth reversed wired object, we confirmed that the effect was in 3D. We also found no effect when the inducer and the test do not overlap in space. They indicate that the effect is neither specific to face nor a 2D phenomenon, although it may be stronger for face images. They suggest that the effect is related to spatial perception rather than object or face recognition.

Neural mechanisms: Human electrophysiology

Orchid Ballroom, Boards 401–408

Tuesday, May 11, 2:45 - 6:45 pm

56.401 **Early VEP magnitude is modulated by structural sparseness and the distribution of spatial frequency contrast in natural scenes**

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The contrast response function of early visual evoked potentials (VEPs) elicited by sinusoidal gratings is known to exhibit characteristic potentials associated with the parvocellular and magnocellular pathways. Specifically, the N1 component has been linked with parvocellular processes, while the P1 component has been linked with magnocellular processes (Ellemberg, et al., 2001, Spatial Vision). However, little is known regarding the response of those pathways during the encoding of complex (i.e., broadband) stimuli such as natural scenes. Natural scenes are known to vary in terms of: 1) the amount of structural content (i.e., structural sparseness) contained within each image, and 2) the distribution of contrast across spatial frequency (i.e., 1/f slope of the amplitude spectrum) across each image. Thus, the present study was designed to examine the extent to which the physical characteristics of natural scenes mentioned above modulate early VEPs in humans. The stimuli consisted of 50 natural scene images, grouped according to the slope of their amplitude spectra (five different levels of slope: -0.76, -0.87, -1.0, -1.2, & -1.4) and degree of structural sparseness (two levels of structural sparseness: high and low) contained within each image. We recorded EEGs while participants viewed each natural scene image for 500ms, preceded by a 500ms mean luminance blank from which base-line measurements were taken. The results show that: 1) the relative magnitude of the early VEPs was highly dependent on the amount of structure contained within the scenes, independent of amplitude spectrum slope; 2) the overall magnitude of the early VEPs was dependent on the slope of the amplitude spectrum such that the presence of more contrast at the higher spatial frequencies yielded higher overall early VEP magnitude. These results suggest that it is the amount of structure at the higher spatial frequencies in natural scenes that dominate early VEPs.

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56.402 **Relative latency of visual evoked responses to reversals in contrast, orientation, and motion direction**

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Conventional VEP recording tests neural responses evoked by reversing pattern contrast. VEPs for orientation-reversal (OR) [Braddick et al (1986), Nature, 320: 617] and direction-reversal (DR) [Wattam-Bell (1991), Vision Res, 31: 287] use stimulus sequences designed to isolate cortical responses to these higher-order changes from responses to contrast change. Since these require more complex processing than contrast changes, we might expect some additional delay of the measured response, reflecting this additional processing.

We have tested this hypothesis by recording pattern-reversal (PR-), OR- and DR responses, at reversal rates up to 4 /sec, from occipital scalp electrodes on adult subjects, and assessing the mean latency of the first positive peak. OR- and DR- sequences isolate the effect of reversals from accompanying contrast changes, by embedding the reversal event within a sequence of equivalent contrast changes ('jumps'). We use two methods to avoid our latency measures being contaminated by responses to jumps – filtering out harmonics in the signal related to the jump frequency, or subtracting a 'jump-only' section of the waveform from the response to reversal + jump.

We find very similar latencies for OR- and PR- responses, suggesting that responses to pattern reversal arise from a level of cortical processing which is already orientation-selective. The DR- response is more complex, but typically contains components with a latency 10-20 ms lower than either PR or OR - evidence against any time penalty associated with motion processing.. We will discuss these results in relation to possible differences in the balance of magno- and parvocellular inputs to the three responses, and possible 'fast' routes for motion processing bypassing V1. Future work will test the overall temporal properties of the different responses, beyond the initial latency, and also the potential use of this comparison in analysing cortical processing in infancy.

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56.403 **Orientation selectivity in primary visual cortex using MEG: an inverse oblique effect?**

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Orientation discrimination is much better for horizontal or vertical than for orientations with a 45-degree tilt. In partial support of these behavioural findings, some animal physiology studies show that a moderately larger number of neurons are tuned to cardinal than oblique orientations in primary visual cortex, and the former are more tightly tuned to their preferred orientation. A limited number of human neuroimaging studies also support this classic 'oblique effect', with the BOLD response localising the neural effect to V1, and EEG demonstrating both increased response magnitudes and reduced latencies. How is orientation selectivity reflected in the magnetoencephalography signal? The animal literature shows that GABAergic interneurons play a critical role in orientation selectivity. As these inhibitory interneurons are also important for stimulus-induced gamma oscillations, it is likely that responses in the gamma spectrum are influenced by orientation. We measured the evoked response, as well as the initial spike and sustained induced gamma response to maximum contrast, 3 cycle/degree, stationary black/white sine-wave circular grating patches of diameter 4 degrees. Three orientations (0, 45 and 90 degrees from vertical) were randomly chosen and presented in the lower left quadrant 2.5 degrees from fixation. Our results point towards a larger induced gamma response for oblique stimuli over cardinal ones in contralateral V1, reflected both in the initial spike as well as in the sustained response during stimulus presentation. The specific frequency of the peak response did not differ. Interestingly, in contrast to the EEG findings, we also found this 'inverse oblique effect' in the evoked response around 80ms post-stimulus. These results may suggest that V1 neurons have a more complex response tuning to non-preferred orientations. Alternatively, the results may be due to an oddball phenomenon, implicating that cardinals are grouped in perception, and that oblique stimuli attracted attention.

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56.404 **Neural Mechanism of Inverse Oblique Effect on Broad-band Noise Stimuli: An ERP Study**

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When resolution acuity or contrast sensitivity is evaluated using simple stimuli such as lines or gratings, visual performance is often best for horizontal and vertical orientations and worst for oblique orientations. It's the well known 'oblique effect'. However, using more complex stimuli of broad-band spatial frequencies and orientations, Essock et al. found an inverse oblique effect, which visual performance is worst for horizontal orientation and best for oblique orientations. The anisotropy in the number of cortical neurons tuned to different orientations in visual cortex has accounted for the oblique effect by previous fMRI and physiological studies. But the neural mechanism of this inverse oblique effect remains largely unknown. In the present study, seventeen subjects were first tested for orientation salience threshold before they were recorded EEGs. Thresholds were highest for horizontal orientation and lowest for oblique orientations, which was consistent with Essock et al.'s work. Then, we recorded high resolution electroencephalography from the whole-scalp sensor array while subjects took part in an orientation identification task, in which orientation salience was 1.2~2.5 times of the threshold of horizontal orientation. We found the response accuracies were lower and the response times were longer for cardinal orientations than for oblique orientations. The event-related potential results revealed that the difference between cardinal orientations and oblique orientations occurred around 200 ms post stimulus onset, which was much later than the traditional oblique effect. Besides, the P300 latency was much earlier for oblique orientations than for cardinal orientations. These findings indicated that this inverse oblique effect of broad-band noise stimuli might occur at relatively higher levels of visual information processing and might involve more complex neural mechanism than oblique effect.

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56.405 **EEG and MEG Time Functions Are the Same**

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Previous studies with simultaneous EEG and MEG recordings, have reported significant intermodal differences. These differences reflect the differential contributions from multiple sources due to the different dependencies of EEG and MEG on tissue conductivity. Our multifocal stimuli composed of 32 small patches that randomly check-reversed at 30Hz activate in a time-locked fashion only early visual areas, while effectively suppressing higher level processes. We suspect it is this selective activation and the availability of many patches for SVD analysis that permits the impressive intermodal agreements in our study.

We performed three analyses to assess the time-function similarity.

1) Estimation of the overall fit by correlation measures. EEG/MEG correlation coefficients for the first three SVD time-function components were [0.99, 0.99, 0.99], [0.94, 0.97, 0.97] and [0.61, 0.57, 0.88] ([S1, S2, S3] denotes the three subjects).

2) ChiSquare estimation of intermodal time-lag. To p=.001 confidence, we can detect the difference between EEG and MEG when the EEG signal is shifted by [1.6, 1.9, 1.6], [1.5, 1.3, 1.1] and [3.7, 9.3, 1.5] milliseconds for the three components. These surprisingly small values are a powerful demonstration of EEG/MEG agreement especially since we allowed arbitrary linear combination of the EEG components to match each MEG component.

3) Identification of signal differences at specific temporal locations. In order to carefully test the significance of temporal regions where signals differ, we used cluster-based permutation analysis to determine the location and significance of these differences. We found that for the three subjects, the cluster analysis ($p<0.05$) resulted in only 3, 2, and 2 clusters that occupied 4, 2.4, and 2.9 percent of the total signal durations, well within the significance criterion.

This close time function agreement is a powerful step enabling EEG and MEG to complement each other for solving the source localization inverse problem.

56.406 **Lorazepam reduces stimulus visibility by impairing recurrent processing in visual cortex**

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It is becoming increasingly accepted that reentrant processing in the visual cortex plays a crucial role in perceptual organization and visual awareness. It is however unclear what the fundamental differences are between reentrant and feedforward processing. Therefore, we investigate the contribution of specific neurotransmitters to these types of processing, and study the effects of pharmacological interventions on conscious visual perception. Here, we use EEG measurements to determine what happens in the human visual cortex during the detection of a texture-defined square under non-masked (seen) and masked (unseen) conditions. The strength of the masks was varied spanning the range from not visible to visible. Previous research has demonstrated that masking disrupts reentrant processing in the human visual cortex, while leaving feedforward processing relatively untouched. In a within-subject design, subjects were given the benzodiazepine Lorazepam (1,5 mg) or a placebo, to study the effect of GABAergic neurotransmission on reentrant processing and stimulus visibility. Our behavioral results show that detection rate decreased with increasing masking strength and that the detection rate decreased even more in the Lorazepam condition compared to the control condition. The subtracted ERP signal (figure - homogeneous) showed: (1) an early posterior occipital and temporal component (90-125 ms), not influenced by Lorazepam and (2) a later recurring bilateral occipital component (168-203 ms), which was influenced by Lorazepam. The period between 90-125 ms is related to boundary detection and was not influenced by masking strength. The second period represents recurrent processing and was modulated by masking strength; the stronger the mask, the smaller the difference wave. Furthermore, this modulation was correlated with detection behavior; the poorer the detection, the larger the decrease of the ERP deflection. Lorazepam deteriorates this correlation with behavior. These results give more insight in the role of GABAergic neurotransmission in visual processing and perception.

56.407 **Perceptual Echoes At 10Hz In Human EEG**

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Physiology studies have revealed an oscillatory 'afterdischarge' or 'augmenting response' at 10 Hz that may be attributed to cortico-thalamic reverberation. Such reverberation should be visible in the visual impulse response function (VIRF - the electrophysiological response of the brain to a brief luminance increment); however, VIRF estimates in human EEG via the classic 'visually evoked potential' method do not reveal any reverberation. Here, we estimated the VIRF by reverse-correlating the EEG response to a prolonged (6.25 s), dynamic stimulus that was luminance-modulated by a broadband temporal function (0-80 Hz white noise generated anew for each trial). The reverse correlation revealed a pure oscillation at ~10 Hz that persisted for between 5 and 10 cycles, located over occipito-parietal cortex. The specific frequency and amplitude of this oscillation was closely related to each participant's resting state alpha frequency and amplitude, although it was not a mere reflection of the presence of alpha, since it disappeared when luminance sequences and EEG epochs were shuffled before the analysis. In a second experiment, we presented two independent random luminance sequences, one on each side of fixation, and participants attended to one or the other during each trial. The oscillation in the VIRF in response to the attended stimulus was 20% greater than for the unattended; this contrasts with the typical decrease of ongoing alpha with attention. Our findings demonstrate that the brain resonates with the random fluctuations in our the noise stimulus at its natural frequency (~10 Hz), and disregards other frequencies; in accordance with this interpretation, our participants tended to perceive the stimulus as periodic flicker rather than as a broadband white noise signal. Therefore each luminance modulation in our stimulus, i.e., each 'event', generated not just one potential, but a periodic series of potentials - 'echoes' of the first, akin to cortico-thalamic reverberation.

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56.408 The spatial distribution of VEP responses to temporal modulations of motion contrast in human adults

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Single unit and fMRI evidence suggests that extrastriate cortical regions process motion contrast. In this study, we employed high-density steady-state visual evoked potential (SSVEP) recordings to study the tuning curves of cortical areas sensitive to the separation of a figure from its background using different classes of motion contrast information--direction and global coherence. Participants (n=21; 11 female) viewed moving dot displays (7 cd/m2 size; 8% density) in which four square "figure" regions (9° wide) emerged from and disappeared into the background at a specific frequency (1.2 Hz: 1F1), based on differences in dot direction and motion coherence. We found responses at 1F1 that increased monotonically to both types of motion contrast, observed over midline channels near the occipital pole. Responses at the second harmonic (2F1) were strongest over lateral channels; there the response curves saturated once a minimal threshold of motion contrast magnitude was reached. We interpret the midline activity at 1F1 to reflect the processing of the magnitude of motion contrast information in early visual association areas, possibly V2 or V3A/D. The lateralized activity at 2F1 appears to reflect a non-linear thresholding operation associated with extracting the figure from background, perhaps engaging lateral occipital cortex (LOC), among other areas. Source modeling techniques will allow us to locate the precise coordinates of the processing centers of these functionally distinct evoked responses in the brain.

Attention: Tracking

Orchid Ballroom, Boards 409–425

Tuesday, May 11, 2:45 - 6:45 pm

56.409 Neural measures of interhemispheric information transfer during attentive tracking

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People are generally able to track 4-5 objects as they move amongst visually identical distractors. However, Alvarez & Cavanagh (2005) found that if tracked objects are lateralized to one visual hemifield, tracking capacity is drastically reduced relative to bilateral tracking trials. These data suggest that tracking for each hemifield is carried out independently by the contralateral hemisphere. If so, what happens when an object moves from one hemifield to another? If the right hemisphere is tracking an object that moves to the right visual field, does the left hemisphere pick up the object representation the moment that it crosses the midline, does it preemptively start tracking the object before it crosses the midline, or does it wait until some point after the midline has been crossed? When does the right hemisphere stop tracking the object? We studied these questions using a sustained contralateral negativity that indexes tracking activity during lateralized versions of the attentive tracking task (Drew & Vogel, 2009). We measured contralateral and ipsilateral activity while a tracked object moved horizontally across the midline. As predicted, activity with respect to the hemifield where the object originated initially exhibited a strong contralateral negativity that then flipped to an ipsilateral negativity as the object moved to the opposite hemifield. We found that ipsilateral activity prospectively increased prior to the moment when the object crossed the midline whereas contralateral activity did not decrease until several hundred milliseconds after the object crossed the midline. This suggests that the two hemispheres were both tracking the object for several hundred milliseconds. Furthermore, we were able to influence the timing of this interaction by manipulating the predictability of object motion. When the object movement was less predictable, the duration of interhemispheric information sharing decreased.

56.410 The coordinate systems used in visual tracking

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Tracking moving objects is a fundamental attentional operation. Without tracking, attention cannot be maintained on objects translating through space. Here we ask which coordinate system is used to track objects, retinal (retinotopic), scene-centered (allocentric), or both. While maintaining gaze on a fixation cross, observers tracked three of six disks, which were confined to move within an imaginary square. Relative to the imaginary square, the disks all moved at the same speed. By moving either the imaginary square (and thus the disks contained within), the fixation cross (and thus the eyes), or both, we could increase disk speeds in one coordinate system while leaving them unchanged in the other. Increasing disk speeds in either coordinate system reduced tracking ability by an equal amount. These data support the hypothesis that humans track objects simultaneously in both retinotopic and allocentric coordinates. This finding imposes a strong constraint on models of multiple object tracking.

Acknowledgement: We would like to acknowledge NIH MH65576 to TSH

56.411 Effects of Distinct Distractor Objects in Multiple Object Tracking

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Previous studies investigating the question of whether feature information is maintained during multiple object tracking (MOT) have found mixed results. The present experiment addresses this question by manipulating the color of some of the distractor objects in MOT. Can the visual system filter out distractors that have a distinct feature from the targets? At the beginning of each trial, several circles were displayed, and 5 of them flashed to designate them as targets. Then the circles moved about the screen. When they stopped moving, one circle was highlighted, and the observer answered whether it was a target or not. On each trial, there were 5 targets, 5 distractors that were identical to the targets, and also several (0, 1, 2, 5, or 10) additional distractors. The additional distractors were either the same color as the targets, or a different color. The highlighted circle was always one of the targets or 5 identical distractors. Tracking performance declined as the number of additional distractors increased, both for same-color and different-color additional distractors. Yet tracking performance was higher when the additional distractors were different in color from the targets. These results demonstrate that distractors hinder tracking, but that if distractors have a distinct feature from targets, the distractors' effect is reduced. However, even featurally distinct distractors interfere with tracking to some extent. These findings show that the visual system can use feature information about objects to facilitate MOT, which supports the claim that feature information can be maintained during tracking.

56.412 Adaptive Training in Multiple Object Tracking Expands Attentional Capacity

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One popular 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 a variety of factors, including the number of targets and their speed (Alvarez and Franconeri, 2007). Thus, the MOT task 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. Here, we explored whether these measures of attentional capacity can be increased through an adaptive training regime. A threshold procedure was used to determine the speed at which two subjects could track four targets among eight distractors (mean speed = 5.3 deg/s). Subjects then completed twenty sessions of MOT practice (40 trials per day), with the object speed

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on each trial adaptively updated. When all targets were accurately tracked on two consecutive trials, speed was increased by 1 deg/s. When any targets were missed, the speed was decreased by 1 deg/s. After the last session of training, we assessed the number of items that could be tracked at the initial pre-training speed. Over twenty sessions of training, subjects increased the speed that they could reliably track four objects from 5.3 deg/s to an average speed of 12.3 deg/s. The maximum speed they could track objects was proportional to the time spent training (r = .843, p <.001). After training, both subjects could track six objects at their initial baseline speed. These findings indicate that it is possible to dramatically increase the capacity of visual attention through training. Furthermore, training along one measure of capacity (increasing speed) transferred improvements to the second measure of capacity (increasing number of targets), suggesting that a single resource constraint underlies both limits.

56.413 **A Cost for Hemifield "Crossover" During Attentional Tracking**

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Previous studies have demonstrated that observers can select and track objects independently in the left and right visual field, as if separate attentional systems were engaged in each hemifield (Alvarez & Cavanagh, 2005). This previous work required observers to track objects that were always contained completely within one half of the visual field. However, in real world viewing conditions, tracked objects often move freely from one hemifield to another. We tested how attention selects and tracks objects as they move across hemifields by comparing performance when tracked items shift from one quadrant to another, either within one hemifield, or crossing between hemifields. On each trial 8 items were presented in diagonally opposite quadrants (e.g. 4 in the top left and 4 in the bottom right), and two items in each quadrant were highlighted as targets for tracking (4 targets total). All of the items began to move, then at one point during the trial all of the items shifted to an adjacent quadrant, either staying within the same hemifield (vertical shift), or crossing over (horizontal shift). At the end of the trial, all of the items stopped, and observers had to click on the target items. Observers tracked targets less accurately when the targets crossed hemifields (70%) than when they remained within a hemifield (76%, t(9)=2.82, p <.05). The relative distance the target items shifted was equal, whether the shift occurred within or across hemifields. Thus, these results suggest that the critical factor is whether the targets remained within one half of the visual field, or shifted across the left and right hemifields. The difficulty of tracking objects that shift across the left and right hemifields could reflect a cost in "handing off" the tracking of an object between the attentional systems engaged in the left and right hemifields.

56.414 **Individual differences in the shape of visual attention during object tracking**

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Performance in visual tasks varies across individuals. For example, video game players (VGPs) perform better than non-video game players (NVGPs) in a variety of spatial attention tasks. We were interested in whether these differences are due to an enhanced focus of attention at fixation, a greater spread of attention around fixation, or a combination of the two. We studied this by developing a dual-task experiment that measured the shape of the spatial 'spotlight' of attention during a single object tracking task.

A set of experienced VGPs and NVGPs tracked a single object moving at either low or high speed around a display and monitored a continuously changing digit embedded on the object. After a random period of tracking time, the object was removed and a probe was presented at a random location. Participants reported both the final digit on the tracked object and the location of the probe. Performance on the probe detection task was analyzed as a function of the probe's position relative to the final position and direction of the tracked object.

Results show that VGPs performance on the probe task was both greater than NVGPs for probes near fixation and fell off less sharply with distance from fixation. In addition, for NVGPs, increasing the speed of an object (1) forced a shrinking of spatial attention around the tracked object and (2) changed the shape of spatial attention from a circular spotlight to an ellipse oriented in the direction of the tracked object. However, the shape of the attentional spotlight for VGPs was largely unaffected by the speed of the tracked object. Overall, our results suggest that when tracking single objects, VGPs employ a significantly stronger, larger and more invariant spotlight of attention than NVGPs.

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56.415 **Eye Movements Across Scene Rotations in Multiple Object Tracking**

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Observers can visually track multiple independently moving target objects among identically looking distractor objects (e.g., Pylyshyn & Storm, 1988). Experiments examining multiple object tracking within three-dimensional scenes demonstrate that while smooth scene rotations do not affect tracking performance (Liu et al., 2005) abrupt scene rotations yield tracking more difficult but not impossible (Huff, Jahn, & Schwan, 2009). We report three experiments examining the mechanisms involved in successful tracking of three target objects across abrupt scene rotations by recording observers' eye movements. In addition to the target and distractor objects we analyzed eye movements towards the invisible centroid of the target configuration as suggested by previous research (Fehd & Seiffert, 2008). The centroid is less displaced by scene rotation than the target objects and the centroid moves slower than the target objects thus being a stable reference for the target set. With our first experiment, we demonstrated a significant drop of gaze time spent on the target objects but not the centroid for 500ms following an abrupt scene rotation. Distractor objects were irrelevant for explaining the eye movement data. The second experiment replicated these findings and extended them by showing increasing centroid looking with increasing object speed. With our third experiment, we replicated and therefore reinforced our previous findings using an eye-tracker with 500Hz that had a higher spatial and temporal resolution than the eye-tracker with 50Hz that we used in experiments one and two. Summarizing, we show that observers take advantage of the higher stability of the centroid of the target configuration when tracking multiple target objects in displays with abrupt scene rotations or increasing object speed.

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56.416 **Inability to perceive the spatial relationship of objects revolving too quickly to attentively track**

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What is perception missing when one cannot attentively track? To find out, we exploit the finding that an object revolving about fixation faster than 1.5 revolutions per second (rps) cannot be tracked (Verstraten, Cavanagh, Labianca 2000). Methods. Six Gaussian blobs were evenly spaced along a circular orbit (radius 2 deg). Three colors were used in two identically-ordered triplets, e.g. red-green-cyan-red-green-cyan. The triplet of colors was chosen pseudorandomly on each trial. The blobs moved for three seconds. Observers fixated the center of the rotating ring and subsequently attempted to report the colors' relative order. In a second experiment, an outer (radius 4 deg) ring of blobs with three new colors, e.g. yellow-blue-fuchsia-yellow-blue-fuchsia, was added. Each blob in the inner ring was aligned with another in the outer ring and observers judged, for any color they chose of the inner ring, which color was aligned with it in the outer ring. In an identification control experiment, observers reported which colors were presented. To confirm the tracking limit, with all blobs set to the same color observers were cued to track one blob and at the end are tested on which blob it was. Results. Observers could identify the colors (>90% correct) at rates over 2.5 rps. The limit on attentive tracking was much lower with average 75% threshold <1.5 rps. For the two experiments eliciting judgments of spatial relationships, 75% threshold rates were again 1.5 rps or lower and participants were near chance at rates for which the colors could easily be identified. Indeed, when viewing the display rotating at 2 rps, most observers are struck by their inability to grasp the relative location of any two colors, despite clear perception of the colors' identity. Conclusions. Coordinated individuation by attention may be necessary to extract most spatial relationships.

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56.417 Tracking seven is not the same as tracking three: The roles of parallel and serial resources in object tracking

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Tracking a subset of moving targets among a group of identical items, typically studied with the multiple object tracking paradigm (MOT), has long been known to be capacity limited, usually to about three items. But recent work suggests that this limit can increase to as many as eight when objects move slowly enough. The current studies asked whether seven items are tracked in the same way as three. Participants performed MOT while also detecting transient probes that appeared on targets. In Experiment 1, participants tracked between one and five targets. Targets were always revealed one at a time, and in half the trials participants had to identify targets in the same order as they were revealed, adding serial order (SO) memory requirements. Whereas probe detection rates declined linearly as a function of load in the SO task, detection only declined in the spatial task when tracking four or five targets compared to two or three. Monotonic costs associated with additional targets in the SO task reveal the operation of a serial processing mechanism. But the absence of such costs for fewer than three targets in the spatial condition suggests that two or three targets were tracked in parallel, while tracking four or more demanded serial resources. An experiment with slow object speeds and tracking loads up to seven confirmed these intuitions. Declines in probe detection evolved for more than three targets, though there were no significant costs associated with tracking three compared to two. Further experiments used an object localization procedure and found a similar absence of per-item costs for one to three targets, compared with steep per-item costs for more than three. Overall, these experiments demonstrate that only up to three targets can be tracked in parallel, and that tracking more than three requires the allocation of serial resources.

56.418 The spatial representation in multiple-object tracking

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During multiple-object tracking visual attention is allocated asymmetrically across target and distractor objects: probe-detection experiments showed that visual tracking benefits from inhibiting distractors (Pylyshyn, 2006). However, experiments examining multiple-object tracking within 3D-scenes across scene rotations suggest that the spatial relations between all objects may be used in visual tracking (Huff, Jahn, & Schwan, 2009). In the current study, we examined the role of spatial relations among target and distractor objects within 3D-scenes. Participants tracked five of ten balls moving on a circular monochromatic floor-plane. Halfway through each trial, we abruptly rotated only distractors, only targets, or all objects (complete rotations) during a masking flash of 100ms. In control conditions there was a flash but no rotation. If spatial relations between all objects are used in multiple-object tracking, performance should be impaired in conditions with distractor rotation. However, if the distractors are processed separately from the targets and if the relations between distractors and targets are irrelevant for tracking, abrupt distractor rotations should not affect tracking. Additionally, tracking should be easier for complete compared to target only rotations if relations between all objects are used. Compared to the control condition, abrupt distractor rotations impaired tracking performance only in trials in which distractor rotations led to increased crowding around a target object. When distractor rotation involved no increased crowding, tracking performance was comparable to the control condition. Additionally, abrupt complete rotations impaired tracking performance the same way as target only rotations did. Two implications can be drawn from this study. First, there is some evidence that targets and distractors are processed separately. More specific, the spatial relations between targets and distractors seem to be irrelevant for multiple-object tracking. Second, crowding plays an important role for allocating visual attention as crowding around target objects due to distractor rotations impaired tracking.

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56.419 Reallocating Attention in Multiple-Object Tracking Without Explicit Cues

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Wolfe, Place, and Horowitz (2007) presented data from multiple experiments designed to increase the real-world relevance of the typical multiple object tracking paradigm (Pylyshyn & Storm, 1988). They found that continuously adding and removing objects from the tracked set during tracking produced very little change in performance. Ericson and Christensen (VSS 2009) tested the addition and removal of objects during tracking separately, and found that performance increases with an addition and decreases equally with a removal as compared to tracking a fixed set. The increase was explained using a performance model that assumes the probability of losing tracking on a dot is solely a function of the number of dots tracked at that time. A new second experiment demonstrates that the decreased accuracy produced by removing an object is eliminated when the object to be removed is offset rather than cued via sudden onset. The results of applying the performance model support the idea that object tracking can be described as a continuous-time Markov process with highly efficient reallocation of attention as long as cues do not conflict with reallocation.

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56.420 Shrinking or Falling? Naturalistic Optical Transformations Do Not Increase Multiple Object Tracking Capacity

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Objects that shrink and expand at occluding surface boundaries in multiple object tracking are more difficult to follow than objects that delete and accrete (Scholl & Pylyshyn, 1999). Here we ask whether this difficulty is due to the lack of a top-down naturalistic explanation for the shrinking or whether it is due to the bottom-up optical transformation of shrinking itself. If a naturalistic visual context for the shrinking disks was available, would observers exhibit higher tracking capacity? Observers tracked four of eight disks that could pass behind an occluding surface in the middle of the display. The disks moved for 10 seconds and then observers attempted to identify the four disks they were tracking by clicking on them. In the occluded condition, disks deleted/accreted at the occlusion boundary, while in the shrinking condition, disks shrank/expanded at the boundary. In the critical falling condition, disks also shrank/expanded at the occlusion boundary but a background image with a steep slope made the disks appear to fall into and then emerge from a ravine below the occluding surface. The low level optical transformations in the shrinking and falling conditions were identical – only the background image varied. Observers had the highest tracking capacity in the occluded condition, followed by the shrinking condition. Contrary to the naturalistic optical transformation hypothesis, observers exhibited the lowest tracking capacity in the falling condition. We interpret this result to indicate that bottom-up optical transformations per se caused the decrease in tracking capacity. If an object shrinks at an occlusion boundary, the visual system seems to stop tracking it, even if there is a naturalistic visual explanation for the shrinking.

56.421 Event-related Potentials Reveal "Intelligent Suppression" during Multiple Object Tracking

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Recent evidence indicates that distractor objects may be actively inhibited or suppressed during multiple object tracking (MOT; Doran & Hoffman, in press; Pylyshyn, 2006; Pylyshyn et al., 2008) however the mechanism of suppression is currently unclear. In one view, zones of suppression may surround tracked targets so that objects that are near targets (and therefore within the suppressive region) would be suppressed (Franconeri et al., Psychonomics 2009). Alternatively, it may be that suppression is only applied to distractors that are likely to be confused with targets and therefore interfere with tracking performance (Pylyshyn et al., 2008). We examined this issue by measuring the amplitude of the N1 component of the event-related potential (ERP) elicited by probe flashes presented on targets, nearby distractors, and distant distractors. Critically, some of the distractors were "confusable" with the targets (i.e., they were the same color and shape) while others were not (i.e., they were a different color and shape). If distractors are suppressed via an inhibitory region surrounding targets then confusability shouldn't matter and both confusable and nonconfusable distractors should be suppressed when they are near targets. Alternatively, if suppression is "intelligent" or selective then only the confusable distractor objects should be suppressed perhaps because they are more likely to interfere with accurate tracking. The results of this experiment support intelligent suppression as N1 amplitude for probes appearing on nearby distractors was suppressed only when they were confusable with the target. In sum these data suggest that suppression of distractors during MOT is "intelligent" as it is applied only to distractors that are potentially confusable with targets.

56.422 Blink-induced masking and its effect on Multiple Object Tracking: It's easier to track those that stop during interrupted viewing

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When tracking multiple objects, does the visual system encode the location and trajectory of tracked objects? Is encoding only triggered from the abrupt changes that typically occur in the real world such as when objects disappear behind other objects? We extend our 2009 work examining the role of location-coding in Multiple Object Tracking (MOT) using a novel blink-contingent method, enabling us to control simultaneously: item disappearance and abrupt transitions.1 Here, we introduce backward-masking to the eye-blink paradigm to further control onset transitions. Observers were instructed to blink their eyes when a brief tone was presented midway into each 5s trial of tracking (4 of 8 circles). Eye-blinks induced two events: item disappearance (for 150, 450, or 900 ms), and onset of a mask, which occluded the entire display of items (either for the full disappearance time, or 75ms plus a blackout for the remaining interrupt). During their disappearance, objects either continued moving along their trajectories, or halted until their reappearance. Therefore, "move" objects reappeared further along their trajectory while "halt" objects did not. Results replicate Keane & Pylyshyn, (2006); and Aks et al., (2009) with better tracking when items halt [but here only reliably in the 450 and 900 ms trials]. These trends indicate that trajectory information is not encoded during tracking, and the visual system may refer back to past position samples as a 'best guess' for where tracked items are likely to reappear. Importantly, the "halt" advantage occurred in both blocked and randomized forms of object motion, suggestive of an automated and data-driven tracking mechanism; one not inclined to predict objects' trajectories even when presented in a repeated, and thus, predictable context. [1Although an eye-blink is a sudden event optically, we are typically unaware of it and it is likely not encoded as a transient event.]

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56.423 Attentional tracking in the absence of consciousness

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Visual attention and awareness are closely related but dissociable processes. One demonstration of the dissociation between attention and awareness comes from attentional allocation toward invisible targets (Jiang, Costello, Fang, Huang, & He, 2006). However, there are multiple subtypes of visual attention, and it is probable that there are differences in the relationship between attention and awareness for different subtypes. Thus, it might be that some aspects of attention, such as orienting to a change in the saliency map of the visual field, demonstrated by Jiang and colleagues (2006), continue to operate without awareness, while other aspects of attention, such as attentional tracking, only occur with awareness. We designed experiments to determine whether attentional tracking can take place without conscious awareness of to-be-tracked moving targets. First, we replicated the result of Jiang and colleagues (2006). We used continuous flash suppression to render images invisible, then measured subjects' performance on a subsequent visible two-alternative forced-choice gabor orientation judgment task in the location of an invisible attentionally salient or non-salient stimulus. We replicated the result that subjects' discrimination of gabor orientation was influenced by the attentionally salient stimuli. We then modified the paradigm to test attentional tracking. We presented an attentionally salient stimulus which morphed into a dot, then moved across the screen to a different location while remaining invisible. We tested subjects' performance on the orientation discrimination task in both the original location of the attentional stimulus and the final location of the associated trackable dot. We found that subjects' performance on the rotation task was influenced in both locations, compared to control locations where a non-salient stimulus and trackable dot appeared. This suggests that attentional tracking can occur without awareness of the tracked stimulus. These data imply that even certain advanced aspects of attention are dissociable from awareness.

56.424 Spatial Reference in Multiple Object Tracking

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While tracking multiple targets simultaneously, the configuration in the scene as it is projected onto the picture plane provides stable spatial reference for tracking targets. Multiple object tracking in a 3D-scene is robust against smooth movements of the whole scene even without static reference objects (Liu et al., 2005) suggesting that targets and distractors provide enough configurational information. What is important, however, is continuous motion in the picture plane as revealed by the detrimental effect of abrupt viewpoint changes (Huff, Jahn, & Schwan, 2009). Abrupt viewpoint changes suddenly change the configuration of identically looking objects in the picture plane and yield it difficult to establish correspondence between object locations before and after the viewpoint change. The background in a 3D-scene can act as a static and visually distinct spatial reference to solve this correspondence problem. If the presence of a static background turns out to be beneficial, this would demonstrate that static reference objects are used to locate targets in MOT when the configuration of dynamic objects provides insufficient information. We report three experiments employing abrupt viewpoint changes, in which a checkerboard floor plane and a wire-frame floor plane improved performance compared to a display lacking any static background. This floor plane effect was found when viewpoint changes of 20° occurred while two targets were tracked and while a single target was tracked. In contrast, tracking 3, 4, or 6 targets showed no benefit from the presence of a floor plane. We argue that targets are tracked as parts of a continuously changing configuration that provides spatial reference. Discontinuous changes create the need to use static reference objects for relocating targets. Our experiments have revealed narrow limits for relocating targets, which may generalize to other dynamic tasks, in which observers move and targets are not continuously in view.

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56.425 Investigating virtual object structure in multiple object tracking

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Researchers use multiple object tracking to study how people attend to a set of identical, moving targets. Yantis (1992) showed that people conceive of multiple targets as parts of a virtual object (e.g. three vertices of a triangle), even when targets move independently. We investigated whether strengthening object structure by increasing the similarity of target motion would improve tracking performance. Observers tracked 4 of 12 identical dots moving in a box for 5.6 seconds in order to select targets from distractors at the end of the trial. To increase virtual object structure, we made targets maintain the form a rigid polygon that rotated, translated, expanded and contracted during the trial. Distractors formed two other polygons that behaved similarly in the same space. We also tested the effect of object symmetry: the polygons were either symmetric shapes, such as diamonds, or specific asymmetric shapes, such as skewed trapezoids. These conditions were compared to tracking randomly moving objects. Motion condition significantly affected proportion correct, $F(3,30) = 31.50$, $p < .001$. Tracking accuracy was significantly lower for random motion (53% correct) than for polygons (75%; $t(10) = 6.51$, $p < .001$) and there was no difference between asymmetrical and symmetrical polygons ($t(10) > 1$, $p = .27$, n.s.). Stronger object structure, but not object symmetry, may facilitate tracking. However, the results are also consistent with the interpretation that motion redundancy between tracked objects improves tracking performance. These observations are the first investigations of inter-target relationships on how people attend to multiple, moving targets.

Tuesday PM

Attention: Endogenous and exogenous

Orchid Ballroom, Boards 426–429

Tuesday, May 11, 2:45 - 6:45 pm

56.426 Effects of central cue reliabilities on discrimination accuracy and detection speed

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Partially valid central cues have been extensively used to study the effects of spatial attention on visual performance. However, the effect of cue reliability has not been examined in great detail. We assessed the effects of cue reliability in motion discrimination and speeded detection tasks. Four random dots kinematograms (RDKs) were presented in the four visual quadrants at 10° eccentricity. Each RDK was contained within a circular aperture of 5° diameter. In the discrimination task, participants reported the direction of translational coherent motion. Coherent motion occurred in only one of the four apertures. Its likely location was indicated by a cue whose reliability varied across trials over 4 levels (25%, 60%, 75%, 86%). Discrimination accuracy was greater when motion stimuli were preceded by valid than invalid cues. This effect was modulated by cue reliability, the greater the cue reliability the greater the validity effect. Moreover, validity effects were also found in the 25% reliability condition, when no task relevant spatial information was provided by the cue. In the detection task, the set-up was the same, except that participants had to report the onset of expanding motion as quickly as possible, rather than motion direction. Validity and reliability effects were also found in this paradigm. We compared performance when two quadrants were cued either by a pro-cue (pointing to the location where coherent motion will have appeared) or anti-cue (pointing to locations where coherent motion will not have appeared). Anti-cues were associated with poorer performance than pro-cues. On the other hand, discrimination performance when one or two quadrants were cued, by cues which provided the same amount of spatial information, i.e. one bit, was virtually identical. We conclude that visual performance, following central cues, reflect both the utility of cued information as well as automatic processes.

Acknowledgement: A. Close is supported by an ESRC studentship

56.427 Revealing the space in symbolically-controlled spatial attention

Alexis Thompson[1](thoalexi@gmail.com), Bradley Gibson[1]; [1]University of Notre Dame

This study investigated the nature of the spatial computations that underlie the symbolic control of visual attention. At issue is the specificity of the spatial information that is conveyed by directional symbols such as spatial words (ABOVE, BELOW, LEFT and RIGHT) and corresponding arrows. Consider a right-pointing arrow that appears at fixation and is intended to direct attention to a location in the periphery. Abundant evidence has been interpreted to suggest that such cues can direct attention to specific locations based on findings showing that RTs are faster when a subsequent target appears at a location in the cued direction relative to when it appears at an uncued location in the opposite or orthogonal direction. However, previous studies have typically presented targets at only a single location along each cued direction, making it difficult to ascertain the specificity of the spatial information that was conveyed by the cue. Accordingly, the present study presented targets at one of three possible locations in each direction. Three different spatial cues were compared: word cues, arrow cues, and onset cues. The target always appeared at one of the three locations along the cued direction with the constraint that it appeared at one of the three locations 80% of the time and at the other two locations 20% of the time. Observers were informed of these contingencies and they were instructed to shift their attention to the most probable location. The specificity of the spatial information conveyed by the three cues was estimated by the magnitude of the cuing effect (uncued RT – cued RT) observed along each cued direction. The results suggested that the word cues and arrow cues conveyed less specific spatial information than the onset cues, thus revealing weaknesses in the computation of metric spatial information necessary for directing attention to specific locations.

56.428 The influence of goal-directed attention on unattended stimulus-driven responses

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Attention is influenced by internal goals and external stimulus-driven events. In the following experiment we investigate how peripheral goal-directed attention to one visual field modulates the steady-state visual evoked potential (SSVEP) to a flickering noise patch in the opposite visual field. In the experiment, goal-directed attention is shaped by conditions that emphasize 1) enhancement of external noise at the attended location (by detecting changes in external noise contrast) 2) suppression of external noise at the attended location (by detecting a Gabor patch within high external noise), and 3) neither suppression nor enhancement of external noise in the attended location (by detecting a Gabor patch within low external noise). SSVEP responses to the unattended noise flicker allow us to examine how suppression and enhancement of external noise at the attended location may modulate the response to external noise at an unattended location. SSVEP responses to the flickering (f2 = 8 Hz) unattended noise were measured across 40 second trials and Fourier analyzed. We found a patch of occipitoparietal electrodes contralateral to the attended location (ipsilateral to the flicker) that were significantly larger when individuals detect changes in noise contrast at the attended location (condition 1 vs. 2). During Gabor detection within high and low noise (condition 2 vs. 3) we find no significant difference in occipitoparietal responses. These results indicate that 8 Hz occipitoparietal responses to an unattended noise flicker increase when top-down goals match features of the unattended flicker. These occipitoparietal responses do not decrease when top-down goals promote suppression of features at the attended location. The results are consistent with findings suggesting that peripheral attention suppresses external noise primarily at the attended location (Lu, Lesmes, & Dosher, 2002, Journal of Vision) while feature enhancement extends to unattended locations.

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56.429 The D2 dopamine receptor agonist bromocriptine enhances voluntary but not involuntary spatial attention in humans

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The neurotransmitter dopamine has been implicated in cognitive control and working memory. Specifically, the D2 dopamine receptor agonist bromocriptine has been demonstrated to affect task switching and resistance to distraction in visual working memory. Here, we systematically manipulated spatial attention in a cueing paradigm and assessed the effects of bromocriptine administration on behavioral performance. Subjects performed a visual discrimination task in which they reported the tilt of a target grating that appeared in one of four locations. Each trial began with the presentation of a cue in one of the four locations. Voluntary and involuntary attention were separately assessed by manipulating cue probability and cue-to-target stimulus onset asynchrony (SOA). Some blocks were anti-predictive: for 20% of the trials, the target appeared in the cued location. In the remaining 80% of trials, the target appeared in the location diametrically opposite the cue. In other blocks, the cue was not predictive of target location (target appeared in cue or other locations with equal probability). In addition, there were two SOAs: long (600 msec) or short (40 msec). In the predictive blocks, for long SOA trials, allocation of voluntary attention to the expected (opposite) target location resulted in shorter response times (RTs). When the SOA was short, the involuntary capture of attention resulted in the opposite pattern: RTs were significantly shorter when the target appeared in the same location as the cue. When the cue was non-predictive, only involuntary attention effects were observed. Bromocriptine was administered in a double-blind, placebo-controlled, crossover design. We found that bromocriptine enhanced the effect of spatial cueing (difference in RT for targets appearing at the opposite versus cue location) for long SOA but not short SOA blocks and only in the anti-predictive cue condition. This result demonstrates dopaminergic modulation of voluntary but not involuntary spatial attention.

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Perceptual organization: Contours and 2D form

Orchid Ballroom, Boards 430–444

Tuesday, May 11, 2:45 - 6:45 pm

56.430 A Computational Mid-level Vision Approach for Shape-Specific Saliency Detection

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We present a novel computational approach to visual saliency detection in dynamic natural scenes based on shape centered image features. Mid-level features, such as medial features, have been recognized as important entities in both human object recognition and in computational vision systems [Tarr & Buelthoff 1998, Kimia 2003]. [Kienzle et al 2009] have shown how image driven gaze predictors can be learned from fixations during free viewing of static natural images and result in center-surround receptive fields. Method: Our novel shape-centered vision framework provides a measure for visual saliency, and is learning free. It is based on the estimation of singularities of long ranging gradient vector flow (GVF) fields that have originally been developed for the alignment of image contours [Xu & Prince 1998]. The GVF uses an optimization scheme to guarantee preservation of gradients at contours and, simultaneously, smoothness of the flow field. The specific properties are similar to filling-in processes in the human brain. Our method reveals the properties of medial-feature shape transforms and provides a mechanism to detect shape specific information, local scale, and temporal change of scale, in clutter. The approach generates a graph which encodes the shape across a scale-space for each image. Results: We have made medial-feature transforms amenable to work in cluttered environments and have demonstrated temporal stability thus providing a mechanism to track shape over time. The approach can be used to model eye tracking data in dynamic scenes. A fast implementation will provide a useful tool for predicting shape-specific saliency at interactive framerates.

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56.431 Using classification images to reveal the critical features in global shape perception

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Radial frequency contours (RF; sinusoidally modulated circles) have been used to investigate how the visual information is integrated in global shape recognition. However, it is not clear, (A) if the integration is based on particular contour features (RF peaks or throughs; contour corners or sides) and (B) how similar processing of different RF shapes is. Here, classification images (CI), a psychophysical reverse-correlation technique was used to estimate the parts of the RF pattern that are critical for shape discrimination (RF pattern versus circle). Stimuli were composed of difference-of-Gaussian patches (center sd = 5.6 arc min, n=32) in an RF contour (r=1.5 deg). Position noise (jitter) along the radial axis was added. The standard RF contour had zero modulation amplitude (circle). The modulation amplitude of the test was adjusted to keep the proportion of correct detections at 75%. A one-interval shape discrimination task was used with 4-point rating scale. CIs were computed from the position noise. Both four-cycle RF4 and five-cycle RF5 patterns were tested. CIs show that both radial modulation peaks and throughs are used, suggesting that both contour sides and corners are about equally weighted in the shape recognition. The amplitude of the features across the contour length varies but is non-zero everywhere. This suggests that the detection is largely but not purely a global process. Especially, detection of the RF5 is based more on the features on top of the shape.

56.432 Boundary information and filling-in in afterimage perception

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Afterimages are the result of retinal bleaching, and other neural adaptation processes. The mainstream idea is that afterimages disappear when the level of adaptation-modulated signal (the true afterimage) is reduced below a contrast-detection threshold (e.g. Leguire & Blake, 1982). Here we manipulated afterimage visibility by projecting a ring (i.e. a boundary) around the afterimage, without changing the visual stimulation at the position of the aftereffect itself, and thus without directly affecting adaptation-modulated signals. We show that the duration of the afterimage is lengthened by about 50% with a ring that exactly encompasses the afterimage. Rings that are equal or smaller in size than the afterimage increase afterimage duration relative to a condition without a ring, while boundaries larger than the afterimage decrease afterimage duration. We find furthermore that maximum modulation occurs for intermediate contrasts of the ring, making attentional capture (by large luminance changes) an unlikely cause of the effect. Finally, placing a ring around the position of an already faded afterimage, revives the afterimage. Our data show that boundary signals (i.e. the ring) are crucial in the determination of afterimage perception. When boundary signals are present, the area within the boundary is filled in with features that are present just within its circumference, which is true afterimage when the ring snugly fits the afterimage area. When the the ring is larger than the afterimage, or absent, the filled-in feature is the gray background, which effectively shortens afterimage duration, even though the true afterimage is still present. We suggest that an 'active' boundary and filling-in mechanism is involved in afterimage perception, similar to that proposed for peripheral fading and retinally stabalized images.

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56.433 Temporal dynamics of contour and surface processing of texture-defined second-order stimuli

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Psychophysical and neurophysiological experiments have demonstrated that at the implicit (i.e. nonconscious) level first-order luminance-defined contours are processed on average 30-60 ms before surface information. Here, figure-ground segmentation processes establish contours that are later filled in with surface (e.g. wavelength and brightness) information. The present work, using metacontrast masking paradigm, examines whether the same sequence of processing also characterizes extraction of second-order features. On the one hand, first- and second-order contour and surface features might be processed in an analogous succession – form followed by surface details. On the other hand, a preliminary segmentation based on differences between foreground and background surface elements might be required before texture-defined second-order contours can be fully established. In this study texture-defined second-order target stimuli were followed, at varying stimulus onset asynchronies (SOAs), by a surrounding but spatially non-overlapping texture-defined second-order mask. First, we established that a typical U-shaped metacontrast function, obtained with first-order stimuli, can be also obtained with these stimuli. Secondly, in contour-discrimination tasks the subjects identified the shapes of the target stimulus; while in surface-discrimination tasks the subjects identified the surface texture elements of the targets. The results indicate that the suppression of texture-defined second-order contour visibility occurs at an earlier SOA than the suppression of texture-defined second-order surface information. These findings are similar to those reported with first-order stimuli and indicate that texture-defined second-order contours are processed before texture-defined second-order surfaces. These findings bear on theories of metacontrast and place constraints on models proposing that first- and second-order features are processed by separate neural circuits.

56.434 Mind the Gap: The Effect of Support Ratio and Retinal Size on Contour Interpolation

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Adults see bounded figures even when local image information fails to specify the contours, such as in cases of partial occlusion and illusory contours. Here, we examined the effects of support ratio (the ratio of the physically specified contour to the total edge length) and absolute size on interpolation strength. In Experiment 1, adults (n = 24) discriminated fat from skinny shapes formed by real contours, partially occluded contours, or illusory contours. Across conditions, support ratio and absolute size were varied. We formed fat and skinny shapes by rotating the corners of the shape (Ringach & Shapley, 1996). In a 3-down, 1-up staircase procedure, the angle of rotation of the corners increased or decreased over trials, producing various curvatures of the shape. The strength of interpolation was measured by the smallest angle of rotation of the corners for which the shape was discriminated accurately as fat or skinny. Interpolation was better for higher support ratios ($p<0.001$), and had more effect on illusory than on partially occluded contours ($p<0.01$). Thresholds were affected minimally by changes in size, except for worse thresholds for the smallest size at the lowest support ratio ($p<0.001$). In Experiment 2, we used a subset of conditions to test children aged 6- and 9-years (n = 24 per age and contour type) and adults (n = 12 per contour type tested to date) with partially occluded and illusory contours. Preliminary results indicate that, in contrast to adults who show greater effects of support ratio for illusory than partially occluded contours, the interpolation of both 6- and 9-year-olds was affected equally by support ratio for the two types of contours (ps>0.40). Thus, interpolation of contours is still immature at 9 years of age.

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56.435 **More than a simple curve: Evidence for mechanisms which are selective for curves containing inflections**

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Aim: Curved features are regarded as critical for representing global shapes but are not the only local features available. Here we employed an adaptation paradigm to investigate whether inflection points are also units of information for representing shape. Method: We measured the perceived amplitude of 'S'-shaped curves in the upper and lower visual field following a period of adaptation. Observers were adapted to a high amplitude 'whole-S' curve in one visual hemi-field, while simultaneously adapting to two temporally interleaved 'half-S' curves, formed by splitting an S curve into two at the inflection point, in the other. Results: A bigger shift in perceived amplitude occurred after adapting to a whole-S curve (i.e. containing an inflection) compared to two half-S curves (i.e. with no inflection). Control experiments showed that the advantage for the whole-S curve could not be explained on the basis of local curvature or orientation adaptation. The whole-S curve advantage was however abolished when the test and adapting stimuli were opposite in sign. Conclusions: Our data suggest that there are shape encoding mechanisms that selectively respond to curves containing inflections. However, unlike the encoding of curvature, the coding of an inflection is selective for its sign. These findings have important implication for psychophysical and physiological models of shape processing.

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56.436 **Curve completion as minimum action in the primary visual cortex**

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Visual contour completion is a fundamental task in perceptual organization. Previous computational studies, which pursue a mathematical description for the shape of the completed contour (the "shape problem"), are typically motivated by formal description of perceptual characteristics such as minimum total curvature, extensibility, roundedness, and scale-invariance (e.g., Ullman 1976; Kimia etal. 2003). However, it is difficult to examine and determine these characteristics psychophysically, and there is no consensus in the perceptual literature for what they should be. (e.g., see Ullman 1976 vs Guttman & Kellman 2004 regarding the axiom of roundedness, or Kimia etal. 2003 vs. Gerbino & Fantoni 2006 regarding scale invariance). Instead, we suggest to leverage the fact that contour completion occurs in low level vision in order to formalize the problem in a space that explicitly abstracts the primary visual cortex. Such a suitable abstraction is the (unit) tangent bundle R2xS1, where curves represent the activation pattern or orientation selective cells due to real or completed image contours. We show that a basic principle of "minimum energy consumption", namely completion according to minimum total length in the unit tangent bundle, entails desired perceptual properties for the completion in the image plane, minimizing both total curvature and total length in the image plane and thus expressing the two Gestalt principles of good continuation and proximity in a single elegant framework. Moreover, we show that our model does not support the roundedness and scale-invariance axioms, as has been promoted by recent psychophsyical findings. We present our modal and amodal completion result on both natural and synthetic images and discuss further implications and connections to perceptual findings and theories.

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56.437 **Parameter exploration of contextually modulated collinear Gabor patches**

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Context is an important factor that often hinders or helps one's performance in a visual task. In a contour detection task, Dakin and Baruch, 2009 found that collinear Gabor patches in a parallel context increased the detection threshold while an orthogonal context decreased the threshold. However, our exploration of a parameter space including eccentricity, spacing, and spatial frequency revealed that this contextual effect is dependent on how the visual scene is arranged. Psychophysical data were collected in a 2AFC task where the subject determined which side of the visual scene (left or right) contained a set of five collinear Gabor patches. The eccentricity at which the collinear Gabors were presented (1.4-4.2 degrees), the spacing between Gabors (0.6-1.8 degree), and spatial frequency of the Gabors (2-4 cpd) varied across blocks of trials, for a total of eighteen configurations. The target Gabors were embedded in a grid of identical Gabors; tolerance to orientation jitter was measured using the method of constant stimuli (fifty trials at each of six levels of orientation jitter). Three different contexts were implemented in the surrounding grid: control, parallel, and orthogonal, where the orientations of the flanking Gabors were drawn from a distribution of orientations randomly oriented, parallel, or orthogonal to the target Gabors, respectively. For all three conditions, eccentricity had the greatest effect on the contour detection thresholds. The strength of orientation-dependent contextual effects varied over the parameter space, but depended most strongly on spatial frequency. The results also suggest that collinear facilitation and orientation-dependent modulation operate on different spatial scales implying involvement of different neural mechanisms. Overall, these results provide a systematic analysis of contour detection within a specific parameter space and while supporting that context influences performance in visual tasks, the magnitude of the effect is dependent on the composition of the visual scene.

56.438 **Holes are perceived as shaped in a speeded perceptual task**

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A surrounded region perceived as a hole presents an interesting case for figure-ground perception. Previous experiments have demonstrated that the shapes of holes are remembered nearly as well as objects (Palmer, Davis, Nelson, & Rock, 2008), although according to classic figure-ground theories, the region in front should receive a shape description. Others have suggested that holes would not receive a shape description in a speeded perceptual task (Bertamini, 2006). To address this possibility, in the current experiment participants made a speeded perceptual judgment (4AFC) about the matching shape for either a hole or an object, and when they were given either the surrounded shape or its complement. Results clearly show that, contrary to predictions that the shape of the front region should always be perceived, participants were faster when matching the shape of the hole than in matching the shape of its complement (that is, the edge belonging to the surrounding region that was in front). These results are discussed in terms of a functional visuomotor theory of why the shape of holes might be perceived.

56.439 **Spatiotemporal contour integration in the human brain**

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Successful recognition of objects in cluttered scenes entails integration of fragmented images across space and time. Previous work focused on the integration of visual information across space. However, little is known

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about spatiotemporal integration that involves storing discrete image components in short-term memory and binding them across space and time. Our psychophysical work showed that collinear contours are reliably detected and identified when moving behind a narrow slit, suggesting that the spatiotemporal contour integration may not depend on V1 horizontal connections that are thought to underlie spatial contour integration. In the current study we used fMRI to investigate the neural mechanisms that mediate spatiotemporal contour integration under slit-viewing. The stimuli comprised arrays of randomly orientated Gabor patches, either with (contour stimuli) or without (random stimuli) embedded contour paths. The contour stimuli contained five embedded contours each comprising 4~9 collinear Gabor elements. The global orientation of the contours was jittered between 30°-45° or 135°-150°. In a blocked design the contour or random stimuli moved behind a slit whose width (0.75°) was equal to the average inter-element distance. As a result, at any given moment only one or parts of two contour elements could be seen through the slit. Within a block of trials a small proportion (12.5%) of stimuli contained vertical contours as targets. Observers were instructed to detect the target stimuli. A GLM analysis showed stronger fMRI responses to contour stimuli than random stimuli in higher dorsal visual areas (V7, V3B/KO, VIPS) and in the LOC, suggesting that spatiotemporal integration involves interactions between ventral and dorsal visual areas. We hypothesize that the dorsal areas may contribute to binding moving contour elements across space and time, and that the ventral regions may generate the integrated percept of the global contour.

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56.440 An improved model for contour completion in V1 using learned feature correlation statistics

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How to establish standards for comparing human and cortically-inspired computer model performance in visual tasks remains largely an open question. Existing standard image classification datasets have several critical shortcomings: 1) Limitations in image resolution and number of images during set creation; 2) Reference to semantic knowledge, such as the definition of "animal," and 3) Non-parametric complexity or difficulty. To address these shortcomings, we developed a new synthetic dataset, consisting of line segments that can form closed contours in 2D ("amoebas").

An "amoeba" is a deformed, segmented circle, in which the radius varies with polar angle. Small gaps between segments are preserved so that the contour is not strictly closed. To create a distractor "no-amoeba" image, an amoeba image is divided into boxes of random size, which are rotated through random angles so that their continuity no longer forms a smooth closed object. Randomly superimposed no-amoeba images serve as background clutter. This dataset is not limited in size, relies on no explicit outside knowledge, has tunable parameters so that the difficulty can be varied, and lends itself naturally to a binary object classification task ("amoeba/no-amoeba") designed to be pop-out for humans.

We show that humans display high accuracy (>90%) for this task in psychophysics experiments, even at short stimulus onset asynchrony=50 ms. Existing feed-forward computer vision models such as HMAX perform close to chance (50-60%). We present a model for V1 lateral interactions that is biologically motivated and significantly improves performance. The model uses relaxation labeling, where support between edge receptors is based on statistics of pair wise correlations learned from coherent objects, but not incoherent segment noise. We compare the effectiveness of this approach to existing computer vision models as well as to human psychophysics performance, and explore the applicability of this approach to contour completion in natural images.

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56.441 Why do certain spatial after-effects increase with eccentricity?

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Aim. The shape-frequency and shape-amplitude after-effects (SFAE and SAAE) describe the shifts in perceived shape-frequency/shape-amplitude of sinusoidal-shaped contours following adaptation to contours with slightly different shape-frequencies/shape-amplitudes. When measured using pairs of adaptors/tests positioned above and below fixation, both after-effects increase with eccentricity. Why? We have considered the following explanations: (i) scaling (magnification) of contour-shape receptive fields with eccentricity; (ii) reduced spatial interactions between the contour pairs when presented peripherally; (iii) less rapid decline of adaptation at test onset in the periphery; (iv) greater positional uncertainty in the periphery. Methods. We measured SFAEs and SAAEs as a function of eccentricity using a staircase procedure. At each eccentricity, we varied stimulus scale, the spatial separation between the contour pairs, and the time interval between adaptor offset and test onset. We also compared shape-frequency/shape-amplitude discrimination thresholds between center and periphery. Results. We found: (i) similar-size after-effects for all scales at each eccentricity; (ii) only a small increase (~10%) in the after-effects with increased spatial separation between the pair of contours when eccentricity was held constant; (iii) similar temporal rates of decline of adaptation for center and periphery, and (iv) comparable center-to-periphery ratios for shape discrimination thresholds and shape after-effects. Taken together, the results are inconsistent with all the above explanations except positional uncertainty. Conclusion. The increase in the SFAE and SAAE with eccentricity is best explained by increased positional uncertainty in the periphery.

56.442 The Effects of Closure on Contour Shape Learning

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Shape information is fundamental to object recognition. Objects can be recognized from shape in the absence of color, relative size, or contextual information. To support object recognition from shape, a large number of distinguishable shape representations must be learned and stored in memory. In 4 experiments presented here, participants learned to recognize 16 novel, 2D contour shapes over the course of 9 alternating training and test sessions. In the first experiment (Exp. 1), half of the subjects learned to recognize closed shapes and half learned to recognize open shapes of equivalent complexity. We tested how the presence or absence of closure affects 2D contour shape learning. Our results show that closed shapes are easier to learn to recognize than open shapes. We then show that the benefit for recognition is due to better encoding of closed shapes (Exp. 2) and not due to easier comparison between closed shapes and their representations in memory (Exp. 3). Finally, we show that potential closure (contours that appear likely to close behind an occluder) does not lead to better recognition performance. In fact, open shapes are more easily recognized than equivalent, occluded shapes (Exp. 4). Together, these experiments suggest that closed shapes are, in general, more easily or more effectively encoded. However, for the benefits of closure to be realized, a shape must be geometrically closed (the visible contour must close), not just perceptually closed (behind an occluder).

56.443 Kanizsa illusory contour perception in children: a novel approach using eye-tracking

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The time course for development of sensitivity to Kanizsa Illusory Contours (KIC) is unclear. Some previous studies have shown that the ability to perceive Kanizsa illusory forms is present near birth, while others suggest that KIC perception develops around age 5 years or later. The variability observed in the literature may in part be due to limitations inherent in testing infants or young children. We are using a novel approach to this problem by combining a match-to-sample (MTS) test paradigm in conjunction with eye tracking.

Sixteen participants were recruited into 4 age groups (3-4, 5-6, 7-9 yrs, adults). Participants were seated in front of a touch-sensitive video display and equipped with a head-mounted eye-tracker. Each participant was instructed on the match-to-sample concept, and then completed 2 practice runs consisting of a shape or orientation discrimination task using real, complete forms (10 trials each). They were then tested with 6 different real shapes as sample stimuli and KICs for matching comparison stimuli (40 trials).

Only one of four 3-4 year-olds tested performed above 80% correct (criterion) on both practice runs and the KIC discrimination. All older participants passed criterion on the practice runs, while performance with KICs was 77% (5-6), 96% (7-9), 100% correct (adult). Interestingly, location of gaze and locus of touch (response) depended on age and stimulus type. With real forms, final gaze position and touch location were directed at the image center regardless of age. However, with KICs, children under 6 primarily looked at and touched individual contour inducing elements (pacmen), whereas older children and adults looked at and touched the center of the KIC. These results show clear developmental changes in the ability to appreciate illusory forms, and a modification of processing strategy with age and stimulus type.

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56.444 Switching Percepts of Ambiguous Figures: Specific skills or a General Ability?

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The study of ambiguous figures emphasizes that perception involves not only the incoming visual stimulation, but also internal mental processes. But which ones? Previous research has explored both the temporal dynamics of switching rates and the degree to which they can be influenced by intentional control. Moreover, this research has explored both individual differences and several different ambiguous figures. Previous work has rarely put these pieces together, though: Is intentional perceptual switching mediated by a general ability, or a set of skills specific to individual figures? People clearly differ in their ability to intentionally switch percepts, but it is not clear whether the good switchers for different figures are the same people. To find out, we measured the time it took for observers to intentionally switch percepts in response to haphazardly-timed tones, using many ambiguous figures -- including both static images (e.g. bistable geometric figures, silhouettes, and semantically interpretable figures such as the duck/rabbit) and dynamic animations (e.g. the Ternus apparent-motion configuration, and bistable structure-from-motion displays). Neither of the extreme possibilities was supported by the data: perceptual switching was neither a completely uniform ability, nor a completely unconnected set of figure-specific skills. Rather, perceptual switching seems to be controlled by a set of specific visual abilities. For example, intentional switching latency was highly inter-correlated for those ambiguous figures that primarily involved depth reversals. At the same time, several other plausible factors (such as whether a figure was dynamic, or whether the ambiguity involved a semantic difference) played no systematic role in mediating perceptual switching. However, strong correlations for specific figure pairs (e.g. between Ternus motion and the duck/rabbit) suggested the existence of previously unsuspected factors. We conclude that volition is expressed in perception not as a monolithic cognitive ability, but rather as a set of particular visual skills.

3D perception: Distance and size

Orchid Ballroom, Boards 445–451

Tuesday, May 11, 2:45 - 6:45 pm

56.445 A surprising influence of retinal size on disparity-defined distance judgments

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From simple geometry, the retinal projection of an object in the environment depends on both its size and distance from an observer. Thus, given a sensed retinal size, the brain should not know the distance of the object: the retinal measurement is compatible with infinite combinations of physical sizes and distances. A number of previous studies have demonstrated that, in the absence of visual cues to distance, an object with a larger retinal image is perceived as closer than an object with a smaller retinal size. However, when binocular disparity information is available, observers should be able to judge the distance between two objects accurately. Here we report the seemingly surprising result that the retinal size influences observers' judgments of disparity-defined distance. Our stimuli consisted of large and small discs surrounded by a peripheral reference volume of textured cubes that provided a continuous reference frame to support reliable disparity estimates. Observers judged which of two sequentially-presented stimuli of different retinal sizes was closer to them. Disparity-defined depth was varied parametrically to measure psychometric functions. Our results showed a shift in the PSE of around 5 cm, so that large objects were seen as closer than small objects when disparity-defined distance was the same. In contrast, there was no bias when two objects of equal size were presented. Varying the ratio of object sizes, and testing objects placed at different distances revealed that bias increased as (i) the viewing distance increased; and (ii) the ratio of the object sizes increased. We propose that the retinal size of an object is probabilistically related to its distance in the environment and this information is combined with disparity when making judgments of distance.

Acknowledgement: BBSRC, UK

56.446 The intrinsic bias influences the size-distance relationship in the dark

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A dimly-lit target in an otherwise dark environment is perceived as located at the intersection between its projection line from the eye and an implicit slant surface (intrinsic bias) (Ooi et al, Nature 2001). To investigate if the intrinsic bias affects the size-distance relationship, observers used a perceptual matching task to report the perceived size of a dimly-lit target (0.75deg) at multiple locations (1.5-6.75m and 0 or 0.5m above the floor). Based on the matched metric size and physical angular target size, we derived the perceptual target location (perceived target direction is veridical in darkness). We found the derived perceptual target locations form a profile of a slanted surface, resembling the intrinsic bias. This indicates the intrinsic bias supports size perception in the dark. We then used a blind-walking-gesturing-size-estimation task to measure the judged target location and judged target size. In this task, observers walked blindly to traverse the perceived target distance, gestured its perceived height and indicated its size. From the indicated target sizes we derived the perceptual target distances, and compared these with the measured distances. We found a reliable correlation between the two distances, suggesting the intrinsic bias is responsible for both perceived size and distance in the dark. Finally, we investigated the effect of knowledge of target size on judged location. Using the blind-walking-gesturing task, we measured observers' judged location of the dimly-lit target in the dark when they either had, or had no, knowledge of the physical target size. We found knowledge of the physical target size (2.5cm) improves the accuracy of the judged target locations. Altogether our findings reveal that in the reduced cue environment where the intrinsic bias dictates our perceptual space, there exists a lawful relationship between perceived size and distance, which reflects the uniqueness of our perceptual world.

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56.447 The importance of a visual horizon for distance judgments under severely degraded vision

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Critical for understanding mobility in low vision is knowledge of one's ability to judge an object's location in the environment under low vision conditions. A recent study investigating distance judgments under severely degraded vision yielded surprising accuracy in a blind walking task (Tarampi et al., 2009). It is suggested in the current study that participants may have access to certain visual context cues despite the low vision manipulation. Specifically, the angle of declination from the visually defined horizon to the target on the ground may be used to determine distance.

To test this hypothesis, normally sighted individuals wore goggles that severely reduced acuity and contrast. All participants monocularly viewed targets which were placed on the ground in a large room at distances of 3, 4.5, or 6 meters. Targets were equated for visual angle, and viewed through a viewing box that restricted horizontal and vertical field of view in order to occlude the information provided by the sidewalls and ceiling. Participants were instructed to walk to the target location without vision. In one condition, the context in which participants viewed target objects was manipulated such that the perceived intersection of the floor and back wall appeared raised. If the visual frame of reference for the horizontal is used, this manipulation increases the angle of declination to the target, and should lead to an underestimation in distance compared to a condition where the floor is not changed. Preliminary results suggest individuals in the raised floor context condition are showing a decrease in distance estimates in a blind walking task relative to the control condition. These results support the account that reliance on the visually-defined horizon may have contributed, in part, to accuracy in previous blind walking performance under severely degraded vision. Subsequent manipulations will be performed to further explore this hypothesis.

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56.448 **Ground surface advantage in exocentric distance judgment**

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Previous studies have shown a ground surface advantage in the organization of 3-D scenes (Bian, et. al., 2005, 2006). In the current study, we examined whether there was a ground surface advantage in exocentric distance judgments. Observers were presented with displays simulating either a ground plane or a ceiling surface with random black and white checkerboard texture. In Experiment 1, there were three vertical red poles standing on the ground plane or attached to the ceiling surface. The three poles formed an inverted L-shape so that poles 1 and 2 were separated in depth and poles 2 and 3 were separated horizontally. The observers' task was to use a joystick to adjust the distance between the two poles that were separated horizontally to match the perceived distance between the two poles separated in depth. In addition to the surface presented, we also manipulated motion parallax, the distance of the L-shape, and the size of the L-shape. In Experiment 2, there were 3 horizontal red poles lying on the ground plane or attached to the ceiling surface. The three poles were parallel to each other and separated in depth. The task of the observer was to bisect the distance between the front pole and the back pole, that is, to adjust the distance between the front pole and the middle pole so that it matched the distance between the middle pole and the back pole. In both experiments we found that judged depth on the ground plane was larger than that on the ceiling surface, suggesting less compression of space on a ground surface as compared to on a ceiling surface.

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56.449 **Perception of Distance in the Most Fleeting of Glimpses**

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Humans can walk without vision to previewed targets (floor-level, 3-5 m distant) without large systematic error and with near perfect sensitivity to target distance, even when targets are glimpsed for as little as 9 ms. To determine whether performance at brief viewing durations is controlled by perceived distance, versus nonperceptual strategies (e.g., inferential reasoning), we compared blindwalking to verbal distance estimates and gestured size estimates (9- and 113-ms viewing durations). In Experiment 1, blindwalking and verbal reports showed equivalent sensitivity to distance. While there was greater underestimation in verbal reports (-27%) than blindwalking (-17%), the pattern remained constant across viewing durations, despite very different functional requirements across tasks. This suggests that both responses are controlled by the same variable, ostensibly perceived distance. In Experiment 2, targets varied in size and distance, and the required response (blindwalking or size gesture) was not revealed until after the glimpse. We assumed that participants would thus be unlikely to use inferential strategies for both responses on each trial. There were large differences in bias: distance was underestimated (-18%) and size was overestimated (47%). The magnitude of bias was unaffected by viewing duration in the blindwalking task, but the bias towards overestimation in size judgments was reduced with extended viewing. Nevertheless, participants were highly sensitive to changes in target size, even though the visual angle remained constant across distances. Furthermore, sensitivity to size changes was statistically equivalent to sensitivity to distance changes, suggesting a constant ratio of indicated size to indicated distance when visual angle remained fixed—in accordance with Emmert's law. This linkage strongly suggests that perceived distance indeed varies during brief glimpses and likely controls the responses tested here. The overall pattern of results provides converging evidence for the idea that distance is perceived even in the most fleeting of glimpses.

56.450 **Tool use affects perceived shape: An indirect measure of perceived distance**

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When targets are presented just beyond arm's reach, the targets look closer when observers intend to reach to the targets with a tool, and are thus able to reach them, than when they reach without the tool. This finding is just one of several examples that a person's ability to act influences perceived distance to objects. In nearly all previous experiments, the dependent measure was a direct measure of perceived distance such as verbal reports or visual matching tasks. As such, some critics have argued that the previous results are simply due to response bias. According to their account, the target does not actually look closer, but participants report that it is. To counteract this argument, the current experiments used an indirect measure of perceived distance, specifically perceived shape. In several experiments, the target constituted one corner of a triangle. Participants made judgments about the shape of the triangle then reached to the target with a tool, their hand, or a laser pointer. The results indicate that participants who reached with the tool perceived the shape of the triangle to be shorter. These results suggest that the ability to reach an object changes the perceived distance to the object, and are not due simply to response bias.

56.451 **Arousal and imbalance influence size perception**

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Previous research has demonstrated that manipulating vision can influence balance (Edwards, 1946). Here, we assess the influence of manipulating balance on size perception. In Experiment 1, participants visually matched the widths of beams when balanced and unbalanced by standing on a balance board. When unbalanced, participants estimated the widths to be thinner than when balanced. Experiments 2-5 tested possible mechanisms of this effect. In Experiment 2, participants did not estimate the width of the beam differently when viewing the board for a limited amount of time, suggesting that the effect when unbalanced was probably not due to reduced attention to the beam. Experiment 3 tested another hypothesis: that imbalance increases arousal, which affects perception. Participants' arousal level was increased by jogging in place. They estimated the board as thinner when they jogged as compared to when they were balanced. However, when participants were jogging or unbalanced they may have experienced greater movement in the visual scene. In Experiment 4, we raised participants' level of arousal without having them move, by asking them to count backward by 7s. When participants counted backward, they estimated the width of the beam as thinner than when not counting. In all conditions that produced an effect (unbalanced, jogging, counting by 7s), participants were aroused, but also performed two tasks simultaneously. In the final experiment, participants viewed arousing pictures before estimating widths. In this case, arousal was increased, but a dual-task paradigm was not employed. Again, participants estimated the width of the beams as smaller after viewing arousing images. Overall, the observed effects on size perception seem to be due to higher levels of arousal that may be experienced when unbalanced.

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Eye movements: Perisaccadic perception

Vista Ballroom, Boards 501–516

Tuesday, May 11, 2:45 - 6:45 pm

56.501 Perceptual grouping of contour elements survives saccades

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Visual exploration of a scene relies on the frequent execution of saccadic eye movements. At the retinal level, this implies that the projection of the scene constantly undergoes large, rapid displacements. Yet, the human perceptual experience is stable and continuous. A long-standing question is then whether visual object representations constructed before a saccade can be retained until after saccade landing, and if so, whether this transsaccadic representation is subsequently employed in postsaccadic processing of the same object. In the present study we show that this is indeed the case for image-abstracted yet detailed representations of visual form. Specifically, subjects glimpsed a closed contour defined by the perceptual grouping (by similarity) of spatially separated local elements in the periphery of the visual field, and made a saccadic eye movement towards it. After saccade landing this preview information was observed to affect the perceptual grouping speed of a second closed contour in the same spatiotopic location, despite an intrasaccadic change to the grouping principle defining it (good continuation instead of similarity). This yielded a benefit for an identical preview and a cost for a different but well-defined preview contour, compared to a baseline condition where only vaguely defined form information was contained within the preview display. In addition, it was found that the presaccadic presence of such a vaguely defined preview object by itself already decreased the speed of postsaccadic object contour grouping, relative to conditions in which unstructured preview displays were presented. We conclude that the visual system pools its local feature information across space, cues, and time into transsaccadically persistent object form representations, providing a robust basis for the integration of detailed shape information as well as perceptual continuity across saccades.

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56.502 The effect of perceptual grouping on perisaccadic spatial distortion

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Purpose: Target flashes immediately before the onset of a saccade appear displaced in the direction of the saccade (perisaccadic spatial distortion). In this study we observed that the horizontal spatial distortions of flashes presented above the fovea, immediately before a horizontal saccade, increase with retinal eccentricity. We also investigated perceptual interactions between spatial distortions produced with two brief (1 ms) flashes presented simultaneously at different retinal elevations from the fovea. Methods: In condition one, single or horizontally-aligned paired (synchronous) flashes were presented at combinations of three different elevations (1, 4 and 8 deg) above the fixation target before the onset of a horizontal saccade. In condition two, paired flashes were presented with misalignment in both horizontal (4 deg) and vertical (1 deg) directions. Observers reported the perceived horizontal location of each flash in both conditions. Results: The amount of perceptual mislocalization increased with vertical eccentricity with single-flashed targets. In condition one, vertically-aligned pairs of simultaneous flashes presented at different elevations were distorted equally by an amount approximately equal to the average of single flash distortions, and distortions of paired flashes had the same horizontal offset as presented in the retinal image in condition two. Paired perisaccadic distortions were the same for monoptic and dichoptic conditions. Conclusions: Our results suggested that perisaccadic spatial distortions resulting from flashes at different eccentricities undergo perceptual grouping associated with their simultaneous presentation. Grouping most likely occurs after the stage of binocular integration of distorted visual directions.

56.503 Updating for perception: An ERP-study of post-saccadic perceptual localization

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With every eye movement the retinal positions of objects in our environment change, and yet we perceive the world around us as stable. Efference copies of motor commands are used to update the retinal positions across saccades. Saccadic updating after two successive saccades (oculomotor updating) has been shown to take place between the saccades and to involve parietal regions. However, there is evidence that updating of object locations across a single saccade (perceptual updating) may represent a distinct process. The present study investigated the timecourse and topographical organization of perceptual updating in twenty healthy human subjects by means of simultaneous eyetracking and event-related potential (ERP) recording. Participants were asked to perform single horizontal left- and rightward saccades and to subsequently localize a target perceptually that was briefly shown before the saccade. Successful completion of the task involved either intra- or interhemispheric updating of the target location. Localization was less precise when updating of visual space was necessary relative to a control condition with no updating requirement. In the updating condition, we observed a positive deflection over parietal electrode sites starting about 300 ms after saccade onset. This effect was more pronounced over right parietal electrode sites, corroborating findings of right hemispheric dominance in updating of visual space. While this component likely reflects memory of the updated stimulus location, we suggest that an earlier negative deflection occurring at about 100 to 180 ms after saccade onset may be more directly linked to the updating process. The need for interhemispheric transfer of target related information did not have an impact on either localization accuracy or magnitude of the associated ERP components. These results indicate that perceptual updating takes places shortly after the saccade, a finding which is similar to what has been observed for oculomotor updating.

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56.504 Background is remapped across saccades

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Saccadic eye movements evoke a motion that disrupts stable perception. One way to prevent this disruption is to remap visual features before saccades and to maintain the remapped representation during saccades. Since object recognition is important, previous studies have focused on the remapping of objects. However, we investigated the influence of pre-saccadic remapping on the background rather than objects. In Experiment 1, a display was presented with a fixation point in the center of the left visual field, a 5° sine grating tilted 20 or -20° (figure) located in above or below 4° of the fixation, and a grating tilted oppositely to the figure (background) was presented in the entire left visual field. This display was shown for 3 seconds to produce tilt aftereffects, followed by the fixation period for 300 ~ 500 ms. After this variable fixation, participants were required to make a 10° saccade. Their task was to determine whether a sine grating (a probe) presented either above or below the saccadic target was tilted towards the left or the right. Note that the probe could appear in the remapped location of the figure or the background. We found strong tilt aftereffects in the background region as well as in the figure region, suggesting that background information was also remapped to the location of the saccadic target. In Experiment 2, we investigated whether the remapped representation was maintained during saccades and if the effect of remapping could be generalized to orientation-specific aftereffects. Figure-ground configuration was similar as in Experiment 1, but we measured threshold elevation during saccades rather than tilt aftereffects before saccades. We again found significant threshold elevation for both the figure and the ground. Thus, our results suggest that remapping before and during saccades occurs for both the figure and the background.

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56.505 **Translation of a visual stimulus during a saccade is more detectable if it moves perpendicular, rather than parallel, to the saccade**

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A feature of visuomotor behavior is the stable visual percept that the brain generates despite the volatile input provided by the retinas. One mechanism of visual stability invokes neurons that presaccadically shift their receptive fields. These neurons seem to sample the same region of space twice, permitting a comparison between the presaccadic and postsaccadic samples. We found previously that frontal eye field neurons perform such a comparison operation in the context of intrasaccadic translations. Moreover, the neurons are more sensitive to translations that occur perpendicular to the saccade than parallel to it. Here we extend our physiological findings to the behavioral level. Our aim was to characterize the ability of monkeys to report intrasaccadic translations to visual stimuli. We trained monkeys to perform a scan task in which they made repetitive saccades between two visual targets. After a random number of saccades, a third visual stimulus present on the screen was translated intrasaccadically by a small distance. Upon detecting the change, the monkey was tasked to report his percept by immediately saccading to the translated stimulus. We included two conditions: one in which the stimulus translated parallel to the scanning saccades, and another in which the stimulus translated perpendicular to the saccades. Based on the physiological findings, we made two predictions: that the monkeys' performance would increase with greater translation amount, and that a greater proportion of hits would occur for perpendicular than for parallel translations. The data confirmed both predictions. First, monkeys performed at chance level for small translations, attained ~50% levels for translations around 2 degrees, and achieved 90% performance at translations greater than 5 degrees. Second, the monkeys had a higher percentage of hits for perpendicular translations. Taken together with our physiological data, these results suggest that monkeys rely on FEF activity for performing intrasaccadic change detection.

56.506 **Preview benefit facilitates word processing in Fixation Related Brain Potentials**

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In fixation-related potential (FRP) experiments stimuli can be presented simultaneously, whereas classical event-related potential (ERP) settings are restricted to a serial presentation. Hutzler et al. (2007; Welcome to the real world: Validating fixation-related brain potentials for ecologically valid settings. Brain Research, 1172, 124-129) were able to validate the FRP approach using the old/new effect. They found that this marker effect occurred earlier in FRPs than in a classical ERP setting, whereas the shapes of FRPs and ERPs were similar. In the current study two possible explanations for this finding were investigated: a preview benefit and the self-pacing of stimulus presentation. To assess these two explanations, we established four different settings. We compared a classical and a self-paced ERP experiment and two FRPs settings, where the target stimulus was either visible or masked until fixation. We found a substantially earlier occurrence of effects only in the FRP setting, where the target was already visible before fixation. The results clearly show that processing of the target was significantly facilitated when parafoveal information had been available. Therefore, FRPs indicate a substantial influence of the preview benefit, while there was no effect of the self-paced processing rate on ERPs.

56.507 **Dynamic recurrent processing for coordinate transformation explains saccadic suppression of image displacement**

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When we shift our gaze, the image on the retina abruptly changes. What are the mechanisms that establish our subjective experience of visual stability? This question has been more formally addressed by experiments in which the image is displaced during the saccade, showing that subjects do not notice small image displacements. The observation has been interpreted by a built-in assumption of visual stability according to which we align our pre-saccadic view with a reference found in the post-saccadic view (Deubel, Schneider, & Bridgeman, Vis Res, 1998), or similarly by a prior expectation that object jumps do not occur (Niemeier et al., Nature, 2003). We simulated the saccadic suppression of image displacement task as done by Deubel et al (Vis Res, 1996) with a dynamic recurrent basis function network of coordinate transformation which maps eye-centered into head-centered representations using realistic visual processing including visual latency, persistence and saccadic suppression. Eye position is not modeled as a continuous but rather discrete signal, which transiently switches from the pre- to the post-saccadic eye position. This model explains the suppression of displacement by simple dynamic properties of the visual system rather by higher-level strategies as emphasized in earlier theories: According to the simulations, the displacement is not perceived since the displaced stimulus interacts with the pre-saccadic stimulus trace. The head-centered representation of pre-saccadic stimulus feeds back to the incoming displaced stimulus response and stabilizes the representation in the presence of small displacements. The model can also explain the paradoxical target blanking effect in which displacements become apparent when the target is blanked before or after the saccade: in this case, no stabilization occurs because the pre-saccadic stimulus trace is missing.

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56.508 **The influence of saccades on visual masking**

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Visual masking is a well known phenomenon in which the visibility of a stimulus, the target, is reduced by the rapid presentation of either a subsequent or preceding stimulus, called the mask. In a typical masking paradigm participants are not allowed to move their eyes and asked to maintain fixation throughout the trial. Outside the laboratory, however, people typically make several saccadic eye movements per second. Since saccades have been shown to influence the perceived spatial and temporal properties of briefly presented stimuli, we investigated whether these changes in perception might also influence masking. We tested subjects, with and without saccades, in a series of masking experiments including metacontrast masking (a single target followed by a backward mask) and masking of a pattern by noise (repeated forward and backward masking in a sequence). We measured discrimination performance for the target as a function of when the target was shown with respect to saccade onset. We found that performance did indeed change during the time period around saccades, leading either to "unmasking" or stronger masking of the target, depending on the type of masking and the timing of the target and mask with respect to saccade onset. Overall, the results suggest that changes in perception around the time of saccades influence the spatial and temporal attributes of the target and mask. These results also imply that saccades might be useful, in everyday life, at reducing the influence of masking on perception of briefly presented targets.

56.509 **A model of perisaccadic flash mislocalization in the presence of a simple background stimulus**

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Subjects tend to mislocalize a perisaccadic target-flash presented in the dark (Honda, 1991; Matin & Pearce, 1965). It is often suggested that a primary reason for this perceptual phenomenon is an extraretinal (exR) signal that changes before, during and after the saccade. However, Pola (2004, 2007) proposed that such mislocalization is not simply the effect of a time-varying exR signal, but is a consequence of flash retinal (R) signal persistence interacting with the exR signal. A number of studies have shown that flash mislocalization can be substantially influenced by the presence of background stimuli (e.g., Lappe, Awater & Krekelberg, 2000; Maij, Brenner & Smeets, 2008; Matin, 1976). To explore the role of such stimuli, a R-exR model was used to simulate data from an experiment conducted by Matin (1976). A principle virtue of Matin's experiment, from the perspective of modeling, is that the perisaccadic flash occurred either in complete darkness or in darkness with a simple background stimulus (a small, stationary target) present

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throughout and after the saccade. The model simulation indicates that flash R signal persistence is substantially involved in the difference between the features of flash mislocalization in the dark and with the background stimulus. Essentially, the model suggests that just as R signal persistence interacting with the exR signal produces mislocalization in the dark, the persistence, interacting with the background stimulus as well as the exR signal, accounts for some of the main features of mislocalization with the background. These findings, together with earlier results (Pola, 2004, 2007) show that R signal persistence can influence flash mislocalization in a wide range of visual circumstances: i.e., in the dark, with sequential stimuli, and with a variety of background stimuli.

56.510 **Phase-encoded fmri investigation of retinotopic remapping responses**

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In order to maintain visual stability in the face of continuous saccadic eye movements, the brain has to incorporate the motor commands for upcoming saccades into visual processing. The process by which saccadic motor commands impinge on visual processing is called remapping. In remapping, neurons with receptive fields sensitive to the post-saccadic retinotopic location of the stimulus pre-activate before the saccade, and thus, before they receive visual input. Using single-cell physiology in monkeys and fmri in humans, evidence for remapping has been found in areas ranging from parietal lobe to lower levels of visual cortex.

We devised a novel method to investigate the topographic properties of remapping activity in the human brain. Subjects made saccades back-and-forth between two lateral fixation marks every second. An expanding ring stimulus was shown alternately at either fixation position. In separate runs, the ring appeared either at the current gaze position (shifting position in sync with gaze, foveal stimulation condition), or at the position opposite the current gaze location (shifting position out of sync with gaze, remapping condition). In the first condition, the intermittent presentation of the expanding ring stimulus caused a traveling wave of activity, allowing us to employ classic phase-encoded retinotopic mapping techniques. In the second, remapping condition, subjects always made a saccade to the location where a stimulus had just disappeared. Remapping responses of this stimulus presentation should therefore produce responses with phases equivalent to the first condition. Furthermore, phases in the remapping condition should be uncorrelated with a control condition that has identical retinal stimulation but no saccades.

We use this novel technique to extend previous results regarding remapping responses in human visual cortex.

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56.511 **Perisaccadic response properties of MT neurons**

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Humans perform an average of 3 fast eye movements per second. During these eye movements, the physical image of the world races across the retina at speeds up to 1000 deg/s, yet this movement is not perceived. A recent publication (Bremmer et.al. JNeurosci, 2009) described how saccades decrease the population activity of areas MT, MST, VIP, and LIP. The time course of suppression qualitatively matched the perceptual loss of sensitivity around the time of saccades in humans. In our current study, we investigated the temporal dynamics of visual responses around saccades in a large population of MT cells. Unlike the previous study, our design allowed us to investigate perisaccadic responses at high temporal resolution in each cell (and not just at population level).

The monkeys either fixated a central target or performed optokinetic nystagmus (OKN), which was induced by moving random dots. At the same time, a noise stimulus was presented in the background. This stimulus drove the MT cells quite strongly and allowed us to observe the influence of eye movements on an ongoing visual response. We aligned the firing rates of each neuron to the saccades. We corroborated the finding that the population response is reduced for stimuli presented around saccade onset, and enhanced just after the saccade offset. However, modulations in single cells were surprisingly heterogeneous. Some cells decreased their firing during and prior to saccades, others increased theirs tenfold. Some modulations started before saccade onset; hence at least part of the modulation in area MT is due to an extraretinal signal. Taken together these data suggest that while the overall reduction in firing may be a correlate of the behavioral phenomenon of saccadic suppression, a significant number of neurons in area MT change their responses in a manner that is not compatible with simple reduced responsivity.

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56.512 **Borders between areas with different colors influence peri-saccadic mislocalization**

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The location of a brief flash is misperceived when the flash is presented around the time of a saccade. This phenomenon has been studied intensively, but there are still some unanswered questions. In a previous experiment we showed that the saccade target is used as a visual reference when localizing flashes that are presented before or after a saccade. The saccade target is a visual reference, but it also provides direct feedback about the saccade. In the study that we present here we examine whether other visual structures can also be used to improve the accuracy of the perceived location of the flash. In particular we examine whether a border between differently colored backgrounds can be used as a visual reference. Moreover we hypothesize that the perceived location of the flash would always be on the correct background color. This would influence the perceived location whenever the border between the two colors is at a position across which flashes are mislocalized on trials with a uniform background. The results showed that there is indeed an increase in accuracy when the flash was presented before and after the saccade, but when the flashes were presented during the saccade they were readily perceived on the background with a different color. This suggests that visual references other than the saccade target can be used as visual references before and after the saccade, but that they are not effective during saccades.

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56.513 **Peri-saccadic mislocalization centered at salient stimulus instead of saccade goal**

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It is generally believed that visual localization is performed based on retinotopic position and an efference copy of oculomotor signals. However, this model has difficulty in explaining the non-uniformity of many visual mislocalization phenomena associated with eye movements, e.g. the "compressed" pattern of peri-saccadic mislocalization with its locus centered at the saccade target. We investigate whether the mislocalization locus follows the actual saccade landing point or the salient object, which are typically at the same location, but were separated by up to 14° in our study.

Subjects made saccades from a fixation marker on the left (-10°) to a position on the right (+10°), and a vertical bar was flashed for one frame (100Hz frame rate) at -9°, 1°, 9°, or 15° contemporaneous to saccades. In the baseline condition, there was a salient target at the saccade landing point (+10°), in the control condition, there was no saccadic target and subjects made saccades to the memorized point (+10°). In the main experiment, there was no saccadic target either, but a salient stimulus (distracter) randomly appeared at -4 or 5° at the same time as the saccade cue and persisted for 600ms.

The results show that: (a) the mislocalization in the baseline was consistent with that in previous publications (compression index CI=0.44); (b) the mislocalization in the control condition was smaller (CI=0.22); and (c) the mislocalization in the main test was strong (CI=0.43), but the mislocalization locus was shifted to the distracter.

Our results imply that in the case of uncertain retinotopic and oculomotor signals (as during eye movements), the spatial coding of an object may be affected by other objects that are spatially well established in addition to commonly accepted retinotopic position and ocluomotor signals. This influence might contribute to the "compressed" pattern of saccadic mislocalization.

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56.514 **Rapid development of spatiotopic representations as revealed by inhibition of return**

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Inhibition of return (IOR), a performance decrement for stimuli appearing at recently cued locations, occurs when the target and cue share the same screen-position (i.e. spatiotopic mapping; Posner and Cohen, 1984; Maylor and Hockey, 1985). This is in contrast to cue-based attention-facilitation effects that were recently suggested to be mapped in a retinotopic reference frame (Golomb et al., 2008), the prevailing representation throughout early visual processing stages. Here, we investigate the dynamics of IOR formation in both reference frames, using a modified cued-location reaction-time task with an intervening saccade between cue and target presentation. This enabled creating trials in which the target was present at the same retinotopic location as the cue, and trials with the same screen-position (spatiotopic trials). IOR was primarily found for targets appearing at the same spatiotopic position as the initial cue, when the cue and target were presented at the same visual hemifield, as early as 10 ms after the intervening saccade ended. Therefore, under these experimental conditions, the representation of previously attended locations is not remapped after the execution of a saccade. Rather, either a retinotopic representation is remapped prior to the end of the saccade (using prospective motor command) or the position of the cue and target are encoded in spatiotopic reference frame, regardless of eye position. We suggest that deficits in the formation of such spatiotopic representation due to right parietal lesions may explain classical aspects of neglect syndrome, such as re-fixating previously visited targets on a visual search task.

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56.515 **TMS over the Human Frontal Eye Field Distorts Perceptual Stability across Eye Movements**

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We perceive a stable outside word despite the constant changes of visual input induced by our own eye movements. An internal monitoring of eye movements may contribute to the seemingly perfect maintenance of perceptual stability. The frontal eye field (FEF) represents a candidate area for the cortical integration of oculomotor monitoring signals: It receives information about an impending eye movement from the brainstem (Sommer and Wurtz, 2002) and exhibits predictive receptive field changes that could serve the trans-saccadic integration of visual space (Umeno and Goldberg, 1997; Sommer and Wurtz, 2006). However, what perceptual consequences may arise from altered remapping circuits within the FEF remains unclear. Here, we show that transcranial magnetic stimulation (TMS) over FEF distorts perceptual stability across eye movements. To assess trans-saccadic perceptual integration, we asked normal healthy subjects to report the direction of intra-saccadic stimulus displacements. The saccade target was switched off intra-saccadically and reappeared 250 ms later at a displaced position (Deubel et al., 1996). In a critical condition, we applied offline TMS in a continuous theta-burst stimulation (cTBS) protocol before subjects were tested in this task. The cTBS protocol has been shown to suppress cortical excitability for up to 30 min after stimulation when applied over primary motor cortex (Huang et al., 2005) or FEF (Nyffeler et al., 2006). We determined the perceptual thresholds for intra-saccadic displacement detection. Immediately after cTBS over the right FEF, subjects showed significantly elevated detection thresholds for leftward saccades (i.e., for saccades directed to the contralateral hemifield with respect to the stimulated FEF). Control stimulation over the vertex yielded no significant threshold differences compared to a baseline measure without prior stimulation. These findings indicate that the FEF is involved in the integration of oculomotor feedback signals that support visual stability across eye movements.

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56.516 **Pre-saccadic attention during development**

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Saccadic eye movements to spatial locations are preceded by attentional shifts which enhance perception at the selected location relative to other locations. This link between action preparation and perception is thought to be mediated in part by the frontal eye fields. We examined pre-saccadic attention at different ages to ascertain the role of frontal cortex maturation on the expression of the pre-saccadic perceptual enhancement. We replicated the oft-reported pre-saccadic perceptual enhancement in adults, examined it in adolescents, and used a modified version of the paradigm to test perception during saccade preparation in 10-month-old infants.

Development: Lifespan

Vista Ballroom, Boards 517–528

Tuesday, May 11, 2:45 - 6:45 pm

56.517 **Sensory transmission, rate of extraction and asymptotic performance in visual backward masking as a function of age, stimulus intensity and similarity**

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Speed of visual information processing alters as we age. Using a visual backward masking (VBM) task, we have compared cohorts of various ages (10, 15, 20, 40 and 60 years of age) on three parameters of a two-stage model (Lagged-Accrual Model, LAM) presented by Muise, LeBlanc, Lavoie and Arsenault, 1991. Of particular interest were the duration (Tlag) of initial chance performance reflecting sensory transduction and transmission, the rate (theta) of central information accrual and level (alpha) of asymptotic performance. These parameters were shown to vary systematically as a function of age, similarity of stimulus set (CGOQ vs IOSX) and stimulus intensity (0.57, 0.70, 0.86, and 1.06 cd/m2). Surprisingly, speed of sensory processing was already at its fastest for the 10 year-olds. The rate of extraction was at a maximum at 15 years with a sharp deline for older subjects. Older subjects were less able to take advantage of enhanced information available in increased stimulus intensities and dissimilarities. Differential asymptotic performance in the youngest group as a function of intensity suggests attentional lapses. Results will also be presented that suggest increasing stimulus intensity may “normalize” parametric VBM performance as a function of age. Older subjects may simply need more intense or high contrast stimuli. A discussion follows that may be pertinent to the comparison of different clinical populations in early visual information processing within the context of VBM.

56.518 **Aging and the use of implicit standards in the visual perception of length**

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A single experiment compared younger (mean age was 23.7 years) and older (mean age was 74.0 years) observers’ ability to visually discriminate line length using both explicit and implicit standard stimuli. In some conditions, the method of constant stimuli (i.e., explicitly presented standard stimulus) was used to determine the observers’ difference thresholds, whereas the method of single stimuli (no explicit standard stimulus) was used in other conditions. In the method of single stimuli, younger observers readily form a mental representation of the standard stimulus and can then use that mental standard in order to make judgments about test stimuli (i.e., whether a “test” line on any given trial is longer or shorter than the standard). The current experiment was designed to evaluate whether increases in age affect observers’ ability to form effective mental standards from a series of test stimuli. If older observers cannot form effective mental standards, then their discrimination performance should deteriorate in the single stimuli conditions relative to that exhibited by younger observers. In our experiment, the observers’ difference thresholds were 5.845 percent of the standard when the method of constant stimuli was used and improved to 4.57 percent of the standard for the method of single stimuli (a decrease in threshold of 22 percent). Both age groups performed similarly: the older adults discrimination performance was equivalent to that of the younger observers. The results of the experiment demonstrate that older observers retain the ability to form effective mental standards from a series of visual stimuli.

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56.519 Older adults misjudge deceleration

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Both speed discrimination and optic flow perception show age-related declines in performance. Given the importance of these signals for maintaining good driving, we investigated how well older adults were able to judge braking.

Participants viewed a display of dots simulating constant deceleration over a groundplane towards a visual target. Deceleration was varied from trial to trial, and participants indicated whether or not braking was sufficient to stop safely at the target.

Older adults were less likely than young adults to recognize under-braking. E.g. from an initial speed of 20 mph, they reported deceleration at only 84% of the required value to be safe on almost half the trials, whereas younger adults made this error on only one fifth of trials. Performance by older adults improved at faster speeds (errors reduced to less than 20%). There was considerable variation in performance between older individuals, with some performing nearly as well as the younger adults but others performing poorly.Both age groups tended to misjudge over-braking e.g. from 20mph, younger adults reported 125% of the required braking to be insufficient on almost 100% of trials.

There is an age-related decline in the ability to discriminate deceleration rates. This is likely to be linked to the known age-related decline in motion processing mechanisms. Given that good performance on this task also requires integrating changes in motion speed over 1-4 seconds, we suspect that age-related changes in sustained attention also play a role.

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56.520 Modulatory effects of binocular disparity and aging upon the perception of speed

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Two experiments investigated modulatory effects of a surround upon the perceived speed of a moving central region. Both the surround's depth and velocity (relative to the center) were manipulated. The abilities of younger observers (mean age was 23.1 years) were evaluated in Experiment 1, while Experiment 2 was devoted to older participants (mean age was 71.3 years). The results of Experiment 1 revealed that changes in the perceived depth of a surround (in this case caused by changes in binocular disparity) significantly influence the perceived speed of a central target. In particular, the center's motion was perceived as fastest when the surround possessed uncrossed binocular disparity relative to the central target. This effect, that targets that are closer than their background are perceived to be faster, only occurred when the center and surround moved in the same directions (and did not occur when center and surround moved in opposite directions). The results of Experiment 2 showed that the perceived speeds of older adults are different: older observers generally perceive nearer targets as faster both when center and surround move in the same direction and when they move in opposite directions. In addition, the older observers' judgments of speed were less precise. These age-related changes in the perception of speed are broadly consistent with the results of recent neurophysiological investigations that find age-related changes in the functionality of cortical area MT.

56.521 The effects of age in the discrimination of curved and linear paths

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Previous research has found that younger observers show a greater accuracy in detecting curved trajectory of moving objects when a three-dimensional background was present (Gillespie & Braunstein, VSS 2009). The current study examined age-related differences in detecting curved trajectories of moving objects. Younger and older observers viewed two displays in which a ball moved towards the observer. In one of the displays the ball moved along a linear path, while in the other display the ball moved in an upwards arc along one of three curved paths. Curvature of the path was indicated by projected velocity information, size change information, or by both types of information. In addition to age, four independent variables were manipulated: the background information (3D scene vs. uniform background), the information indicating the curved trajectory (velocity, size, or both), the order of the trajectory (linear first vs. curved first), and the curvature of the curved trajectory (three levels). The task was to indicate which display simulated a curved trajectory. A three way interaction was found between age, background information, and information indicating the curved trajectory. When background information was present, the performance of older observers was similar to that of younger observers when only velocity information was available and when both size and velocity information was available. Accuracy was at chance for both age groups when only size change information was provided. When uniform background information was given, this trend was the same for younger observers. However, for older observers, performance was at chance level regardless of what type of information was available. These results show the importance of velocity information when detecting forward moving curved paths. The results also suggest that older individuals in particular use ground plane information to determine curved paths.

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56.522 Aging and common fate

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Common fate is a fundamental law of Gestalt psychology: elements that move together are perceived as being part of the same object (Wertheimer, 1923). Although common fate suggests that the perception of motion drives object perception, the spatial arrangement of the elements also can have an effect on the perception of motion, even when that arrangement is perceived only via motion. For example, Uttal et al. (2000) showed that dots that moved in a common direction within a cloud of randomly moving dots were detected better when the target dots were arranged collinearily than when they were non-collinear. These results indicate that both motion direction and spatial organization are crucial for target detection in random dot motion displays.

As we age, some aspects of our motion perception remain relatively unchanged, while other aspects are impaired. For example, the ability to integrate form and motion information in the context of higher-level visual stimuli, such as biological motion stimuli, seems to be impaired (Pilz et al., in press). Here, we investigated the effect of aging on the perception of common fate, and the way common fate interacts with form perception.

In the current experiment, older (~65 years) and younger (~ 23 years) subjects detected a group (collinear or non-collinear) of four coherently moving dots that appeared in one of two sequentially presented sets of randomly moving dots with limited lifetime. The target dots always moved in a common direction, which varied across trials. Compared to younger subjects, older subjects showed a general decline in target detection based on common fate. This decline was significantly greater for non-collinear targets. These results indicate that with aging, form regularity is especially important for detecting coherently moving targets, which may underlie previous results regarding perception in higher-level visual tasks such as biological motion.

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56.523 Assessing the effect of aging on spatial frequency selectivity selectivity of visual mechanisms with the steady state visually evoked potential (ssVEP)

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Electrophysiological studies suggest that the spatial frequency selectivity of V1 neurons declines with age (Leventhal et al., 2003; Zhang et al., 2008). However, no psychophysical evidence for such an age-related decline has been found in humans (Govenlock et al., Vision Res, submitted). Three possible explanations for this discrepancy exist: (1) psychophysical performance is determined by the few neurons that remain highly-selective throughout aging, rather than by a larger less-selective population of neurons; (2) compensatory mechanisms enhance tuning in older humans; or (3) human and macaque monkeys are differentially affected by age. To test hypothesis 1, we measured the bandwidth of spatial frequency-selective mechanisms using the steady-state visually evoked potential (ssVEP) (Regan & Regan, 1988; Peterzell & Norcia, 1997). Twelve younger (22 years) and 12 older

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(69 years) subjects viewed two superimposed, iso-oriented, high contrast Gabor patterns counter-phase flickering at 6.67 (F1) and 8.57 (F2) Hz. The spatial frequency of one Gabor was fixed at 1 cpd; the frequency of the other Gabor varied +/- 0.66 octaves around 1 cpd. The dependent variable -- the amplitude of the F1+F2 Hz component of the ssVEP -- was measured as a function of the spatial frequency difference (Δf) between the Gabors. In both age groups, F1+F2 amplitude was greatest when Δf was zero and declined as Δf increased. The full bandwidth (at half-amplitude) of the F1+F2 response was approximately 0.65 octaves in both age groups. Thus, spatial frequency selectivity, as indexed by the population response registered by the ssVEP, does not become more broadly tuned in older humans. These results do not support the hypothesis that the discrepancy between human and macaque results can be explained by performance being determined by a few highly-selective neurons.

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56.524 **Effect of aging on the use of orientation and position in shape perception**

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Grouping local elements to extract shapes is a crucial task of the visual system. Recently, Day and Loffler (2009) showed that shape perception results from a weighted combination of local element positions and orientations, and the weighting of each cue depends on their relative strength. When elements whose orientations were consistent with a pentagon were positioned on circle, the orientation information dominated the percept and a pentagon shape was perceived. With increasing number of elements, the position information became more dominant and a circular shape was perceived.

Shape discrimination is unaffected by healthy aging (Habak et al., 2009). However, older adults are less influenced by local orientation information when integrating contours (Roudaia et al., 2008). Here, we examined whether the relative roles of orientation and position information in shape perception change with age.

Following Day and Loffler (2009), conflicting target stimuli were created by sampling the orientation of a rounded pentagon with Gabors and positioning them on a circle. Test stimuli were composed of Gabors whose positions and orientations were consistent with pentagon shapes of varying amplitude. On each trial, older (~ 66 yrs) and younger (~ 24 yrs) subjects viewed a target and test stimuli in two intervals and judged which shape looked more circular. The amplitude of the test stimulus was varied to measure the point of subjective equality between the perceived target and the test shapes. The number of Gabors comprising the stimuli was varied to manipulate the strength of position information. Consistent with previous findings, the perceived target shape was consistent with a pentagon for stimuli comprising 15 - 40 elements. This orientation dominance effect disappeared with denser sampling. Interestingly, this effect was equal in older and younger subjects across all sampling levels. These results support the findings that shape perception mechanisms are preserved in older age.

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56.525 **Effects of aging on discriminating emotions from point-light walkers**

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The visual system is able to recognize human motion simply from point lights attached to the major joints of an actor. Moreover, it has been shown that younger adults are able to recognize emotions from such dynamic point-light displays. Here, we investigated whether the ability to recognize emotions from point-light displays changes with age. There is accumulating evidence that older adults are less sensitive to emotional stimuli. For example, it has been shown that older adults are impaired in recognizing emotional expressions from static faces. In addition, it has been shown that older adults have difficulties perceiving visual motion, which might be helpful to recognize emotions from point-light displays. In the current study, ten older (mean = 70.4 years) and ten younger adults (mean = 26.1 years) were asked to identify three emotions (happy, sad, and angry) displayed by four types of point-light walkers: upright and inverted normal walkers, which contained both local motion and global form information; upright scrambled walkers which contained only local motion information; and upright random-position walkers which contained only global form information. Observers in both age groups were able to recognize emotions from all types of point-light walkers, but performance was best with upright-normal walkers, worst with scrambled walkers, and intermediate with random-position and inverted-normal walkers. Older subjects performed worse than younger subjects in the scrambled and random-position conditions, but no age difference was found in the upright- and inverted-normal conditions. These results suggest that both older and younger adults are able to recognize emotions from point-light walkers on the basis of local motion or global form information alone. However, performance is best when both form and motion information are presented simultaneously, an effect which is enhanced in older subjects.

56.526 **The Ebbinghaus Illusion as a function of age: complete psychometric functions**

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In the Ebbinghaus illusion the visually perceived size of circles is affected by contrast with the size of neighbouring circles. Children under 6 years are thought to show little or no illusion. We have collected data for groups of children of ages 4 to 9. Each participant was shown a series of images of a pair of target circles: one target circle was surrounded by larger circles; the other by smaller. The relative size of the two target circles was varied and participants were asked which was the larger circle. The proportion of trials when the target circle surrounded by the larger circles was selected, was plotted as a function of target cirlce size. Normally, one would take the point where this function crossed 50% to be a measure of the illusion. However, we have found that participants up to age 6 have a tendency to report on a proportion of trials the target circle surrounded by the larger ones, irrespective of the size of the target circle itself. This suggests visual crowding in these age groups: the occasional intrusion of surround circles into the judgement. When one allows for this, then there is no further difference between any age groups and adults.

56.527 **Age and guile vs. youthful exuberance: Sensory and attentional challenges as they affect performance in older and younger drivers**

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With age there are reductions in sensory, attentional, and motor function that would predict deficits in performance in older drivers. A variety of studies suggest that the magnitude of these effects varies with the attentional demands of the task: age-deficits in performance are especially notable in tasks where there is high attentional load. These studies typically manipulate attentional load by imposing a secondary task that does not go naturally with driving (e.g. mental arithmetic). In this study, an attempt was made to manipulate the demands of the drive by using challenge factors intrinsic to driving. Three manipulations were investigated: a sensory challenge (driving in fog as compared to driving on a clear day); a traffic density challenge (driving in high as compared to low density traffic); and a navigational challenge (having to use memorized directions, signs and landmarks to navigate while driving as compared to simply "following the road"). The effects of these manipulations were investigated alone and in combination in 19 older adults (M age = 70.8 years) and 21 younger adults (M age = 18.2 years). Participants were tested in a high fidelity driving simulator. Hazard RT, collisions, steering performance and navigational errors were measured. Contrary to prediction, when the driving task was made more challenging, the older drivers performed as well or better than the younger adults, with significantly fewer collisions and marginally lower hazard RT. This high level of performance may have arisen because older drivers adjusted their speeds more appropriately in the face of different driving challenges. Speed adjustment indices were calculated for each condition and participant. For the older adults, these speed adjustment indices correlated with measures of selective and divided attention, which suggests that older adults with deficits in attentional processing adjust their driving speeds to compensate.

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56.528 **The role of ageing on searching for a multisensory object in 3-dimensional arrays**

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With ageing sensory acuity declines, however, recent studies suggest that perception is compensated by combining inputs from across the various senses [Laurienti, et al., 2006]. However, perception can be compromised when unrelated sensory information is combined across the senses [Poliakoff et al., 2006]. What is not known is how efficient is multisensory integration in older adults when the task is to search for an object in a large spatial array. In a task involving visual target localisation, we investigated whether an auditory stimulus presented from the same location improves performance relative to a visual-only condition and whether an auditory target presented to a different location (left or right, in front or behind) to the visual target compromises performance. We also tested whether these effects were more pronounced in older than younger adults. In Experiment 1, we manipulated the spatial congruency between the auditory and visual events along the depth plane (z-axis) and in Experiment 2 along the horizontal plane (x-axis). Overall, performance was worse for older than younger adults in both experiments. In particular, performance in the older adults group did not benefit from spatial congruency between the visual target and the auditory non target, but it was hindered by a sound coming from a spatially incongruent depth location. Conversely, in Exp.2 no detrimental effect of a spatially incongruent sound on the horizontal plane was found in the older adult group suggesting that visuo-spatial processing is not affected by sounds mislocated to the left or right.

These results show that when auditory and visual stimuli are available older adults may integrate unreliable auditory inputs to perform a visual task, in particular along the depth plane. These findings support the idea that multisensory integration is enhanced in older relative to younger adults.

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Face perception: Eye movements

Vista Ballroom, Boards 529–541

Tuesday, May 11, 2:45 - 6:45 pm

56.529 **Dissociating holistic from featural face processing by means of fixation patterns**

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In the face processing literature, holistic/configural (HP) has classically been dissociated from featural processing (FP) (Sergent, 1984). HP, the interactivity of feature processing, promotes the generally observed efficiency in recognizing/discriminating individual faces and forms the basis of phenomena such as the whole-part advantage (Tanaka & Farah, 1993) and the composite-face effect (Young et al., 1987). FP, characterized by a lack of such interactivity, renders a local, serial processing style suboptimal for face processing (as seen in acquired prosopagnosia). Past investigations have assessed HP/FP behaviorally, by e.g. discrimination/recognition of features embedded in the facial context, or presented in isolation. Here we suggest that the extent to which HP/FP is engaged in varies depending on the information that can be derived from full-face stimuli, and furthermore can be assessed by means of fixation patterns. Participants' eye-movements were recorded during a delayed face-matching task. The stimuli were morphs created from personally familiar/unfamiliar faces that were either easily discriminable (50% difference), or more difficult (20%, 50% blurred faces). The rationale was that greater similarity (20%) would decrease HP and increase reliance on individual features (FP). Contrariwise, HP should increase with dissimilarity, or when featural information is unavailable, as given for blurred faces (Collishaw & Hole, 2000). For easily discriminable faces, participants fixated the face-center, below the eyes (Hsiao & Cottrell, 2008). However, the individual features (eyes, mouth) were fixated more with increased similarity. The distributed nature of fixation patterns, along with more fixations, cannot be attributed to lower performance, as this pattern was not found for blurred faces. Here, despite decreased performance, fixations remained even more centrally located, as if seeing the whole face from the central point was the optimal strategy. Our results are the first to demonstrate that stimulus quality and similarity can determine processing style, which is directly linked to the observed pattern of eye-gaze fixations.

56.530 **Gaze contingent methods reveal a loss of holistic perception for inverted faces**

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The face inversion effect (FIE) is often attributed to the inability of the human face recognition system to simultaneously perceive multiple features of an inverted face and integrate them into a single global representation, a process called holistic processing. If inversion reduces holistic processing, then for inverted faces the functional visual field should be constricted, as opposed to global (expanded) for upright faces. Until now, however, there are only indirect indications supporting this hypothesis. In the current experiment, we directly manipulated holistic processing by using a gaze-contingent technique allowing manipulation of the amount of facial features simultaneously perceived. First, a gaze-contingent foveal mask covering all foveal information prevented the use of high resolution information, necessary for part-based processing, but allowed holistic processing based on lower resolution peripheral information. Second, a gaze-contingent foveal window covering all peripheral information prevented the simultaneous use of several facial features, but allowed detailed investigation of each feature individually. A delayed face matching task showed an increased FIE with a foveal mask compared to full view and an almost absent FIE with a foveal window. These data provide direct evidence that the FIE is caused by the inability to process inverted faces holistically.

56.531 **Ultra-rapid saccades to faces : the effect of target size**

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When two images are simultaneously flashed left and right of fixation, subjects can initiate saccades to the side where a face is present in as little as 100-110 ms (Crouzet, Kirchner & Thorpe, submitted). In the present study, we tested how performance is affected by reducing the size of the target region within the image. Six different scales were used so that the percentage of the pixels in the image that corresponded to the head (not including hair) was set at 20%, 10%, 5%, 2%, 1% or 0.5%. We generated sets of 100 target and distractor images by taking two photographs of the same scene, one with a human present (target), and another without (distractor). On each trial, a fixation cross was presented for 800-1600 ms followed by a gap lasting 200 ms. Then, a target stimulus at one of the six scales was paired with either one of the matched distractors, or one of 500 other highly varied distractor images. 8 subjects were required to saccade towards the side containing a human target. Although accuracy decreased when face size was reduced, overall performance remained surprisingly high, even for the smallest sizes. For example, accuracy dropped from 94.6% to 84.2% when the face was reduced from 20% to 0.5% of the image. Furthermore, average reaction time was under 150 ms for all six sizes, and the minimum reaction time defined as the bin where correct responses statistically outnumber errors was still only 100-110 ms, even for the smallest size. Although there is now increasing evidence that these ultra-rapid saccades towards faces may depend on relatively low level information contained in the power spectrum, the current results demonstrate that this sort of analysis must be performed locally, rather than being a feature of the global power spectrum for the image.

56.532 Power spectrum cues underlying ultra-fast saccades towards faces

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When images of a face and a vehicle are flashed left and right of fixation, subjects can selectively saccade towards the face only 100 ms after image onset (Crouzet et al., submitted). This is so quick that it probably does not allow time for complete analysis of the image by the ventral stream. What sorts of information could be used for triggering such fast saccades? One possibility is that this ultra-rapid processing relies on relatively low level power spectrum (PS) information in the Fourier domain (Honey et al., J. Vis., 2008). Thus, PS normalization in the task can significantly alter face detection performance, especially for the very first saccades (Crouzet et al., ECVP 2008). However, a decrease of performance following PS normalization does not prove that PS-based information is sufficient to perform the task (Gaspar & Rousselet, Vis. Res., 2009). Following the Gaspar and Rousselet paper, we used a swapping procedure to clarify the role of PS information in fast face detection. Our experiment used 3 conditions: (i) with the original images, (ii) inverted, in which the face image has the PS of a vehicle, and the vehicle has the PS of a face, and (iii) swapped, where the face has the PS of another face, and the vehicle has the PS of another vehicle. The results showed very similar levels of performance in the original and swapped conditions, and a huge drop in the inverted condition. The conclusion is that, in the early temporal window offered by the saccadic choice task, the visual saccadic system effectively makes use of low level PS information for fast face detection, implying that faces may be detected by some particular combination of spatial frequency and orientation energy.

56.533 Human and foveated ideal observer eye movement strategies during an emotion discrimination task

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Introduction: Previously, we have shown that eye fixation patterns during a quick, difficult facial identification task are highly observer-specific, with these differences mirroring idiosyncratic fixation-dependent task ability (Peterson, 2009). Here, we extended this exploration to the task of emotion recognition. Specifically, we investigated the optimality with which humans adapt their eye movements to changing task demands during face recognition. Methods: We implemented an ideal observer limited by a human-like foveated visual system in order to evaluate the expected performance for each possible fixation location. In order to assess human strategy optimization we ran observers in two tasks. In both, observers began each trial by fixating along the edge of a monitor. A face embedded in white noise would then appear in the middle of the screen for 350ms during which observers made a single eye movement. In one task, observers were shown and then asked to identify one of ten faces. In the second task, observers were shown either a smiling face or a neutral face and asked to choose the displayed emotion. Results: Ideal observer results show that a shift in eye movement strategy between identification and emotion recognition downward toward the mouth is optimal. This move is driven largely by the differences in the locations of information concentration between the two stimuli and task types. Humans continued to show individualized fixation patterns across both tasks. Furthermore, humans showed a significant shift in gaze locus between the two conditions on a subject-by-subject and group basis. However, fixations did not shift as much as optimality would suggest. A foveated system with differential upper-field and lower-field visibility (Cameron, 2002) is able to explain the pattern of eye movements. Conclusion: Humans optimally adapt their eye movements depending on the face recognition task at hand and on the individual's observer-specific, fixation-dependent ability.

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56.534 Location of pre-stimulus fixation strongly influences subsequent eye-movement patterns during face perception

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Interpretation of eye-tracking data rests on the assumption that observed fixation patterns are mainly stimulus and task dependent. Given this assumption, one can draw conclusions regarding where the most diagnostic information is for a given perceptual task (e.g. face recognition, scene identification). If the assumption is true, then the fixation location at stimulus onset should not largely influence subsequent fixation patterns. However, we demonstrate that start location very strongly affects subsequent fixation patterns. Participants viewed upright and inverted faces and were told that they would be required to recognize the faces later in the experiment. We imposed five different start locations relative to the faces: above, below, right, left, and center (tip of nose). We found a distinct pattern of fixations for each start location that extended through at least the first five fixations. In particular, there was a strong fixation bias towards the side of the face opposite the start location. For the center start location, we found the classic result of more fixations to the eyes, particularly the right. The initial saccade from the center start location was delayed relative to the other start locations, suggesting that participants were already sampling information from the face. These general fixation patterns held regardless of face orientation. However, the difference in fixation patterns between upright and inverted faces was dependent on start location. While the central start location produced the classic result (more fixations to eyes for upright and to mouth and nose for inverted), the relative preference for eyes in upright over inverted was dependent on the start location. We conclude general biases in saccadic programming as well as stimulus information influence eye-movements during face perception. Eye-tracking allow us to tease these influences apart only if both factors are carefully controlled and analyzed.

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56.535 Scan Patterns Predict Facial Attractiveness Judgments

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We investigated the role of eye movements during judgments of facial attractiveness. Forty participants had to rate high and low attractiveness faces while their eye movements were registered. High attractiveness faces evoked a more configural scanpath compared to low attractiveness faces. This suggests that attractiveness is perceived by collecting information from different regions of the face and by integrating them to form a global representation. Moreover, high attractiveness faces elicited a higher number of fixations compared to low attractiveness faces. Participants looked preferably at the eye region and the poser's left hemiface when the faces were attractive whereas they spent more time fixating the mouth region and the right hemiface in unattractive faces. Our findings are in line with evidence showing that the perception of attractive and unattractive faces relies on different mechanisms.

56.537 Gaze direction mediates the effect of an angry expression on attention to faces

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An angry expression on someone's face can draw and hold our attention. Research demonstrating this typically uses faces gazing directly at the participant. Other research has shown that gaze direction affects the way emotions are processed, so we looked for an attentional effect of angry expressions with averted gaze. In this study, a serial stream of faces appeared alternating randomly between positions left and right of fixation and participants searched for a target face. All faces either had averted gaze or direct gaze. The target face had either a neutral or an angry expression, as did the face that appeared immediately before the target (the distractor face). We looked for effects of angry expressions drawing attention spatially (when the target was neutral and the distractor was angry, we looked for slower responses when they were at different locations than the same location; when the target was angry and the distractor was neutral, we looked for faster responses when they were at the same location than different locations) and also for engagement effects (focusing on trials where target and distractor were at the same location, we looked for slower responses when either the target or distractor were angry compared to neutral). No attention-drawing effects were seen. There was an engagement effect of anger and it was mediated by gaze: (1) Angry targets were responded to more slowly than neutral targets. (2) When gaze was averted, responses were slower when the distractor was angry than when the distractor was neutral. (3) But when gaze was direct, the distractor's expression had no impact. Thus, regardless of gaze, engagement is high when the target is

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angry. If an angry non-target face is encountered during search, that face is more disruptive if all faces are looking away than if looking directly at the observer.

56.538 **Fear expressions enhance eye gaze discrimination**

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Evidence suggests that facial expressions may have originated from a primitive sensory regulatory function (Susskind et al., 2008). For example, wider eye-opening in fear expressions is associated with a subjectively larger visual field and enhanced peripheral stimulus detection. Here we examined the Functional Action Resonance hypothesis (Susskind et al., 2008), predicting that these benefits for fear expressers are, in parallel, passed on to their observers by enhancing gaze directionality discrimination. To test this hypothesis, we derived schematic eye gazes by averaging across 19 individuals expressing canonical fear and disgust facial actions. Eye aperture was interpolated from wide "fear" to its functionally opposite, narrow "disgust", and gaze direction was parametrically modulated from 0 (straight) to 0.25 degrees (left and right). The remainder of the face was removed to examine directly how expression effects on eye aperture influence gaze perception. Participants viewed a pair of eyes and made forced-choice response judgments of left vs. right gaze direction. Logistic regression revealed that accuracy increased with gaze angle and with increased eye aperture characteristic of fear expressions. This effect appears specific to eyes, and not reducible to simple geometric properties, as the discrimination enhancement did not extended to analogous rectangles (matching dimension and proportion) that were not perceived as eyes. In an additional exogenous attentional-cuing experiment, where gaze matched or mismatched the location of a target, participants responded faster to the eccentric targets with increasing eye aperture. This facilitation was correlated with increased visibility of the iris, consistent with how fear physically enhances the gaze signal. In sum, these results support the Functional Action Resonance hypothesis demonstrating links between how emotions are expressed on the face, their functional roles for the expresser, and how they influence their observer's perception and action.

Acknowledgement: Natural Sciences and Engineering Research Council of Canada

56.539 **First fixation toward the geometric center of human faces is common across tasks and culture**

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Cultural diversity in eye movements has been shown between East Asian (EA) and Western Caucasian (WC) observers across various face processing tasks: the recognition of upright and inverted faces, categorization by race and expression. Eye-tracking studies in humans have also consistently reported that first gaze fixations are biased toward the center of natural scenes or visual objects. However, whether such low level perceptual bias is universal remains to be established. To address this question, we re-examined the initial fixations of a large set of eye movement data of EA and WC observers performing diverse tasks: the learning and recognition of (1) upright and (2) inverted faces, (3) categorization by race, and (4) categorization of emotional expressions. In all experiments, to prevent anticipatory eye movement stategies and record a genuine location of the first fixation, we presented faces pseudorandomly in one of the four quadrants of a computer screen. We measured the mean Euclidian distance between the geometric center of each face stimulus and the center-of-gravity of the first saccade across tasks and observers. Consistent with previous visual search findings with objects, the first saccade directed the fovea towards the center-of-gravity of the target face, regardless of the culture of the observer or the task. Interestingly, we observed differences in the onset of the first saccade, with upright faces eliciting the fastest onset compared to inverted or emotionally expressive faces across both groups. The first fixation could relate to a basic visual function and universal human ability to localize objects in the visual environment, possibly representing the entry level for information processing. Top-down factors modulate the speed of preparatory saccades, but not their landing locations. Culture does not shape the landing location of the first fixation, but only modulates subsequent stages of information processing.

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56.540 **You must be looking at me: the influence of auditory signals on the perception of gaze**

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The direction of another's eye gaze provides a cue to where they are currently attending (Baron-Cohen, 1995). If that gaze is directed at the observer, it often indicates a deliberate attempt to communicate. However, gaze direction is only one component of a social signal that may include other emotionally salient information in the face or the voice. A recent study from our laboratory has shown that gaze is more likely to be seen as direct in the context of an angry as compared to a fearful or neutral facial expression (Ewbank, Jennings & Calder, in press). This is consistent with the presence of a 'self-referential bias' when participants are faced with ambiguously directed gaze in the context of a threatening face. However, it remains unclear whether a self-referential signal in the auditory modality could exert an influence on the perception of gaze. To address this question, we presented neutral faces displaying different degrees of gaze deviation whilst participants heard a name in the unattended auditory channel. Hearing one's own name and seeing direct gaze both capture and hold attention (Moray, 1959; Senju & Hasegawa, 2005). These two ostensive signals have also been shown to activate similar mentalizing regions (Kampe, Frith & Frith, 2003). Given the shared signal value of the two cues, we predicted that participants would evaluate a wider range of gaze deviations as looking directly at them when they simultaneously heard their own name. Our data supported this hypothesis showing, for the first time, that the communicative intent signalled via the auditory modality influences the visual perception of another's gaze.

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56.541 **Enhanced detection in change via direct gaze: Evidence from a change blindness study**

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Purpose: A number of questions remain unclear regarding direct gaze. Does change via direct gaze elicit more specific attention than change via non-direct gaze? In addition, change via direct gaze can be categorized into two types: "look toward," which means gaze changing to look toward observers, and "look away," which means gaze changing to look away from observers. Which type of change via direct gaze triggers more specific attention? This study answers these questions.

Method: We conducted the one-shot paradigm of the flicker task. The task requires specific attention for change detection, otherwise change blindness occurs. We hence explored how change detection occurred through aspects of attention. To explore the above questions, we compared among "look away," "look toward," and non-direct gaze change. In experiments, we prepared six schematic faces positioned at 5 deg visual angle from the center fixation which observers were required to fixate their eyes to. In the direct gaze conditions, gaze changed from the center to both sides of eyes ("look away") or from both sides to the center of eyes ("look toward") whereas in the non-direct gaze conditions, gaze changed from side to side of eyes.

Results and Discussion: The experiments indicated that detection of change via direct gaze was more significantly accurate than detection of change via non-direct gaze. A post hoc analysis showed "look toward" was more effectively detected than "look away". Moreover, under manipulating distance of gaze change, explanation by simple motion detection was excluded. Our study showed two novel findings. First, change via direct gaze drew more particular attention than non-direct gaze. Second, "look toward" elicits more specific attention than "look away." These results demonstrate that individuals pay more attention when they perceive direct gaze and that "look toward" draw their more specific attention than "look away" in direct gaze.

Face perception: Parts and configurations

Vista Ballroom, Boards 542–556

Tuesday, May 11, 2:45 - 6:45 pm

56.542 Face identification and the evaluation of holistic indexes: CFE and the whole-part task

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Konar, Bennett and Sekuler (Psychological Science, in press) showed that performance in a standard measure of holistic processing, the composite-face-effect task (CFE), was highly variable across observers, and did not correlate with accuracy on a face identification task. This result suggests that the influence of holistic processing on face identification may not be as significant, or automatic, as commonly assumed. Of course, holistic processing can be measured in more than one way, and, although it is typically assumed that the measures are tapping into a single mechanism, that assumption is not typically tested.

Here we examine the reliability of and relations between face identification, the CFE, and another measure of holistic processing, the whole-part task (e.g., Tanaka & Farah, 1993). Our whole-part task was modelled after Leder and Carbon's (2005) second experiment: subjects learned associations between names and whole faces or face parts, and then were tested with whole faces and parts in upright and inverted conditions. Our face set removed external features (hair, chin, and ears) to ensure that discrimination was based on internal facial features.

Consistent with Konar et al., measures of the CFE and identification accuracy exhibited moderate-to-high reliability, but were uncorrelated with each other. Like other researchers have found, there was a whole-face superiority effect on the whole-part task: performance was better on whole-face trials regardless of learning or orientation, and the effect had high within-observer reliability. Notably, however, there were no significant correlations between performance in the whole-part task and either the CFE or face identification accuracy.

These results, based on 10 observers, suggest that different holistic tasks may, in fact, be tapping into distinct perceptual mechanisms, neither of which is predictive of our face identification task.

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56.543 The influence of horizontal structure on face identification as revealed by noise masking

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Dakin and Watt (J Vis., 2009, 9(4):2, 1-10) suggested that face identity is conveyed primarily by the horizontal structure in a face. We evaluated this hypothesis using upright and inverted faces masked with orientation filtered Gaussian noise. Observers completed a 10-AFC identification task that used faces that varied slightly in viewpoint. Face stimuli were presented in horizontal and vertical noise, and in a noiseless baseline condition. Both face and noise orientation were varied within subjects, with face orientation blocked and counter-balanced across two sessions and noise orientation varying within each session. We measured 71% correct RMS contrast thresholds for each condition and then converted the thresholds into masking ratios defined as the logarithm of the ratio of the masked and unmasked thresholds. There was a significant effect of noise orientation for upright faces ($F(1,11)=5.162$, $p<0.05$), with horizontal noise producing more masking than vertical. However, this effect did not appear for inverted faces. In a second experiment, we found that the pattern of masking did not change significantly with the RMS contrast of the masking noise ($F(2,4)=1.013$, $P>0.4$). Finally, we simulated the performance of Dakin and Watt's so-called barcode observer for our experimental conditions, and found that the predictions of the model were consistent with the masking data obtained with upright faces. Together, these data suggest that observers may indeed identify faces preferentially using the horizontal structure in the stimulus.

Acknowledgement: NSERC

56.544 Facial Perception as a Configural Process

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Configural or gestalt processing are general terms given to phenomena where the whole is different from the sum of its parts. Here we explore these phenomena through face perception, a known configural process. Split faces have often been employed as a manipulation that disrupts the configurality typically found in face processing. By applying systems factorial theory we can discover the differences in processing that result from splitting faces. This knowledge can help us further our understanding of what configurality is, and what qualities are necessary to observe it. We find that the difference in this case is due to a reduction in the workload capacity of the system, as measured by Townsend's capacity coefficient. Systems factorial technology is employed to draw conclusions regarding architecture, stopping rule, capacity and independence.

56.545 Attentional weighting in configural face processing

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The composite face effect (CFE, Young, Hellawell, & Hay, 1987) has, in recent years, been suggested as one possible empirical signature of the holistic (configural, gestalt, etc.) characteristics of facial perception and cognition. In CFE people's performance with one part of a composite face appears to be dependent on the other. Theoretical analyses of the CFE using multidimensional signal detection theory (general recognition theory, GRT) has suggested that the behavioral regularities can potentially have both perceptual and decisional sources, with recent empirical studies documenting the influence of decisional factors in the CFE. However, GRT (like classical univariate signal detection theory) addresses behavioral regularities without assuming specific mechanisms. Consequently, the present study investigated one possible source for the decisional factors that can be involved in the DFE: differential attentional weighting. Our hypothesis was that observers will distribute visual attention to the two components of a component in accord with the statistical regularities of the presentation frequencies, and that shifts in thedistribution of attention will drive shifts in response in criteria. We tested this hypothesis using a composite face task, in which we varied the base rates (e.g., prior frequencies) for the two halves of the composite stimuli. The base rate manipulation imposed correlational structure on the dimensional space (Garner, 1974), and thus allowed for the emergence of various decisional criteria within individual observers. This enabled us to relate statistical regularities in the stimulus space to various GRT constructs, including those that tap the decisional components. Based on our results, we highlight the need for further theorizing and experimentation on the role of attentional mechanisms in configural face perception.

56.546 Internal and external features of the face are represented holistically in face -selective regions of visual cortex

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The perception and recognition of familiar faces depends critically on an analysis of the internal features of the face (eyes, nose, mouth). We therefore contrasted how information about the internal and external (hair, chin, face-outline) features of familiar and unfamiliar faces is represented in face-selective regions. There was a significant response to both the internal and external features of the face when presented in isolation. However, the response to the internal features was greater than the response to the external features. There was significant adaptation to repeated images of either the internal or external features of the face in the FFA. However, the magnitude of this adaptation was greater for the internal features of familiar faces. Next, we asked whether the internal features of the face are represented independently from the external features. There was a release from adaptation in the FFA to composite images in which the internal features were varied but the external features were unchanged, or when the internal features were unchanged but the external features varied, demonstrating a holistic response. Finally, we asked whether the holistic response to faces could be influenced by the context in which the face was presented. We found that adaptation was still evident to composite images in which the face was unchanged but body features were varied. Together, these findings show that although internal features are important in the neural representation of familiar faces, the face's internal and external features are represented holistically in face-selective regions of the human brain.

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56.547 Beliefs alone alter holistic face processing...If response bias is not taken into account

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Faces are processed holistically and the composite paradigm is widely used to quantify holistic processing (HP) but there is debate regarding the appropriate design and measures in this task. Important theoretical conclusions hinge on which measure of HP is adopted because different approaches yield qualitatively different results. We argue that some operational definitions of HP are problematic because they are sensitive to top-down influences, even though the underlying concept is assumed to be cognitively impenetrable. Participants matched one half of two sequentially presented face composites while trying to ignore the irrelevant half. In the often-used partial design the irrelevant halves are always different, and HP is indexed by higher hit rates or d' for misaligned vs. aligned composites. Here, we used the complete design, which also includes trials where irrelevant halves are the same. We told one group of subjects that the target half would remain the same on 75% of trials, and another group that it would change on 75% of trials. The true proportion of same/different trials was 50% - groups only differed in their beliefs about the target halves. We assessed the effect of beliefs on three measures of HP: the difference in hit rate for aligned vs. misaligned trials (the standard measure used in the partial design), d' for aligned vs. misaligned trials based only on partial design trials, and the interaction between congruency and alignment, which can only be obtained from the complete design. Critically, beliefs influenced response biases and altered both partial design measures of HP while the complete design measure was unaffected. Thus, top-down biases, in addition to stimulus transformations (Cheung et al., 2008), can complicate partial design measures of HP. Many claims about face processing depend only on partial design measures should be re-examined with more valid measures of HP.

Acknowledgement: This research was supported by grants to the Temporal Dynamics of Learning Center (NSF Science of Learning Center SBE

56.548 Interactive Processing of Componential and Configural Information in Face Perception

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The relative dominance of componential and configural information to face processing is a controversial issue. We investigated this issue by examining how componential information and configural information interact during face processing, using Garner's speeded classification paradigm (Garner, 1974). This paradigm examines the ability to process one dimension of a multidimensional visual stimulus, while ignoring another dimension, using selective attention measures, and provides a powerful test of perceptual separability between stimulus dimensions. When classifying upright faces varying in components (eyes, nose, and mouth) and configural information (inter-eyes and nose-mouth spacing), observers were unable to selectively attend to components while ignoring irrelevant configural variation, and vice versa (indexed by symmetric Garner Interference). Performance with inverted faces showed selective attention to components but not to configural information (indexed by asymmetric Garner interference). When faces varied only in components, spatially distant or spatially close, selective attention to different components was possible (nearly zero Garner interference). These results suggest that facial components are processed independently, and that components dominate the processing of inverted faces. However, when upright faces vary in componential and configural information, as in natural faces, the processing of componential information and the processing of configural information are interdependent, with no necessary dominance of one type of information over the other.

56.549 What Did the Early United States Presidents Really Look Like?: Gilbert Stuart Portraits as a "Rosetta Stone" to the Pre-Photography Era

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There are no photographs for the first five United States Presidents (George Washington through James Monroe). However, there does exist a photograph of the sixth President John Quincy Adams (1767-1848, President 1825-1829). The fact that President John Quincy Adams straddled the eras of portraiture and photography thus offers the exciting possibility of seeing how faithful portraitists in the pre-photography era were, and, if found faithful, to knowing the true likenesses of the early Presidents and other individuals who were never photographed—a veritable "Rosetta Stone" into the pre-photography era. The great American painter Gilbert Stuart (1755-1828) painted the first six presidents. Stuart's 1818 portrait of Quincy Adams bears a striking resemblance to an 1848 photograph of Quincy Adams, ever more so when we "aged" Stuart's portrait using a freely available program. Similarly, Stuart's portraits of US Senator Daniel Webster and physician John Collins Warren are remarkably faithful to photographs taken years later. However, conversely, we find a likeness of Quincy Adams painted by another well-known American painter, Charles Willson Peale (1741-1827) to be not as faithful to the photograph as Stuart's. Thus, Stuart's portraits can serve as a "Rosetta Stone" to know the images of individuals who lived before photography. In theory one can bootstrap further back in time. This perspective on portraits also gives a way of viewing artists from all eras: Indeed, while Stuart is faithful to his subjects, and his portraits capture critical features of a subject's face, they not nearly as detailed as portraits by Holbein (c. 1497-1543), for example, Holbein's 1527 portrait of Sir Thomas More. This portrait in turn pales in terms of detail in comparison with van Eyck's 1438 portrait of Cardinal Albergati. van Eyck used the same detail in the portrait, e.g., lines, creases, hairs, as he did in all aspects of his other paintings.

56.550 Downloadable Science: Comparing Data from Internet and Lab-based Psychology Experiments

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As a medium for conducting behavioral experiments, the internet offers the opportunity to collect large samples from a broad cross-section of the population on a relatively low budget. Despite the increasing use of the internet as a means of gathering data for psychology experiments, it is unclear how comparable internet-based data is to data gathered in the lab. Furthermore, it is not clear how recruitment method might impact data quality: for instance, tests conducted on the internet might produce comparable results to tests conducted in the lab, as long as the participants were recruited through traditional methods (i.e. privately). In order to assess the quality of data from internet-based experiments, we compared data from the Cambridge Face Memory Test (Duchaine & Nakayama, 2006) from participants tested in the lab and on the web, with different recruitment methods. Specifically, data were gathered from (a) 3004 unpaid participants who followed links to our website (testmybrain.org) to 'test their skills' (public/internet), (b) 594 participants recruited through the Australian twin registry, via traditional methods, but tested on the internet at testmybrain.org (private/internet), and (c) 209 participants tested in the lab (private/lab). Reliability, as measured by cronbach's alpha, was similar across all three datasets (public/internet: 0.90; private/internet: 0.89; private/lab: 0.89). Performance, in terms of proportion correct, was also comparable in the three datasets (public/internet: 0.76, SD = 0.13; private/internet: 0.74, SD =0.14; private/lab: 0.72, SD = 0.13). Our data indicate that, even for tests like the Cambridge Face Memory Test that include complex visual stimuli (faces), the internet has the potential to provide data comparable to data gathered in the lab and from participants recruited through more traditional methods.

56.551 Heads, bodies and holistic processing in person recognition

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Interest has recently increased into how we recognise human bodies, as well as faces. Here we present two experiments on body identity. Experiment 1 tested holistic processing of unfamiliar bodies using a same-different matching version composite task. Results for top-, bottom-, left- and right-halves of bodies were compared to those for top-halves of faces (where the effect is generally largest). Orientation was manipulated between subjects. Results replicated previous findings of a larger composite effect for upright than inverted faces. Results also showed holistic processing for bodies, which was most apparent for left-right splits. This may be because gestures etc. require more integration across left and right halves of the body than top and bottom halves, and because the left-right splits always included the head. In Experiment 2 we tested the relative importance of head versus body to person recognition. We trained subjects to name 6 females from full-body pictures. Subjects then named new images, both upright and inverted, with sometimes only head or body shown. We also included head-body composites (head of one person, body of another). Subjects had a strong tendency to correctly identify the head of these composites (80%) rather than the body (10%). Inversion made people less likely to correctly recognise heads (62%) but slightly more likely to correctly recognise bodies (14%). Upright recognition was best for whole body (93%) and head-only pictures (91%), but still very good for body-only pictures (63%). Large inversion effects were shown for whole bodies (22%), head-only (25%) and body-only (15%; all significant, ps <.01). This is in contrast to previous studies that showed no inversion effect for bodies without heads. Overall, our results suggest that heads are used more than bodies for person recognition, but that bodies still provide information to identity and may be holistically processed.

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56.552 Response patterns in human Superior Temporal Sulcus discriminate the direction of observed head turns

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Humans and monkeys alike are sensitive to where other individuals are looking, an ability that is fundamental to social cognition. In monkeys, neurons in anterior superior temporal sulcus (STS) are selective for the direction of others' head turns and eye gaze, but it is not currently known whether human STS codes head turns in a similar manner. We used multivariate pattern analysis (MVPA) of functional MRI data to investigate whether human STS codes the direction of head motion. Using dynamic video stimuli, we found that voxel response patterns in anterior but not posterior STS discriminate left and right head turns. Neither anterior nor posterior STS discriminated between left and right rotation of ellipsoid control stimuli, even though these were matched in spatial frequency and motion dynamics. These results suggest that head turn direction is coded in homologous locations in human and monkey anterior STS, and highlight the potential of MVPA for better understanding of the neural coding of social attention.

Acknowledgement: Medical Research Council

56.553 Does your EBA response to my bum look big? Differential sensitivity to body orientation in the extrastriate body area

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Body orientation is an important cue to the direction of others' attention, especially when cues from the head are insufficient or obscured. Neurophysiological research has revealed cells in macaque temporal cortex that respond selectively to different directions of seen body orientation in the absence of head or face based cues (Wachsmuth, Oram, & Perrett, 1994) and recent adaptation research suggests that humans possess a similar form of separable coding for different body directions (Lawson, Clifford, & Calder, 2009). This study employs fMRI to investigate the coding of body orientation in two previously identified body-sensitive regions of human visual cortex – the extrastriate body area (EBA) (Downing, 2001) and the fusiform body area (FBA) (Peelen & Downing, 2005). In each block, images of bodies were shown at either a front facing viewpoint (0°) or at 60°, 120° or 180° rotations away from 0°. The results showed that the EBA, but not the FBA, is sensitive to the orientation of the body, furthermore, the EBA shows a greater response to bodies oriented away from 0º (front facing). These results have implications for our understanding of the functional role of these regions in the processing of human bodies.

Acknowledgement: Medical Research Council

56.554 The timing of categorical face perception

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The visual system's ability to organize the world into distinct object classes manifests itself in categorical perceptual judgments – two patterns with very similar low-level attributes might nevertheless be perceived as members of different categories and hence as very distinct objects. Previous studies in our lab have investigated neural correlates of categorization in the domain of faces (Meng et al., VSS, 2008). We collected a set of natural images that spanned a range of facial similarity from non-faces to genuine faces. By using fMRI, neural response patterns in the left fusiform gyrus were found to change in a graded fashion as the stimuli became increasingly face-like, while those in the right fusiform showed a step-like profile corresponding to a categorical difference between faces and non-faces. An important question that arises from these results concerns the functional dependencies between the graded analyses of the left fusiform gyrus and the categorical analyses of the right. To address this question, we tested the timing of categorical face perception. Subjects viewed each image for either a brief duration or unlimited duration and categorized the image as a face or non-face. When the duration was brief, false face report gradually increased as a function dependent on face likeness of the stimulus image. In contrast, when the presentation duration was unlimited, subject's report revealed a sharp, step-like categorical boundary. These results suggest that categorical face perception requires substantial processing time. Image-level facial similarity analyses may precede categorization. Taken together with previous neuroimaging results, we will discuss possible functional relationships between the graded analyses of the left fusiform gyrus and the categorical analyses of the right.

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56.555 The composite face effect: possible roles and evidence for perceptual and decisional factors

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The history of the study of face perception has been characterized by a search for the behavioral and neurophsyiological signatures of the holistic (configural, gestalt, etc.) processes that are assumed as a hallmark of face perception. Theoretical analyses of these regularities, based on the application of multidimensional signal detection theory (general recognition theory, GRT), have suggested that these regularities can be obtained by a variety of combinations of perceptual and decisional factors. In order to try to disentangle the roles of perceptual and decisional factors contributing to one of these regularities---the composite face effect---Kuefner and Rossion (VSS, 2009) used electrophysiological results (the N170 and the lateralized readiness potential, LRP) to suggest that the composite face effect---and, by extension, the assumed holistic processing of faces---is driven solely by perceptual factors. The goal of the present study was to show that the results of Kuefner and Rossion are actually one of a set of outcomes predicted by GRT. We do this by examining performance of individual observers, all of whom completed three experimental tasks involving the same stimuli. The first was a replication of Kuefner and Rossion's composite face task, allowing examination of critical neurophysiological regularities suggestive of perceptual sources. The second was an implementation of the Eriksen flanker task, allowing explicit consideration of aspects of decisional sources. The third was a complete identification task, in which both perceptual and decisional sources could be assessed. Results illustrate how the set of possibilities for the perceptual and decisional sources of the composite face effect predicted can be expressed and measured in the performance of individual observers.

56.556 Perception and Visual Working Memory Emphasize Different Aspects of Face Processing

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This experiment investigates both perceptual encoding of configural information and the maintenance of second order configural information in working memory. We collected data from 32 participants. In the perceptual condition, participants viewed two sequentially presented faces with essentially 0 ISI. The faces were configurally manipulated in either the eyes region, the mouth region, or the contour region. The stimulus set contained 48 faces with 6 degrees of difficulty. Difficulty was increased along a continuum with a 1-pixel change comprising the hardest condition and a 6-pixel change comprising the easiest condition. In the perceptual task, participants were asked to judge whether the two faces were the same or different. Importantly, participants' attention was directed to the specific face region (eyes, mouth, or contour) that was relevant in each condition. Our findings show that participants perform comparably in the various face regions, suggesting that configural perceptual encoding between face regions is equivalent in perception. In the working memory condition, participants again viewed two sequentially presented faces, and their attention was directed in the same manner as before. In contrast to the perceptual experiment, the first face was viewed for varying exposure durations (500 ms, 1500 ms). Additionally, the ISI was varied, although the SOA remained the same throughout conditions. Results showed that performance in the eye region was significantly better than performance in the mouth or contour conditions. These findings suggest that configural eye information is given more importance in working memory than configural mouth or contour information, but that these differences are not accounted for by perceptual processing. This study provides new insight into normal processes of human face perception and memory.

Wednesday Morning Talks

Eye movements: Updating

Wednesday, May 12, 8:15 - 10:00 am
Talk Session, Royal Ballroom 1-3
Moderator: Tamara Watson

61.11, *8:15 am*

Dynamics of eye position signals in macaque dorsal areas explain peri-saccadic mislocalization

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Human observers mislocalize visual stimuli that are flashed around the time of saccadic eye movements. Specifically, targets presented just before (after) the onset of a saccade are perceived at positions that are shifted in (against) the direction of the eye movement. This biphasic pattern has been attributed to a damped internal representation of eye position across saccades, but this claim has not been by verified by electrophysiological data. In the current study, we recorded the extracellular activity of single neurons in two macaque monkeys (four hemispheres) as they performed a combination of fixations and saccadic eye movements in near-darkness. Recordings were performed in four dorsal cortical areas: the lateral and ventral intraparietal areas (LIP; VIP), the middle temporal area (MT), and the medial superior temporal area (MST). Individual neurons in each of these areas were found to have 'eye position fields': a systematic relationship between mean firing rate and the position of the eyes in the orbit. Our analysis used these eye position fields to translate observed instantaneous firing rates across the population into scalar estimates of ongoing eye position. During fixation, the decoder estimated eye position with a good degree of accuracy for all fixation locations. Across saccades, the decoder revealed an anticipatory change in the representation of eye position just prior to the onset of the eye movement, followed by a brief retraction toward the initial fixation position and an eventual stabilization at the final fixation position after around 250ms. The mismatch between the actual eye position and that encoded by the recorded neurons across saccades predicts a pattern of perceptual mislocalization that is consistent with the human psychophysical data. These results suggest that eye position signals in dorsal cortical regions underlie the localization of peri-saccadic visual targets.

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61.12, *8:30 am*

A study of peri-saccadic remapping in area MT

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Area MT has traditionally been thought to operate in a retinotopic reference frame; however, there has been recent fMRI evidence that human MT has some spatiotopic properties (d'Avossa et al, 2007). Also, we have presented psychophysical evidence that area MT plays a spatiotopic role in the memory for motion process (Ong et al, 2009).

Here, we recorded from area MT in animals performing visually guided saccades during which a moving dot stimulus (100% coherence) or a circular stimulus was presented. The dot stimulus moved in the preferred direction of the recorded neuron in the pre-saccadic or post–saccadic receptive field for 500 ms; its onset occurring 80 ms before the saccade target appeared. The luminance-matched circle was flashed for 50 ms in the pre- or post-saccadic receptive field at random time intervals between 100ms before the saccade target appeared to 350 ms after. Mean saccadic latency was 192 ± 35 ms.

We recorded from 31 neurons and none of them showed pre-saccadic remapping with either stimulus. With the flashed circle, approximately 1/3 of the neurons showed late post-saccadic remapping, defined as when stimuli flashed shortly before the beginning of the saccade induced a neural response after the saccade in the post-saccadic receptive field.

We found that the post-saccadic response latencies of the moving dots were similar to onset latencies for most neurons, consistent with saccadic suppression. A subpopulation had shorter latencies, but none were pre-saccadic. These neurons were more likely to show late post-saccadic remapping of the flashed circle.

Although no neurons exhibited pre-saccadic remapping, the presence of the late post-saccadic response to a stimulus flashed entirely prior to the saccade indicates that a remapping mechanism may act on MT neurons and could explain results showing spatiotopic processing in area MT.

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61.13, *8:45 am*

Persistence of Visual Mislocalizations across Eye Movements in a Case of Impaired Visual Location Perception: Implications for Visual Updating and Visual Awareness

Michael McCloskey[1](michael.mccloskey@jhu.edu), Emma Gregory[1]; [1]Department of Cognitive Science, Johns Hopkins University

AH, a young woman with a developmental deficit in perceiving the location of visual stimuli, makes left-right and up-down reflection errors in a variety of tasks. For example, she may reach, point, or saccade to the right for an object on her left, or verbally report that a stimulus is at the bottom of a display screen when in fact it is at the top. Extensive testing revealed that AH's impairment is a selective visual deficit, and that her errors arise not in early vision, but rather at a higher level of visual representation. Remarkably, AH's misperceptions of location often persist across eye movements. When she erroneously perceives an object to be on her left while looking straight ahead, and saccades leftward in an effort to fixate the object, she may then report that she is looking at the object, despite the fact that the eye movement shifted the target further into the visual periphery. We argue that these persisting visual mislocalization errors shed light on trans-saccadic processing of location information in the normal visual system. When the eyes move, a new high-level representation of an object's location could be constructed by updating the initial high-level representation to account for the eye movement (using corollary discharge information), and/or by computing a high-level representation de novo from post-saccadic low-level visual representations. From results of several tasks probing AH's persisting visual mislocalizations, we argue that de novo computation of new high-level representations from new low-level representations is not automatic following an eye movement; as long as low-level representations imply that the visual scene has not changed, new high-level representations may be generated by updating alone. Finally, with respect to visual awareness, we argue that AH's location misperceptions imply that awareness is mediated by high- and not low-level visual representations.

61.14, *9:00 am*

The spatial coordinate system for trans-saccadic information storage

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While memory storage of objects identity and of their spatiotopic locations may sustain cross-saccadic stability of the world, retinotopic location storage may hamper it. Is it then true that saccades perturb more retinotopic than spatiotopic memory storage? We address this issue by assessing localization performances of the penultimate (N-1) saccade-target in a series of 3 to 6 saccades. One white letter-pair (target) and eight black letter-pairs (distracters) were displayed on a virtual 3° radius circle around a fixation dot for 100 ms within a 20°x20° gray rectangular frame. Subjects were instructed to saccade to the target. Once the eye landed at the target position, now displaying a fixation dot, a spatially permuted target-distracters

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arrangement was displayed anew around the fixation dot and triggered the next saccade. At the end of a trial, a color change of the fixation dot prompted subjects to report the location of the target in either retinotopic or spatiotopic coordinates. The retinotopic location was referred to the fixation dot. The spatiotopic location was referred to the gray frame. Identical conditions were run with the eyes maintaining fixation throughout the trial but with the gray frame moving so as to mimic its retinal displacement when the eyes moved. Spatiotopic location was better stored (by ~0.33 d' units) and reported faster (by ~140 ms) in the saccade compared to the maintained fixation condition. Instead, saccades degraded retinotopic location memory (by ~0.29 d' units) and delayed response time (by ~68 ms). The better and faster spatiotopic location storage and retrieval during eye-movements is compatible with the notion that spatiotopic representation takes over retinotopic representation during eye movements thereby contributing to the stability of the visual world as its projection jumps on our retina from saccade to saccade.

Acknowledgement: CNRS

61.15, *9:15 am*

Temporal encoding of visual space by means of fixational eye movements

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The processing of fine detail in moving stimuli appears to rely on information encoded in the temporal domain. During natural fixation, all stimuli continually move on the retina because of perpetual eye movements. Retinal motion caused by eye movements allows for the possibility of encoding and decoding spatial information in the temporal domain (Ahissar, 2001). In this study, we examined whether temporal modulations caused by ocular drift contribute to spatial perception. Observers viewed a standard Vernier two-line stimulus through a narrow, digital, retinally-stabilized aperture. The aperture was too narrow for both lines of the stimulus to be seen at once, and it moved synchronously with the observers' eye, allowing only a thin fixed vertical stripe of the retina to be stimulated. In each trial, the top line of the Vernier stimulus was randomly selected to be either on the left or on the right of the bottom line. Thus, as the observers' eye moved from left to right, the upper line would be seen first for one stimulus arrangement (top-left) but second for the other arrangement (top-right). The order of line exposures and the timing difference between exposures was determined solely by eye movements. Only fixational drift allowed the lines to be seen; saccades and microsaccades were identified in real time and the stimulus was not displayed during these movements. We show that observers can use the temporal modulations caused by ocular drift to make accurate spatial judgments. This research provides a direct link between fixational eye movements and visual perception and shows that temporally-encoded spatial information resulting from eye movements is useful and accessible to the visual system.

Acknowledgement: NIH EY18363, NSF BCS-0719849, NSF CCF-0726901

61.16, *9:30 am*

Where are you looking? Pseudogaze in afterimages

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The point in the visual scene that lands on the center of the fovea is assumed to define where we are looking – our direction of gaze. To test this, we asked subjects to "shift their gaze" to different locations in an afterimage. Once subjects had fixated a dim red laser point in a dark room, a strong flash illuminated a matte stimulus. The fixation point was then extinguished, leaving the afterimage as the only visual input. When subjects were asked to fixate points in the far periphery of the afterimage, they reported that the image jumped away in the direction of the attempted gaze shift. For points in the near periphery, however, subjects reported "fixating" them without causing any perceived motion of their afterimage. The region within which gaze could be shifted was generally limited to 2-4 degrees from true center, depending on the subject. Eye tracking data revealed constant movements of the eye, which the subjects were unaware of. During "fixation" of the central point of the afterimage, these drifts were random. When they set their gaze on a point within 2-4 degrees of the center, an additional, systematic component to the drift was often produced, in the same direction as the intended offset in gaze. Finally, when they fixated a point to the left of fovea and then attempted a saccade to a point directly below the fovea, some subjects' eyes moved diagonally in accordance with their subjective feeling, while other subjects' eyes moved vertically, in accordance with the target's actual position relative to fovea. These results suggest that the apparent direction of gaze can be flexibly assigned to an attended object near the fovea allowing visual coordinates to remain centered on a steady location in the world, despite the incessant small eye movements of fixation.

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61.17, *9:45 am*

An equivalent noise investigation of saccadic suppression

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It is well known that perisaccadic visual stimuli are less visible than those presented during fixation and that many visual areas change their response properties perisaccadically. The link between these phenomena remains tentative however. Our goal was to quantify the behavioral phenomenon to enable a more focused search for its neural mechanism. Several mechanisms may be responsible for reduced perisaccadic visibility: spatial uncertainty1, internal multiplicative noise, and/or response inhibition2 (or, equivalently, additive internal noise3). We tested these using equivalent noise analysis. Each mechanism predicts a unique pattern of detection thresholds when target stimuli are embedded in external noise4. Spatial uncertainty predicts no perisaccadic effect on sensitivity at low external noise, while sensitivity at high external noise should be reduced as the external noise swamps the signal. The multiplicative noise model predicts lower sensitivity at both high and low external noise. The response inhibition model predicts lower sensitivity at low external noise, with equal thresholds at high external noise. In our experiments, participants identified the location of a low spatial frequency grating above or below the fixation point. Stimuli were presented up to 50ms prior to saccade onset. The targets were embedded in Gaussian noise; stimulus and noise contrast were manipulated independently. Detection thresholds were calculated at each external noise level at fixation and perisaccadically. We found that response inhibition was sufficient to describe the perisaccadic detection thresholds relative to those found at fixation. *1 Greenhouse and Cohn. 1991. J. Opt. Soc. Am. A, 8:587-595 *2 Burr, and Ross. 1982. Vis. Res. 23, 3567-3569 *3 Diamond, Ross and Morrone. 2000. J. Neurosci. 20, 3442-3448 *4 Liu and Dosher. 1998. Vis. Res., 38, 1183-1198

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Perception and action: Navigation and mechanisms

Wednesday, May 12, 8:15 - 10:00 am
Talk Session, Royal Ballroom 4-5
Moderator: William Warren

61.21, *8:15 am*

Route selection in complex environments emerges from the dynamics of steering and obstacle avoidance

Brett Fajen[1](fajenb@rpi.edu), William Warren[2]; [1]Cognitive Science, Rensselaer Polytechnic Institute, [2]Cognitive and Linguistic Sciences, Brown University

Fajen and Warren (2003) developed a dynamical systems model of steering and obstacle avoidance based on data from human subjects, in which locomotor paths emerge on-line. By linearly combining goal and obstacle components, the model can be used to predict route selection behavior in complex scenes containing multiple obstacles. In this study, we compare the predictions of the steering dynamics (SD) model with models that minimize path length (MPL) and minimize total lateral impulse (MLI), where $I = \int F\,dt$. The experiment was conducted in a 12 m x 12 m virtual environment viewed through a head-mounted display (FOV 63° H x 53° V). Subjects (N = 11) walked from a home location to a goal 8 m away while avoiding an array of 12 randomly positioned obstacles (2 m posts). There were eight different obstacle arrays, and each array was presented in both the forward and backward directions six times, yielding 16 configurations and a total of 96 trials. The MLI model was the worst predictor of human routes, for the mean total lateral impulse on all observed routes exceeded that of the MLI route by 67%. The MPL model was comparatively better, for the mean length of all observed paths exceeded the minimum path length by just 8%. The SD model generated paths that were nearly identical in length to the human paths, and predicted human routes as well as the MPL model. We conclude that people select routes that nearly minimize path length but not total impulse, and that the SD model captures an on-line control strategy from which human-like, nearly minimum length paths emerge.

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61.22, *8:30 am*

Adaptation of visual straight ahead requires an unrestricted field of view

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Traditional accounts of adaptation to a rotation of the optic array (due to prisms) identify both visual and proprioceptive sites (Redding & Wallace, 1985). Last year (Brandwood, Rushton & Charron, VSS 2009), we reported the results of a walking experiment: Through manipulation of observer's walking behaviour, we demonstrated that the magnitude and site of adaptation depends on the availability of optic flow. Specifically we found that optic flow plays an important role in the recalibration of perceived visual straight-ahead (Held and Freedman, 1963). This year we have taken a different approach to the same problem: In a repeated measures design we manipulated visual information. Participants wore glasses containing paired horizontally orientated wedge prisms and walked back and forth between targets for a short period of time. During locomotion vision was (i) unrestricted; (ii) restricted to 90°, or (iii) restricted to 90° with 400ms snapshots (through the use of optical shutters). Perceived visual straight-ahead and perceived proprioceptive straight-head was measured before and after exposure to the prisms. Adaptation was defined as the difference between the before and after measures. In the natural, unrestricted, condition we found adaptation was primarily visual. However, the site of adaptation switched towards proprioception as vision became more restricted. Thus, in line with our previous study we found that the site of adaptation varied with the availability of optic flow. Interestingly, the reduction of adaptation in visual straight-ahead with the restricted field of view in our study may explain the lack of shift in visual straight-ahead in Bruggeman, Zosh & Warren's (2007) study: They used a HMD with a restricted field of view. To conclude, taken together with our previous findings, the results of this study provide further support to the contention that optic flow drives a recalibration of visual straight ahead.

61.23, *8:45 am*

Anticipating the actions of others: The goal keeper problem

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When humans observe the actions of others, they can often accurately anticipate the outcome of those actions. This is perhaps best exemplified on the playing field, where athletes must anticipate the outcome of an action based in part on the complex movement of an opponent's body. In this study, we tested the reliability and use of local and distributed sources of information available in the actor's motion. These issues were investigated within the context of blocking a penalty kick in soccer. Because of extreme time constraints, the keeper must anticipate the direction in which the ball is kicked before the ball is contacted, forcing him or her to rely on the kicker's movement. In Experiment 1, we used a motion capture system to record the joint locations of experienced soccer players taking penalty kicks. The reliability of both local (e.g. orientation of the non-kicking foot) and distributed (e.g. mode/motor synergy) sources of information was measured by computing the degree to which each source correlated with true kick direction. Experiment 2 investigated the relationship between reliability and use of information sources. The motion data were used to create animations from a keeper's viewpoint of a point-light kicker approaching and kicking a ball. On each trial, subjects watched an animation and judged kick direction (left or right). The sources of information upon which judgments were based were identified by computing the correlation between information and judged kick direction. By comparing the reliability and use of different sources of information, we can characterize the ability to exploit local and distributed information when anticipating a movement's outcome. In Experiment 3, we presented subjects with artificial stimuli in which only one source of information was reliable, providing a more direct test of people's ability to use specific sources of information.

61.24, *9:00 am*

Perceptual Body Illusion Affects Action

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Synchronously stimulating an artificial hand and a participant's hand that is hidden from view induces an apparent proprioceptive shift towards the artificial hand (Rubber Hand Illusion; RHI), such that participants subjectively report their hand location to be between the real and artificial hand. This effect is reduced or eliminated with asynchronous visual and somatosensory stimulation. Although previously thought of as a purely perceptual illusion, here we show that the RHI influences ballistic movements directly. A repeated measures design was used to compare participants' task performance during synchronous and asynchronous stimulation conditions. First, the RHI was induced, and then participants were asked to perform ballistic hand movements towards targets presented in a randomized location on a touch screen. A motion capture system was utilized to record hand movement trajectories for analysis. We found significantly larger reaching endpoint errors in the synchronous than asynchronous conditions. Importantly, these errors were biased to the side of the target opposite the side of the artificial hand, consistent with participants moving their hand as if position is computed to be intermediate between the real and rubber hand. It is believed that peripersonal space systems integrate multisensory information to form body-part-centered (e.g. hand-centered) maps of local space. The computation of hand position incorporates input from visual, tactile and proprioceptive modalities and a shift in any or multiple of these sensory mappings, as induced by the RHI, results in a misperception of hand location. This study suggests that the re-alignment of mappings, which is modulated by the RHI leads to direct effects in reaching biases for action and visually-based proprioceptive judgments. Importantly, these results show, beyond the limitations of subjective report of perceived hand position used in previous studies, that the RHI has a fundamental impact on motor action towards visual targets.

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61.25, *9:15 am*

Active is good for auditory timing but passive is good for visual timing

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People naturally dance to music, and it has been shown that auditory perception facilitates generation of precisely timed body movements. Here we investigated the converse: Does initiating action enhance auditory perception of timing? Participants performed a temporal bisection task; they heard a sequence of three sounds (13 ms each) spread over 550 ms. The timing of the middle sound was randomly varied, and participants responded as to whether the middle sound was temporally closer to the first or last sound. The slope of the resultant psychometric function indicated the precision of temporal bisection. In the active condition, participants initiated each sound sequence (via a key press), whereas in the passive condition each stimulus sequence was initiated by the computer. White noise was played over headphones throughout the experiment to mask key-press sounds. Auditory temporal bisection was more precise in the active than in the passive condition. To determine whether action similarly facilitated visual perception of timing, we repeated the same experiment except that we replaced the brief sounds with brief flashes. Interestingly, visual temporal bisection was more precise in the passive than in the active condition. These opposite results for auditory and visual modalities indicate that the benefit of action in auditory timing perception could not be attributable to increased alertness or reduced temporal uncertainty that could have been caused by voluntarily initiating each stimulus sequence. Thus, we have demonstrated a reciprocal relationship between action and auditory perception; as auditory stimuli facilitate precisely timed action, action enhances auditory per-

 See page 3 for Abstract Numbering System

ception of timing. In contrast, visual timing perception is enhanced when attention is fully focused in the visual modality and is distracted by action. These results suggest that auditory timing operates synergistically with motor mechanisms, whereas visual timing operates most effectively when neural resources are fully engaged to visual perception.

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61.26, *9:30 am*

Human Echolocation I

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It is common knowledge that animals such as bats and dolphins use echolocation to navigate the environment and/or to locate prey. It is less well known, however, that humans are capable of using echolocation as well. Here we present behavioral and fMRI data from two blind individuals (aged 27 and 45 years) who produce mouth-clicks and use click-based-echolocation to go about their everyday activities, which include walking through crowded streets in unknown environments, mountain biking, and other spatially demanding activities. Behavioral testing under regular conditions (i.e. in which each person actively produced clicks) showed that both individuals could resolve the angular position of an object placed in front of them with high accuracy (~ 2° of auditory angle at a distance of 1.5 meters). This extremely high level of performance is remarkable, but not unexpected, given what they are capable of doing in everyday life. To validate the stimuli we planned to use in fMRI conditions, we took in-ear audio recordings from each individual during active echolocation and played those recordings back using MRI compatible earphones. In these conditions, both individuals were still able to use echolocation to determine with considerable accuracy the angular position, shape (concave vs. flat), motion (stationary vs. moving), and identity (car vs. tree vs. streetlight) of objects. Importantly, during the recordings, none of the objects emitted any sound but simply offered a sound-reflecting surface. We conclude that echolocation, during both active production and passive listening, enables our two participants to perform tasks that are typically considered impossible without vision. To investigate the neural substrates of their echolocation abilities, we employed our passive listening paradigm in combination with fMRI (see Abstract 'Human Echolocation II').

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61.27, *9:45 am*

Human Echolocation II

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Here we report fMRI data that reveal the neural substrates underlying the echolocation abilities of two blind individuals (aged 27 and 45 years) (see also Abstract 'Human Echolocation I'). A passive listening paradigm was employed in all fMRI experiments. Using fMRI, we found increased BOLD signal in auditory and visual cortices in both persons in response to the presentation of sounds. Remarkably, however, a contrast analysis, applied to the whole brain, revealed that the BOLD signal in 'visual' cortex increased during the presentation of echolocation sounds as compared to spectrally matched control sounds, while the BOLD signal in auditory cortex remained unchanged. Furthermore, a region-of-interest analysis of visual cortex suggested that the processing of echoes reflected from objects placed to the left or right of the head were associated with increased activity in the contralateral occipital cortex. Finally, when our two participants were instructed to judge either the shape (concave vs. flat) or the location (right vs. left) of a sound reflecting surface, a contrast analysis applied to the whole brain revealed a stronger BOLD signal in ventral occipital areas during the shape judgment task. Importantly, the sounds that had been used in the shape and location tasks were the same. In their entirety, the results suggest that the echolocation abilities in our two blind participants appear to make use of the functional and topographic organization of visual cortex.

Acknowledgement: This research was supported by a grant to MAG from the Canadian Institutes of Health Research.

3D perception: Depth cues and spatial layout

Wednesday, May 12, 11:00 - 12:45 pm
Talk Session, Royal Ballroom 1-3
Moderator: Martin S. Banks

62.11, *11:00 am*

Analyzing the Cues for Recognizing Ramps and Steps

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The detection of ramps and steps is important for the safe mobility of people with low vision. We used ramps and steps as stimuli to examine the interacting effects of lighting, object geometry, contrast, viewing distance and spatial resolution. Gray wooden staging was used to construct a sidewalk with a transition to one of five targets: a step up or down, a ramp up or down, or a flat continuation. 48 normally sighted subjects viewed the sidewalk monocularly through blur goggles which reduced acuity to low-vision levels. In each trial, they indicated which of the five targets was present. Here, we report on a probabilistic cue-based model to explain data in the resulting target/response confusion matrices. A set of cues for distinguishing among the five targets included contrast at the transition from sidewalk to target, discontinuities in the edge contours of the sidewalk, and variations in the height in the picture plane of the targets. We formulated the problem of recognition in two parts: the independent probabilities for detecting the cues, and the optimal use of the detected cues in making a recognition decision. To estimate the cue probabilities, we derived and solved equations relating the cue probabilities to the conditional probabilities in the cells of the confusion matrices. We found that the high probability for detecting the contrast cue explained superior visibility of step up over step down. Cues determined by discontinuities in the edge contours of the sidewalk were vulnerable to changes in viewing conditions. Cues associated with the height in the picture plane of the targets were more robust across viewing conditions. We conclude that a probabilistic cue-base model can be used to understand the effects of environmental variables on the visibility of ramps and steps.

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62.12, *11:15 am*

Direct Physiological Evidence for an Economy of Action: Bioenergetics and the Perception of Spatial Layout

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A good deal of evidence supports the notion that physiological state and the anticipated energetic demands of acting on the environment affect perception (e.g. Proffitt, 2006). Until recently, however, the role of such bioenergetic factors in the perception of spatial layout could only be inferred. Here, we directly assessed the role of bioenergetics by manipulating blood glucose (BG) levels (glucose is the primary source of energy for immediate muscular action). In each experiment, participants ingested either a glucose- or artificially-sweetened (placebo) drink, and multiple blood samples were obtained to assess changes in BG. Two experiments assessing perception of hill slant showed that people who ingested the glucose drink perceived hills to be less steep. An experiment in which participants gave distance estimates before and then again after ingesting a drink revealed that participants given glucose subsequently perceived distances to be shorter while those given the placebo did not. Furthermore, a battery of self-report measures assessed individual differences on a host of bioenergetically relevant properties. Regardless of the experimental manipulation, individuals with a reduced energy state perceived hills to be steeper and distances to be greater. A final study tested highly trained cyclists on two separate days before and after 45 minutes of intense pedaling on a stationary bike. They ingested glucose drinks at regular intervals on one day and placebo drinks on the other. After exercising, participants perceived distances to be shorter when given glucose and greater when given placebo drinks. Multiple direct physiological measures obtained during exercise indicated that across experimental conditions, greater energy expenditure and lower

BG levels predicted greater distance estimates, and multiple indicators of physical fitness (heart rate, oxygen consumption, blood lactate) independently predicted shorter distance estimates for more fit individuals. These findings are consistent with the view that spatial perceptions are influenced by bioenergetic factors.

62.13, *11:30 am*

Testing the generalizability of perceptual-motor calibration on spatial judgments

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The relationship between biomechanical action and perception of self-motion during walking is typically consistent and well-learned but also adaptable. This perceptual-motor pairing can be recalibrated by creating a mismatch between the visual perception of self-motion and walking speed. Recalibration has been shown to influence subsequent distance judgments such as blindwalking and imagined walking to previously viewed targets (Rieser et al., 1995; Mohler et al., 2006; 2007; Kunz et al., 2009). Whether perceptual-motor recalibration generally influences the scaling of space or the process of spatial updating during movement is an open question. Moreover, it is unknown if the perceptual-motor calibration resulting from walking influences other types of locomotion that involve spatial updating. We conducted three experiments to determine how broadly perceptual-motor recalibration influences distance perception. In each experiment, participants completed a pretest in a real world hallway, in which they either blindwalked to previously viewed targets (Experiment 1), matched the perceived size of a sphere with their hands (Experiment 2), or wheeled to previously viewed targets in a wheelchair while blindfolded (Experiment 3). After this pretest, participants donned a head-mounted display and walked through a virtual hallway that appeared to move past them at either twice or half their walking speed. Following this recalibration phase, participants returned to the adjacent hallway and repeated the pretest task. While Experiment 1 replicated previous findings that perceptual-motor recalibration influences posttest blindwalking performance, Experiment 2 showed that adaptation to a new perceptual-motor relationship during walking does not influence size judgments, an indirect measure of perceived distance. Experiment 3 suggests that the effect of perceptual-motor recalibration of walking on blind wheelchair locomotion appears relatively weaker and more variable than the effect on blindwalking. These results have implications for understanding the specificity of perceptual-motor calibration and how this calibration influences spatial judgments made within a virtual environment.

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62.14, *11:45 am*

Blur and Disparity Provide Complementary Distance Information for Human Vision

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Disparity is generally considered the most precise cue to depth, while blur is considered a coarse, qualitative cue. Depth from disparity and depth from blur have similar underlying geometries: one is based on triangulation between images collected by different eyes and the other is based on triangulation between images collected through different parts of the pupil. Thus, from a geometric standpoint, they provide complementary distance information. Physiologically, the two cues have very different sensitivities. Disparity thresholds, expressed as just-noticeable differences in depth, are low near fixation, but increase rapidly away from fixation. In contrast, blur thresholds are relatively large and do not vary significantly with position relative to fixation. Thus, one might expect disparity to determine depth discrimination near fixation and blur to determine discrimination away from fixation. We tested this expectation in a psychophysical experiment. Observers were presented a reference and test stimulus on each trial. The two stimuli were either both in front of fixation or both behind fixation. After each trial, observers indicated which stimulus appeared more distant. We used a novel volumetric display (Love et al., 2009) to present stimuli that contained 1) only disparity information (Gaussian dot viewed binocularly), 2) only blur information (a disk with 1/f noise viewed monocularly), or 3) both disparity and blur information (1/f disk viewed binocularly). As expected, thresholds were lower in the disparity-only condition than in the blur-only condition and the two-cue thresholds were similar to the disparity-only thresholds when the reference and test were near fixation. The situation reversed, however, behind fixation where blur thresholds were lower than disparity thresholds and two-cue thresholds were similar to blur-only thresholds. Thus, disparity and blur are complementary sources of information with disparity providing the best depth information near fixation and blur providing the best information away from fixation.

62.15, *12:00 pm*

Effects of Shape and Surface Material on Perceived Object Rotation Axis

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Using rotating matte and shiny objects, Hartung and Kersten (2002) showed how image motion can affect material appearance. What their demonstrations also revealed, which wasn't however explicitly noted, was that surface material of an object also affects the perceived axis of rotation. For example, a specular teapot appears to rock back and forth while its matte counterpart is perceived as rotating around a vertical axis – though both objects undergo the same rotation. Why is this so? We argue that the perceived axis of rotation of a moving object involves the integration of multiple sources of flow information. Flow from the object contour only (silhouette) can at best provide ambiguous information about an objects rotation axis and at worse give rise to non-rigid percepts. Supplementing contour flow with optic flow arising from the object's material should provide sufficient information to disambiguate the perceived rotation axis, however, flow patterns arising from moving matte textured objects are very different than those arising from specular ones. Here we argue that it is these differences in flow patterns which lead to the differences in perceived rotation axis in the above described phenomenon.

In this work we investigate systematically how 3D shape, contour and surface material contribute to the estimation of the rotation axis and direction of novel, irregular (Experiment I) and rotationally symmetric (Experiment II) objects. We analyze observers' patterns of errors in an orientation estimation task under four different shading conditions: Lambertian, specular, textured and silhouette (Examples: http://bilkent.edu.tr/~katja/orientation.html). Rotation axes were randomly sampled from the unit hemisphere.

Results show, as expected, largest errors for the silhouette condition in both experiments. However, the patterns of errors for the remaining shading conditions differ notably across experiments, yielding larger differences between shaders for the rotationally symmetric objects. We will describe how flow patterns predict these differences.

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62.16, *12:15 pm*

Veridical Perception of Non-rigid 3-D Shapes from Motion Cues

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Many objects in the world are non-rigid when they move. To identify such objects, a visual system has to separate shape changes from movements. Standard structure-from-motion schemes use rigidity assumptions, so are not applicable to these shapes. Computational solutions proposed for non-rigid shapes require additional constraints on form and motion. Despite an enormous literature on human perception of structure-from-motion, the ability of observers to correctly infer non-rigid 3-D shapes from motion cues has not been examined.

We examined whether the human visual system could make metric judgments about simple 3-D shapes using only motion cues, and if there was a difference in performance between rigid and non-rigid shapes.

Stimuli consisted of white dots randomly placed on an opaque black horizontal cylinder on a black background. The cylinder underwent simultaneous rotation about the vertical and depth axes (it did not spin on its own axis). The elliptical cross-section of the cylinder was varied from trial-to-trial and observers reported whether the cross-section was deeper or shallower than a perfect circle. The cylinder was either rigid or flexed non-rigidly in depth or in the fronto-parallel plane. The rigid central portion of the cylinder was occluded.

Observer's judgment of cross-section circularity was generally slightly shallower than veridical. The non-rigid cylinders were judged as deeper than rigid cylinders; however, the psychometric functions had similar slopes. Rotation in depth (about vertical axis) was critical, as 3D shape was not perceived with rotation only in the fronto-parallel plane. We compared human performance with existing computational models. Akhter et al.'s trajectory basis extension (2008) of Tomasi and Kanade's factorization method (1992) yielded cylindrical shapes similar to human judgments. Koenderink's def-based motion-flow analysis (1986) yielded slants and tilts that were consistent with cylindrical shapes. The human visual system thus does not require rigidity assumptions to extract veridical 3-D shapes from motion.

Acknowledgement: NIH Grants: EY13312 & EY07556

62.17, *12:30 pm*

Interactions between disparity, parallax and perspective: Linking 'Reverspectives', hollow masks and the apparent motion seen in random dot stereograms

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Background:Three different perceptual scenarios create the appearance of a rotating 3-D structure during observer motion: Patrick Hughes' 'Reverspective' artworks; hollow masks; and the disparate region of a random-dot stereogram. Papathomas (Spatial Vision 21, 2007) has offered a 'higher level' explanation of the three effects based the 'expected' optic flow while Rogers and Gyani (Perception, 2009, in press) have put forward a low-level explanation based on the properties of the stimulation. One problem in understanding these different effects, and their relationships, has been the difficulty of manipulating the variables involved. For example, the direction and amount of parallax motion is a fixed consequence of the particular 3-D structure used. Purpose: The present experiment was designed to independently manipulate (i) the direction and amount of motion parallax; as well as (ii) the binocular disparities; and (iii) the richness of the perspective information. In doing this, we created a continuum between 'reverspectives' (parallax appropriate for a convex 3-D structure); random dot stereograms (no parallax); and the hollow mask (parallax appropriate for a concave 3-D structure). Methods: A continuous sequence of images was generated depicting a particular 3-D structure seen from a series of different vantage points. The presentation of the sequence was linked to the observer's side-to-side head movements (observer-produced parallax). Results: When either perspective or disparities specified the 3-D structure, the structure appeared to rotate in a direction that was consistent with that information. Perspective information typically dominated over binocular disparities when the two were presented in conflict. Apparent rotation was consistent with a convex interpretation of ambiguous shading information although the effect reversed when disparities were introduced. Conclusions: There is nothing special about the particular scenarios that have been used previously. Rather, they represent particular points on a continuum of possible combinations of 3-D information. Moreover, there is no need to invoke 'higher-level' explanations.

Face perception: Social cognition

Wednesday, May 12, 11:00 - 12:30 pm
Talk Session, Royal Ballroom 4-5
Moderator: Roberto Caldara

62.21, *11:00 am*

Turning neutral to negative: subcortically processed angry faces influence valence decisions

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Fast, efficient detection of potential danger is critical to ensure the survival of an organism. In rodents, this ability is supported by subcortical structures that bypass slow but highly detailed cortical visual processing areas. Similarly, anatomical tracing and functional neuroimaging studies in human and non-human primates suggest that limbic structures responsible for emotional processing, such as the amygdala, receive input from the retina through subcortical structures, as well as through cortical visual areas. Whether outputs from this subcortical pathway can support perception of emotionally laden stimuli and influence cognitive-level decisions, independently of cortical input, is not known. Here we show that information delivered by the subcortical pathway to the amygdala modulates emotional processing. In Experiments 1 and 2, emotional faces were rendered invisible using an interocular suppression technique (Continuous Flash Suppression; CFS), that prevents visual information from reaching the amygdala via the geniculate-cortical pathway, favoring instead the use of subcortical structures. In these experiments, likeability judgments over novel neutral stimuli (Chinese characters) were modulated by invisible pictures of angry but not happy faces. In Experiment 3, the same emotional faces were rendered invisible through backward masking (BM). BM is a visual masking technique that allows visual information to reach inferior and ventro-temporal regions, which can then serve as afferents to the amygdala alongside subcortical afferents. In this experiment, happy and angry faces modulated the likeability judgments. This valence-specific effect fits well with the extant literature on the role of the amygdala in threat detection. It also suggests that subcortical processing may be specifically tuned to threat detection processes. The coarse information processed by the subcortical pathway from the retina to the amygdala may prevent potential threatening events from going unnoticed by enhancing arousal levels and directing attentional resources to areas of interest for further detailed geniculo-striate cortical processing.

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62.22, *11:15 am*

Laughter produces transient and sustained effects on the perception of facial expressions

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Laughter is a powerful auditory stimulus conveying positive emotion. Here we demonstrate that laughter modulates visual perception of facial expressions. We simultaneously presented a sound of a laughing child and a schematic face with a happy (upward-curved mouth) or sad (downward-curved mouth) expression. The emotional face was presented either alone or among a crowd of neutral faces with or without laughter. Participants indicated the valence and magnitude of the perceived expression by selecting a curved segment that most closely resembled the curvature of the mouth of the emotional face. In this way, we were able to measure how laughter influenced both the strength (mean perceived curvature) and tuning (standard deviation of perceived curvature) of the perception of happy and sad facial expressions. We found that when a single emotional face was presented, laughter enhanced the strength of a congruent happy expression. In contrast, when an emotional face was presented in a crowd of neutral faces, laughter enhanced the perceived signal strength of an incongruent sad face. These effects were transient in that they occurred on a trial-to-trial basis. Laughter also produced a sustained effect of selectively enhancing the reliability of perceiving happy faces on no-sound trials following laughter trials compared to a control block with no-sound trials only. These effects arise from interactive processing of auditory laughter and visual facial expression rather than from abstract semantic interactions because presenting the spoken word "laugh" instead of laughing sounds produced no effects. In summary, simultaneous laughter makes a single happy expression appear happier, but makes an incongruent sad expression stand out in a crowd; these opposite effects based on single versus multiple faces preclude response bias. Laughter also produces a sustained effect of fine-tuning the perception of happy faces. These results demonstrate multifaceted auditory-visual interactions in the processing of facial expressions.

Acknowledgement: NSF BCS 0643191, NIH R018197-02S1

62.23, *11:30 am*

Reverse correlation in temporal FACS space reveals diagnostic information during dynamic emotional expression classification

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Reverse correlation experiments have previously revealed the locations of facial features crucial for recognition of different emotional expressions, and related these features to brain electrophysiological activity [SchynsEtal07]. However, in social perception we expect the generation and encoding of communicative signals to share a common framework in the brain [SeyfarthCheney03] and neither 'Bubbles' [GosselinSchyns03] nor white noise based manipulation effectively target the input features underlying facial expression generation - the combined activation of sets of facial muscles over time. [CurioEtal06] propose a motion-retargeting method that controls the appearance of facial expression stimuli via a linear 3D Morphable Model [BlanzVetter99] composed of recorded Action Units (AUs). Each AU represents the surface deformation of the face, given the full activation of a particular muscle or muscle group taken from the FACS [EkmanFriesen79] system. The set of weighted linear combinations of AUs are hypothesised as a generative model for the set of typical facial movements for this actor.

Here we report the outcome of a facial emotion reverse correlation experiment with one such generative AU model over a space of temporally parameterized AU weights. On each trial, a random selection of between 1 and 5 AUs are selected. Random timecourses for selected AUs are generated according to 6 temporal parameters (see supplementary figure). The observer rates the stimulus for each of the 6 'universal emotions' on a continuous confidence scale from 0 to 1 and, from these ratings, optimal AU timecourses (timecourses whose temporal parameters maximize the expected rating for a given expression) are derived per expression and AU. These are then fed as weights into the AU model to reveal the feature dynamics associated with the expression. This method extends Bubbles and reverse correlation techniques to a relevant input space – one that makes explicit hypotheses about the temporal structure of diagnostic information.

Acknowledgement: The Economic and Social Research Council and Medical Research Council (ESRC/RES-060-25-0010)

62.24, *11:45 am*

Attenuation of the dorsal-action pathway suppresses fear prioritization: An evolutionary link between emotion and action

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It is widely thought that emotional facial expressions receive privileged neural status compared to their non-affective counterparts. This prioritization, however, comes at a cost, as the neural capacity of the human brain is finite; the prioritization of any one object comes at the expense of other concurrent objects in the visual array competing for awareness (Desimone & Duncan, 1995). Despite this reality, little work has examined the functional benefit derived from the perceptual prioritization of affective information. Why do we preferentially attend to emotional faces? According to evolutionary accounts, emotions originated as adaptations towards action, helping to prepare the organism for locomotion (Darwin, 1872; Frijda, 1986). To directly examine this relationship between emotion and action, we reasoned that the prioritization of affective events may occur via two parallel pathways originating from the retina - a parvocellular (P) pathway projecting to ventral stream structures responsible for object recognition, or a faster and phylogenetically older magnocellular (M) pathway projecting to dorsal stream structures responsible for localization and action. Here we tested whether the fast propagation along the dorsal-action pathway drives an accelerated conduction of fear-based content. We took advantage of the fact that retinal exposure to red diffuse light suppresses M cell neural activity. Using a visual prior entry procedure, accelerated stimulus perception was assessed while either suppressing the M pathway with red diffuse light, or leaving it unaffected with green diffuse light. We show that that the encoding of a fearful face is accelerated, but not when M-channel activity is suppressed. Additional control experiments confirmed that this affective prioritization is driven by coarse low spatial frequency information, and that red diffuse uniquely affects dorsal competition but not top-down ventral competition. Together, our results reveal a dissociation that implicates a privileged neural link between emotion and action that begins at the retina.

Acknowledgement: This work was supported by a Natural Science and Engineering Research Council of Canada grant to J.P. and a Canada graduate scholarship from the Natural Sciences and Engineering Research Council of Canada to G.L.W.

62.25, *12:00 pm*

The Speed of Race

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Race is a universal, socially constructed concept used to categorize humans originating from different geographical locations by salient physiognomic variations (i.e., skin tone, eye shape, etc.). Race is extracted quickly and effectively from faces and, interestingly, such visual categorization impacts upon face processing performance. Humans are noticeably better at recognizing faces from the same- compared to other-racial groups: the so-called other-race effect. This well-established phenomenon is paired with an intriguing paradox: a faster categorization by race of other-race faces. Yet, the visual information and the cortical correlates driving this speed categorization advantage for race remain unknown. To this end, we combined a parametric psychophysical approach with electrophysiological signals recorded from Westerners and Easterners observers performing face categorization by race. We removed external features and normalized the amplitude-spectra, luminance and contrast of all the faces to control for potential confounds that could arise from trivial physiognomic differences between faces of different races. Importantly, we also manipulated the quantity of information available for race categorization, by using a linear phase interpolation technique with 11 phase noise levels, ranging from 20% to 70% in 5% increments (see supplementary figure). Consistent with current knowledge, race did not modulate the face sensitive N170 component with 60% phase signals or above. Strikingly, however, other-race faces containing weak phase signals were categorized more accurately and induced larger amplitudes differences on the N170 (arising at 40%, peaking at 50%) in both groups of observers. In contrast, same-race faces showed gradual accuracy and gradual N170 sensitivity to the quantity of phase signal, suggesting a more effective coding of information. Our findings show early categorical perception of race in the visual cortex, allowing a speed advantage to the detriment of fine-grained information coding. The very early detection of race could relate to biologically relevant mechanisms that shape human social interactions.

Acknowledgement: The Economic and Social Research Council and Medical Research Council (ESRC/RES-060-25-0010)

62.26, *12:15 pm*

Internal Representations of Facial Expressions Reveal Cultural Diversity

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We recently (Jack et al., 2009) challenged one of the most widely held beliefs in psychological research – the universality of facial expressions of emotion. Merging behavioural and novel spatio-temporal eye movement analyses, we showed that East Asian (EA) observers decode expressions with a culture-specific strategy that is inadequate to reliably distinguish 'universal' expressions of 'Fear' and 'Disgust.' Using a model observer, we demonstrated that EA observers persistently sample ambiguous eye information, while neglecting the mouth, thereby systematically confusing 'Fear' with 'Surprise,' and 'Disgust' with 'Anger.' Our rejection of universality thus raises the question - how are facial expressions represented across cultures? To investigate, we reconstructed the internal representations of Western Caucasian (WC) and EA observers, using a reverse correlation technique. On each trial, we added white noise to a racially ambiguous neutral expression face, producing a perceptively different expressive face (Figure 1 in Supplemental Materials shows sample stimuli). We instructed 15 WC and 15 EA naïve observers to categorize stimuli (12,000 trials per observer) according to the 6 Ekman expressions (i.e., 'Happy,' 'Surprise,' 'Fear,' 'Disgust,' 'Anger' and 'Sad'). We then reconstructed the internal representations of each expression by summing the noise templates across tri-

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als before adding the neutral face (Figure 2 in Supplemental Materials illustrates the procedure; Figure 3 shows examples of reconstructed representations). Using complementary statistical image processing tools to examine the signal properties of the representations, we reveal that while certain expressive facial features are common across cultures (e.g., wide opened eyes for 'Surprise'), others are culture-specific (e.g., only WC observers showed the mouth for 'Surprise'). Furthermore, we show modified gaze direction is unique to EA observers (Figure 4 in Supplemental Materials shows examples). For the first time, our results demonstrate that culture shapes the representations of facial expressions, thereby refuting their universality as signals of human social communication.

Acknowledgement: The Economic and Social Research Council (ESRC) and Medical Research Council (MRC) (ESRC/RES-060-25-0010).

Wednesday Morning Posters

Scene perception: Aesthetics

Orchid Ballroom, Boards 401–409

Wednesday, May 12, 8:30 - 12:30 pm

63.401 Shot Structure and Visual Activity: The Evolution of Hollywood Film

Jordan DeLong[1](jed245@cornell.edu), Kaitlin Brunick[1], James Cutting[1]; [1]Psychology, Cornell University

Few stimuli can captivate human attention like a movie; young children and adults alike are drawn to the screen. Properties of film are able to engage viewer's attention for hours, but what is it about a movie that makes people stop and watch?

Recent research into Hollywood film has revealed a number of trends: the average shot length (ASL) in popular film has decreased while the overall running length of films has remained the same. Our current research into this change began by collecting and analyzing a database of over 150 popular Hollywood films ranging from 1935-2005. Utilizing a mixture of algorithmic cut detection and human confirmation, we were able to accurately find shot transitions for all 150 films. Power and autocorrelation analysis show that shots are not only becoming shorter over time, but the distribution of shot lengths exhibit a distribution that is approaching 1/f. This type of distribution is very similar to the endogenous rhythms found in human reaction times, and is thought to be due to temporal fluctuations in attention. We propose that film has evolved to interface with the rhythms of human attention, and by extension, the temporal structure of the world.

In addition to a changing shot distribution, the correlation of neighboring frames has decreased over the past 70 years. This can be explained as a gradual increase in the amount of visual activity: motion of scenes in front of the camera or movement of the camera itself. This change is evident in the modern Action and Adventure genres including recent "queasy-cam" films such as Cloverfield and The Bourne Ultimatum. These films, among others, exhibit just how fast-moving, and thus uncorrelated, frames in film have become. These trends in film raise questions about where the limits of visual attention are placed.

63.402 Video content modulates preferences for video enhancement

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In a study of image quality using local, adaptive, contrast enhancement, we noted and investigated how responses varied between subjects and varied with video content.

Forty normally sighted subjects made pair-wise comparisons of side-by-side views of HD video enhanced at four levels (off, low, medium, and high) by two PureAV RazorVision devices, each separately connected to one of two side-by-side 42" LCD HDTVs. We used logistic regression to derive Thurstone-like preference scales for the enhancement levels.

After each session subjects were asked to explain their preferences. Responses fell into two broad categories, with some subjects preferring enhanced video whereas others did not. This was reflected in their preference scales, which showed substantial, repeatable, individual differences. From each subject's comparisons of 64 video clips an enhancement preference score (EPS) was calculated. EPS was distributed bi-modally.

Subjects also indicated that video content was important to their enhancement preferences. Thus, in a post-hoc investigation of video content, we re-calculated EPS twice for each subject, once for videos that had primarily human faces, and second for videos with minimal face content ("non-face"). EPS differed between face and non-face videos, with less enhancement preferred for videos with substantial face content. This was true for most subjects (p=.005), and did not depend on whether subjects generally preferred enhancement or not.

Image quality measurement may be complicated by individual preference differences and by video content. This suggests that image quality metrics need to consider content and that a single model or computational metric for preferred image quality may not be representative of all viewers.

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63.403 Photo Forensics: How Reliable is the Visual System?

Hany Farid[1](farid@cs.dartmouth.edu), Mary Bravo[2]; [1]Computer Science, Dartmouth College, [2]Psychology, Rutgers University, Camden

In 1964, the Warren commission concluded that John F. Kennedy had been assassinated by Lee Harvey Oswald. This conclusion was based in part on the famous "backyard photograph" of Oswald holding a rifle and Marxist newspapers. A number of people, including Oswald himself, have claimed that the photograph was forged. These claims of forgery have been bolstered by what appear to inconsistencies in the lighting and shadows in the photo.

This is but one of several cases in which accusations of photographic inauthenticity have spawned national or international controversies and conflicts. Because these claims are often based on perceptual judgments of scene geometry, we have examined the ability of observers to make such judgments. To do this, we rendered scenes that were either internally consistent or internally inconsistent with respect to their shadows, reflections, or planar perspective distortions. We then asked 20 observers to judge the veridicality of the scenes. The observers were given unlimited viewing time and no feedback. Except for the most degenerate cases, performance was near chance, even though the information required to make these judgments was readily available in the scenes. We demonstrate the availability of this information by showing that straightforward computational methods can reliably discriminate between possible and impossible scenes.

We have used computational methods to also test the claims of inauthenticity made about the Oswald backyard photo. By constructing a 3D model of the scene, we show that the shadows in the photo are consistent with a single light source. Our psychophysical results suggest that the claims to the contrary arose because human observers are unable to reliably judge certain aspects of scene geometry. Accusations of photo inauthenticity based solely on a visual inspection should be treated with skepticism.

63.404 What velvet teaches us about 3D shape perception

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Humans are able to perceive a large variety of optical material properties. The shading patterns that convey these properties are used by painters to render e.g. a luxurious dining table with golden bowls and crystal glasses. Furthermore, painters have developed techniques to render the clothing material, e.g the velvet cape of Pope Leo X by Raphael. The shading trick that is often used to convey a velvet appearance is 'inverted Lambertian shading'. While for Lambertian shading the reflected light is highest at frontal illumination, the opposite holds for the hairy surface of velvet.

Whereas it seems easy to identify velvet objects in paintings, it is unknown how these shading patterns affect the perception of shape. On the basis of a computational model we predicted that if the velvet shading is (partly) interpreted as Lambertian, the perceived 3D shape should flatten in the viewing direction. This is indeed what we found in a previous study where we used computer rendered objects. In the present study we used 3D prints of those virtual objects and applied a Lambertian (matte spray paint) and velvet (flock) layer. Photographs of these objects were used in the experiment. We found a similar flattening effect of the velvet surface material. Furthermore, we analyzed the non-linear (second order) differences in perceived shape between reflectance properties (Lambertian and velvet) and between illumination conditions. Surprisingly, we found that the non-linear differences were larger between illumination conditions.

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The results show that real shapes show similar perceived shape deviations as the rendered shapes. This suggests that in both cases, shape perception seems to be affected by a Lambertian prior. Furthermore, the non-linear differences can be interpreted as a stronger shape constancy for different BRDFs than illumination conditions.

Acknowledgement: This work was supported by the Netherlands Organisation for Scientific Research (NWO) and EC FP7 Marie Curie IRG-239494

63.405 **Re-examination of methods for measuring pictorial balance perception using Japanese calligraphy**

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In art, pictorial balance is considered the primary principle that unifies elements of a perceived composition. Balance has the power to turn a random array of elements into a cohesive harmonious picture. The goal of this study was to investigate the role of pictorial balance in visual organization processing. Previous studies suggest that balance is perceived in a 50-100ms glance and serves to create a global image scan path, guiding observer gaze, selecting features for processing (Locher & Nagy, 1996). Individual scan paths depend on art training (Nodine et al.1993) and eye movements relate to visual aesthetics when viewing art (Locher et al. 2007). The Artistic Probabilistic Balance (APB) test (Wilson and Chatterjee 2005) is a computational balance assessment, based on the sum of area balance ratios across eight symmetry axes. APB values successfully matched subject balance ratings and preferences when tested with simple geometric images, without accounting for influences of grouping, training, gaze duration and memory. We now compare APB measures for sixteen Japanese calligraphic characters to results from two psychophysical experiments, using brief (200ms) masked presentation. In Experiment 1, subjects rated balance on the scale of 1-to-6 for Japanese characters presented in the left, center or right of the visual field. In Experiment 2, they rated relative balance in a 2-AFC paradigm for characters presented left/right of fixation. Results show high correlation between performances in different locations and between experiments, but low correlation with APB measures. We suggest a computational revision of APB, assigning different weights to the symmetry axes and adding contribution directionality. This revision revealed interesting orientation preferences in perceiving balance, which were confirmed in new rating experiments using stimuli presented in various rotations.

63.406 **Representational Fit in Position and Perspective: A Unified Aesthetic Account**

Jonathan S. Gardner[1](jonathansgardner@gmail.com), Stephen E. Palmer[1]; [1]Psychology Department, University of California, Berkeley

Previous research on aesthetic preference for spatial compositions has shown robust and systematic preferences for object locations within frames, such as the center bias, the inward bias, and various ecological biases (Palmer, Gardner, & Wickens, 2008; Gardner & Palmer, VSS-2006, VSS-2008, VSS-2009). These preferences can be dramatically altered, however, by changing contextual meaning through different titles for the same picture (Gardner & Palmer, VSS-2009). Perspective is a similar factor: People also prefer canonical perspectives (Palmer, Rosch, & Chase, 1981) when rating their aesthetic response to pictures of everyday objects (Khalil & McBeath, VSS-2006), but these preferences can also be shifted by changing the context through different titles. Our theoretical account of preference for the composition that best fits the context – which we call "representational fit" (Gardner & Palmer, VSS-2009) – can explain not only preferences in the "default" case, where the goal is simply to present the focal object(s) optimally in a way that best captures its most salient features (e.g., as in stock photography, see Gardner, Fowlkes, Nothelfer, and Palmer, VSS-2008), but also more nuanced and realistic cases in which there is a meaning associated with the image beyond its explicit image content. The current research examines several aspects of this preference for representational fit. People prefer non-standard compositions (with regard to position and/or perspective) more than standard compositions, so long as there is a context that justifies the unexpected composition. Put another way, there is greater artistic value in novelty and violating expectations, provided that the results are meaningful and coherent. These results provide strong evidence for representational fit as an aesthetic theory that unifies fluency accounts, where the default context prevails (Reber, Schwarz, & Winkielman, 2004), with classic aesthetic accounts in terms of novelty and violating expectations, where a nonstandard meaning is intended or inferred.

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63.407 **Aesthetics of Spatial Composition: Semantic Effects in Two-Object Pictures**

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Previous research on aesthetic response to spatial composition of simple pictures examined preferences for the horizontal position of single objects within a rectangular frame (Palmer, Gardner & Wickens, 2007). The results revealed a center bias for front-facing objects and an inward bias for left- or right-facing objects. The current studies examined aesthetic preferences for compositions containing two objects. Each picture contained one stationary object, whose position was fixed, and one movable object, whose position was adjusted by the participant to create the most aesthetically pleasing composition. The stationary object was presented at one of five equally-spaced locations along a horizontal axis. In the first experiment, four vertically symmetrical objects without a facing direction – two short, wide objects (sponge, cake) and two tall thin objects (plastic bottle of liquid dish soap, bottle of sparkling wine) – were presented in pairs consisting of one short, wide object and one tall, thin object. The center points of the preferred position for the movable objects were then binned to compute frequency histograms of their preferred positions. When the two objects were related (wine and cake or liquid soap and sponge), people generally placed the movable object close to the fixed object, whereas when they were unrelated (wine and sponge or liquid soap and cake), people generally placed the movable object far away from the fixed object. In a second study the same data were collected in a between-participants design – such that each participant saw only a single pair of objects – to control for possible demand characteristics arising from the same participant seeing both related and unrelated pairs of objects. The second experiment also assessed the effects of semantic relatedness on the preferred direction of facing.

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63.408 **Aesthetic Preferences in the Size of Images of Real-world Objects**

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In previous research, Konkle and Oliva (VSS-2009) found that the preferred visual size ("canonical size") of a picture of an object is proportional to the log of its known physical size: Small physical objects are preferred when their images are small within a frame and large physical objects are preferred when their images are large within a frame. They employed within-participant designs using multiple objects in several different tasks, including a perceptual preference task in which they asked participants to adjust the image size so that the object "looks best." Because of concerns about how the instructions were interpreted (is the image that "looks best" the one at which it "looks most like itself" or the one that is "most aesthetically pleasing") and possible demand characteristics (the same person seeing multiple objects of different sizes may implicitly feel pressured to make their relative sizes consistent), we studied image size effects on aesthetic judgments using a two-alternative forced-choice method in both within- and between-participant designs, asking them to choose the picture that you "like best." In Experiment 1, participants saw all possible pairs of images depicting the same object at six different sizes for twelve real-world objects that varied in physical size. Consistent with Konkle and Oliva's findings, participants preferred small objects to be smaller in the frame and large objects to be larger, regardless of whether they saw only a single object (the between-participant design) or all objects intermixed (the within-participant design). In Experiment 2, we examined whether this effect would still be evident if the amount of visual detail present at different sizes was equated by "posterizing" the images. Here the ecological bias toward relative size effects disappeared. Our findings indicate that multiple factors interact in determining aesthetic responses to images of different sizes.

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63.409 **Perceptual, semantic and affective dimensions of the experience of representational and abstract paintings**

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In this study we investigated the difference between representational and abstract paintings in judgments on three groups of subjective dimensions. All three groups of dimensions were specified in our previous factor analytic studies: (1) Perceptual dimensions Form, Color, Space, and Complexity, (2) Semantic dimensions Illusion-Construction of Reality (bipolar dimension), Expression, Ideology and Decoration, and (3) Affective dimensions Hedonic Tone, Arousal, Relaxation and Regularity. Each dimension was represented by three 7-step bipolar scales (perceptual and affective dimensions) or two 7-step unipolar scales (semantic dimensions). Two samples of paintings taken from our previous studies (18 representational and 18 abstract) were used as stimuli. Two groups of participants (N1= 30, N2 =30) judged either the representational or the abstract paintings. Participants completed three instruments, i.e. judged paintings on three sets of 7-step scales which corresponded to perceptual, semantic and affective dimensions. Results have shown that representational paintings were judged as significantly higher on the perceptual dimensions Form and Complexity, the semantic dimension Illusion of Reality (opposite pole of Construction of Reality), and the affective dimension Regularity. We had expected these differences because the representational paintings were made so to have relatively highly defined, precise, detailed and regular forms which could easily have been associated with objects in the physical world. Also, the abstract paintings are judged as higher on the perceptual dimension Color, semantic dimensions Expression and Construction of Reality (opposite pole of Illusion of Reality), and the affective dimension Arousal. All these differences reflect the basic characteristics of abstract art: abstract paintings are not created to represent anything from the physical reality, but to construct a new iconic world with intention to express the artist's emotions and to arouse the observer's mind. Color is one of the most effective artistic means which artists use to achieve these goals.

Color and light: Categories, culture and preferences

Orchid Ballroom, Boards 410–420

Wednesday, May 12, 8:30 - 12:30 pm

63.410 **What do we know about how humans choose grey levels for images?**

Marina Bloj[1](M.Bloj@brad.ac.uk), David Connah[2], Graham Finlayson[2]; [1]Bradford Optometry Colour and Lighting Lab, School of Life Sciences, University of Bradford, Bradford, BD7 1DP, UK , [2]Department of Computer Science, University of East Anglia, Norwich, NR4 7TJ, UK

From cave paintings that are more than 32000 years old to the work of current artists using charcoal or pastels humans have used different levels of a single colour (e.g. greyscales) to portray the colourful world that surrounds us. The aim of this study was to investigate how we construct these monochromatic images; do we choose the same relative order of grey levels as other people? How does image content and contrast influence our grey settings? For this purpose, we presented, on a calibrated CRT, 5 simplified cartoon-type colourful images. These images where shown in 4 different versions: two where the content of image was recognisable (one with added black outline around each object, the other without). In the other two versions each pixel in an image was grouped with other pixels of the same colour into rectangular areas in a way that made the content of image abstract while preserving the area taken up by a particular colour. One of these versions had a black outline around each colour area; the other did not. Six naïve, colour normal observers used a digital 're-colouring tool' to create greyscales version of the randomly presented colour images. Preliminary analyses of participants' settings for different version of the images indicate that the addition of black outlines does not seem to affect chosen grey levels. More surprisingly, the change in content from a recognisable scene to abstract rectangles also seems to leave grey levels un-changed. Although each individual's absolute settings were different, the overall ranking was largely preserved across participants for a given image. For our chosen set of test images, the most influential factor driving grey settings was the perceived lightness of the coloured patch, not image content or contrast.

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63.411 **Color categories and perceptual grouping**

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Studies of reaction times for color discrimination have found faster responses to differences between (e.g. blue vs. green) compared to within (e.g. two shades of blue) color categories (e.g. Gilbert et al. PNAS 2006). The between-category advantage is more prominent in the right visual field and is abolished by verbal interference, consistent with an effect of language on the perceptual response to color. We asked whether an effect of linguistic category might be manifest early, in the perceptual encoding of color, by measuring the influence of color on perceptual grouping, a task which did not require a speeded response. Stimuli were composed of 5 1-deg circles forming the corners and center of a 4-deg square centered 8-deg in the left or right field. Diagonal corners had the same color and differed from the opposite pair by a fixed hue angle of 30 deg in CIELAB. Absolute angle varied over a range spanning blue and green. For each, the center color was varied in a staircase to estimate the angle at which the two diagonals appeared equally salient. Interleaved settings measured the angle of the blue-green boundary for the center spot presented alone. For corner colors spanning blue and green, a strong categorical effect predicts that the point of subjective equality (PSE) should remain tied to the boundary angle. Instead, PSEs varied monotonically with corner color angles, and did not consistently differ between the right and left fields. Perceptual salience as measured by grouping thus showed little influence of linguistic category. These results are consistent with other recent measures pointing to a lack of categorical effects on color similarity judgments (Lindsey and Brown JOV 2009), and suggest that the influence of language on color could occur late, e.g. at the stage of response selection.

Acknowledgement: EY-10834

63.412 **Cross-Cultural Studies of Color Preferences: US, Japan, and Mexico**

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Consistent with Schloss and Palmer's (VSS-2009) Ecological Valence Theory (EVT) of color preference, 80% of the variance in average American preferences for 32 chromatic colors was explained by the Weighted Affective Valence Estimate (WAVE) of American preferences for the objects that are characteristically those colors. To test predictions of the EVT cross-culturally, corresponding color preferences and ecological WAVE measures were collected in Japan and Mexico for the same 32 colors. American participants showed a broad preference for cool over warm hues, an aversion to dark orange (brown) and dark yellow (olive), and greater preference for more saturated than less saturated colors. Japanese participants showed similar preferences for cool over warm colors, dislike for brown and olive, and high preference for saturated colors, but a greater preference for light colors (pastels) and a lesser preference for dark colors relative to Americans. Mexican participants showed the same aversion to brown and olive, but liked warm and cool colors about equally and tended to like both light and saturated colors less than American and Japanese participants. The WAVEs in each culture were computed from the results of the same three-part procedure: eliciting object descriptions for each of the 32 colors, rating the similarity of the presented color to the colors of the described objects, and rating the affective valence (degree of liking) of each described object. The WAVE for each color is the average valence over objects weighted by the average similarity of the given color to the described object. American WAVEs predict American preferences (r=.89) better than Japanese (r=.77) or Mexican preferences (r=.54). Similarly, Japanese WAVEs predict Japanese color preferences (r=.66) better than American preferences (r=.55) or Mexican preferences (r=.29). These findings are consistent with the EVT, which predicts that culturally specific WAVEs should predict within-culture preferences better than between-culture preferences.

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63.413 **The Color of Emotionally Expressive Faces**

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Schloss, Lawler, and Palmer (VSS-2008) investigated the relation between color and classical music by having participants select the 5 colors that "went best" (and, later, the 5 colors that "went worst") with 18 musical pieces from among the 37 colors of the Berkeley Color Project (Palmer & Schloss, submitted). They found that the emotional associations of the colors that were chosen for a particular musical selection were closely related to the emotional associations of that musical selection. They proposed that when people perform this task, they have an emotional response to the music and chose the colors that are most (or least) closely associated with those same emotions. In this study we used the same paradigm to test for analogous associations between colors and emotionally expressive faces. In the color-face task, the participants were presented with the entire array of 37 colors beside a photograph of a face that appeared happy, sad, angry, or calm to varying degrees. Their task was to choose the five colors that were most consistent with the face and (later) the five colors that were least consistent with the face. In the color-emotion task, the same participants rated the strength of association for each of 37 colors with three emotional dimensions: happy-sad, angry-contented, and strong-weak. In the face-emotion task, the same participants rated the strength of association for the faces along the same three emotional dimensions. Analogous to color-music associations, the emotional associations of the colors chosen to go with the faces were highly correlated with the emotional content of the faces. The results are consistent with the general hypothesis that associations between colors and stimuli that have clear emotional content (e.g., classical music and emotionally expressive faces) are mediated by emotion: People choose the colors that have the most similar emotional content.

Acknowledgement: National Science Foundation Grant BCS-0745820

63.414 **Is Object Color Memory Categorical?**

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Shape is considered the most important visual feature of objects but color can also aid in object recognition and naming. However, it is unclear how much color information is automatically encoded in visual long-term memory. What is the nature of color object memory? And if color is encoded in visual object memory, is it exact or categorical? We investigated these questions in 6 experiments with both color-diagnostic and non-color-diagnostic familiar objects and human faces. The experiments use a study task for object images followed by a perceptual 2-interval forced choice task between two shifted color versions of the same object image. Experiments 1 and 2 found a preference for shifted color images that stay within the original color category of a color-diagnostic object even if the color is more extreme. Experiment 2 found the same result as Experiment 1 without any study trials, which suggests color categories in object memory exist and that they are at least in part based on prior knowledge of object color. Experiments 3 and 4 demonstrated that color memory is influenced by both recent perceptual experience, such as the shifted color of a studied object, and by prior knowledge of the typical color of an object, which may be semantically mediated by object identity. Distance in color space was most important only when a color category boundary is crossed. Experiment 5 found evidence for categorical color memory for human faces and food, categories for which color is an important visual feature. Again categorical color memory seems to be strongest for these object classes, with some evidence for exact color memory. Experiment 6 found no evidence for exact or categorical color memory for non-color-diagnostic objects. Overall, we find that object color memory is categorical for objects for which color is an important diagnostic feature.

63.415 **The Good the Bad and the Ugly: Effects of Object Exposure on Color Preferences**

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Palmer and Schloss (submitted) proposed an Ecological Valence Theory (EVT) of color preferences, which states that color preferences are determined by individuals' emotional experiences with objects characteristically associated with those colors. An implication of the EVT is that an individual's color preferences change as he/she has new emotional experiences with colored objects. The present experiment tests whether exposing subjects to emotional objects of particular colors produces a reliable change in preferences for those colors. Participants first rated their color preferences for the 37 BCP colors. Half then completed four "spatial aesthetics" tasks in which they were exposed to positive green images (e.g., trees and grass) and negative red images (e.g., wounds and lesions), and the other half did the same with negative green images (e.g., slime and mold) and positive red images (e.g., berries and roses). Both groups also saw neutral objects of other colors. The "spatial aesthetics" tasks were designed to insure that participants had processed the content of the images: judging whether a verbal label was appropriate, clicking on the center of the focal objects, rating the complexity of the image, and rating their preference for the depicted object. Following these four tasks, participants rated their color preferences again, and difference scores were computed for the corresponding red and green colors. There was an interaction between the change in color preference and the images viewed: Those who saw positive images of a given color (either red or green) showed an increase in preference relative to those who saw negative images of the same color. These results provide causal evidence in support of the EVT by showing that exposure to (or priming of) emotional objects of a particular color can increase or decrease preference for that color, depending on the emotional valence of the objects.

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63.416 **Effects of school spirit on color preferences: Berkeley 's Blue-and-Gold vs. Stanford's Red-and-White**

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According to the Ecological Valence Theory (EVT), people's color preferences are determined by their average affective response to all "things" associated with those colors (Palmer & Schloss, submitted). Accordingly, preference for a color should increase with increasingly positive feelings for a strong associate of that color (e.g., one's university) and decrease with increasingly negative feelings about that same associate. We tested this prediction by comparing color preference ratings from Berkeley and Stanford undergraduates a few weeks before the intensely rivalrous "Big Game." The EVT predicts that students should like their own school colors more than their rival's school colors, and that the degree of preference for these colors should be related to their amount of school spirit. Berkeley and Stanford undergraduates, rated their preferences for 40 single colors (37 colors of the Berkeley Color Project plus Berkeley-blue, Berkeley-gold, and Stanford-red) and 42 figure-ground color pairs (all pair-wise permutations of Berkeley-blue, Berkeley-gold, Stanford-red, white, light-blue, dark-yellow and light-red). Participants then rated their degree of agreement with five statements designed to assess school spirit. Total school spirit scores from Berkeley and Stanford were combined into a single bipolar dimension by multiplying the Stanford scores by -1. For single colors, there was a significant positive correlation (r=0.44) between school spirit and the signed difference in preference (Berkeley-blue plus Berkeley-gold minus Stanford-red), showing that Berkeley students like blue and gold more than red, whereas Stanford students like red more than blue and gold. Preference for color pairs showed analogous effects: School spirit was significantly correlated with the difference in preference for pairs containing Berkeley's blue-and-gold and those containing Stanford's red-and-white (r=0.36). These results support the EVT by showing that positive feelings towards one's university promote higher preference for colors associated with that university than for colors associated with a rival university.

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63.417 **An Ecological Account of Individual Differences in Color Preferences**

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Schloss and Palmer (VSS-2009) reported that 80% of the variance in average color preferences for 32 chromatic colors by American participants was explained by an ecological measure of how much people like the objects that are characteristically those colors. The weighted affective valence

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estimate (WAVE), computed from the results of a multi-task procedure, outperformed three other models containing more free parameters. One group of participants described all objects that came to mind for each color, which were compiled into 222 categories of object descriptions. A second group rated how similar each presented color was to the color of each object described for that color. A third group rated their affective valences (positive-to-negative) for each object from its verbal description. The WAVE for each color is the average valence for each object, weighted by the rated similarity of the given color to the described object. The WAVEs were strongly correlated with average color preference ratings (r=.89). We now show that when WAVEs are calculated at the level of individual participants, they account for significantly more variance in the same individual's color preference ratings than do average WAVEs computed from the entire group. A new group of participants rated their preferences for all 32 colors, after which they provided their own idiosyncratic object descriptions for each color and rated their affective responses to them. They also rated their affective response to each of the 222 object descriptions provided by the original group. The correlation between the individual's color preferences and his/her individual WAVEs, computed from their personal ratings of the 222 object valences, proved to be reliably better than the fit of the group WAVEs, computed from the average affective ratings. Together, the cone-contrast model (Hurlbert & Ling, 2007) and the WAVE predictor explain 58% of the variance in individual participants.

Acknowledgement: NSF, Google

63.418 **Desaturated color scaling does not depend on color context: an MLDS experiment**

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Previous work showed that visual search for desaturated targets among heterogeneous arrays of white and saturated distractors, of the same hue as their target, is governed by low-level color-opponent responses (Kuzmova, VSS, 2008). Is this a local effect, involving mechanisms that directly process the color signals arising from the targets themselves? Or is it more complex, perhaps involving relatively global perceptual processes that are governed by their low-level inputs? To investigate this question, we asked whether the distractors in the original search experiment influenced the color appearance of the targets. We presented reddish test stimuli of varying saturation and lightness (including the target that was found fastest in the search experiment) and a similar range of tritan-purplish stimuli (including the slowest target), in three color-context conditions: (1) a mixed "distractor" set of 60 red and white squares, (2) a similar set of purple and white squares, and (3) no squares (just the dark surrounding field). We assessed the color appearance of test stimuli, as a function of saturation, using Maximum Likelihood Difference Scaling. Test stimuli fell at equal ΔE intervals, along two lines in CIELAB, passing through red (10 cd/m2) and white (50 cd/m2), and white and purple (9 cd/m2), respectively. Three subjects (two naïve) viewed randomly-selected quadruples of 1-deg. colored squares displayed in the center of a color CRT. On each trial, subjects judged whether the top or the bottom pair of test stimuli had the larger color difference. We found no systematic difference in scaled hue across the three color-context conditions. Thus, the distractors in the original search experiment apparently did not influence the color appearance of the target stimuli. This result reinforces our previous conclusion that visual search engages local, low-level color opponent channels when desaturated targets are embedded in heterogeneous distractor arrays.

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63.419 **Individual Differences in Preference for Harmony**

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Previous research has shown that individuals differ in the degree to which they prefer harmonious color pairs, as measured by the correlation between their ratings of preference for figure-ground color pairs and their ratings of harmony for the same color pairs (Schloss & Palmer, VSS-2007). In this study, we investigated whether individual preference for visually "harmonious" or internally coherent stimuli is consistent across different stimulus types. The stimuli used were: 35 images of a single dot at one of 35 positions inside a rectangular frame, 22 Garner-type 9-dot configurations, and 16 color pairs. All displays were chosen to span the full range of internal coherence possible within the given stimulus type. Twenty subjects were asked to rate aesthetic preferences for each stimulus on a computerized line-mark scale, and were later asked to rate the internal coherence of the same stimuli ("harmony" for color pairs, "goodness of fit" for dot-in-a-frame images, and "simplicity" for Garner dot patterns) using the same method. Subjects also completed the 44-question Big Five Inventory and the 40-question Sensation Seeking Scale. We found that individual subjects' preference for internally coherent stimuli (i.e., harmonious/good-fitting/simple displays) was strongly correlated across different stimulus types: r=.46 for color pairs and dot-in-a-frame images, r=.71 for color pairs and Garner dot patterns, and r=.49 for dot-in-a-frame images and Garner dot patterns). Somewhat surprisingly, the personality measures we examined were not significantly related to preference for harmonious stimuli. These results may indicate that there may be an underlying factor (aesthetic style?) connecting preference for harmony across visual stimulus types, and we are currently engaged in an expanded follow-up study using a larger number of color-pairs, quasi-randomly generated polygons that differ in the number of sides and degree of symmetry, and harmonious-to-dissonant solo piano music.

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63.420 **Adaptation and visual discomfort**

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Images with spatial or chromatic properties that are uncharacteristic of typical visual environments tend to be rated as less comfortable to view (Fernandez and Wilkins Perception 2007; Land et al. VSS 2009). This effect could reflect how visual responses are normalized for the image statistics that are routinely encountered in natural viewing. Here we examine whether short term exposure to modified statistics alters judgments of visual discomfort, to assess whether perceptions of discomfort can be recalibrated for the observer's ambient environment, and whether this adjustment reflects renormalization of perceived image qualities through a process like adaptation. Images consisted of a dense collage of overlapping rectangles of different colors (Mondrian patterns) that could be varied in their spatial (e.g. blurred or sharpened) or spectral (e.g. mean color and color and luminance contrast) properties. In further conditions we also explore the effects of prior adaptation on discomfort ratings for images of art that have been shown to be uncomfortable because they include excessive energy at medium spatial frequencies. Observers initially adapted to a rapidly changing sequence of images with a common attribute that would normally appear comfortable (e.g. focused) or uncomfortable (e.g. blurred). They then used 7-point scales to rate both the perceived discomfort and the aesthetic quality of a succession of test images (e.g. ranging from blurred to sharpened) that were each shown interleaved with periods of readaptation. Separate measurements also directly evaluated changes in the adapting attribute (e.g. perceived focus). Adaptation strongly changes the appearance of the images, and we use the changes in the ratings to assess the extent to which perceptions of both discomfort and aesthetics are tied through this adaptation to the average characteristics of the visual environment.

Acknowledgement: EY-10834

Attention: Brain and behavior II

Orchid Ballroom, Boards 421–430

Wednesday, May 12, 8:30 - 12:30 pm

63.421 **The spatial distribution of visual attention in early visual cortex**

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Purpose: Previous studies have suggested that in addition to the spatially specific enhancement of neural activity in early visual areas due to selective attention, there is a suppression of activity corresponding to regions surrounding the attentional target (e.g., Hopf et al, PNAS, 4, 1053-1058, 2004); the suppressive surround may be one source of the poorly understood "negative BOLD" effect often observed in visual cortex. We use high-resolution (1.4-mm) fMRI to measure the spatial distribution of activity within and surrounding an attentional target in early visual cortex. The experiments examine how attention affects this spatial distribution, and how the distribution is modulated by size of the attentional target. Methods: We compared responses in two conditions. In the attend-toward condition, subjects were sequentially cued to focus attention on one of four circular

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drifting-grating targets (each 1.2° diameter; 14-s period) arranged diagonally around the fixation point at an eccentricity of 2.75°. Subjects' task was to discriminate small changes in grating orientation of the cued target; task difficulty was adjusted continually to maintain performance. In the attend-away condition, subjects performed a fixation point task while the target orientations were orthogonally alternated (24-s period). In a separate localizer experiment we precisely mapped the region of cortex stimulated by the target using a blocked stimulus that alternated between target and surround. Results: Cue-driven responses are clearly evident and are maximal at the centers of each target, with targets subtending a diameter of ~3 mm on V1. Responses drop toward the edge of the target, eventually becoming negative between ~7—12 mm from the center. The magnitude and size of this negative-BOLD surround is modulated by attention. Measurements of target size effects are in progress. Discussion: Attention drives a negative surround around a visual target, where cortical activity is reduced below baseline.

63.422 **Interactions of sustained spatial attention and surround suppression: an SSVEP study**

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We employed steady-state visual evoked potentials (SSVEPs) to measure effects of sustained spatial attention on visual responses and their modulation by orientation-specific surround suppression. Displays contained a circular sinusoidal grating consisting of separate annulus and surround regions. Subjects continuously maintained fixation on a central square for 4.8 s while the contrast of the surround and annulus regions of the display reversed at 12.5 Hz and 16.67 Hz, respectively. In separate blocks, we manipulated spatial attention by instructing participants to detect a contrast decrement either within the target annulus or within the fixation square. Surround suppression of contrast discrimination performance was stronger when the annulus and surround had the same orientation compared to when they were orthogonally oriented. Fourier decomposition was used to separately measure response amplitudes at the surround and annulus frequencies. This analysis revealed distinct scalp topographies for annulus and surround portions of the stimuli, with maximal responses to the annulus at lateral occipital recording sites and maximal surround responses at posterior midline sites. Based on these topographies, sites of interest corresponding to annulus and surround responses were defined. We examined effects of both surround processing and spatial attention. First, orientation-specific modulation of SSVEP responses to the surround was positively correlated with behavioral orientation-specific surround suppression. This finding links neural responses to the surround with surround suppression of discriminability of the annulus. Second, sustained spatial attention exhibited different effects at annulus and surround sites. For annulus sites, attending to the annulus enhanced annulus responses. Furthermore, this enhancement was only observed when the annulus and surround shared the same orientation, corresponding to the condition in which behavioral surround suppression is strongest. For surround sites, attending to the annulus decreased surround responses. These results demonstrate attentional enhancement of responses to a task-relevant stimulus and reduction of responses to an ignored surround.

63.423 **Attentional modulation in perception of speed occurs in the first motion-processing stage**

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Recently, there have been studies indicating that attention does not only improve performance, but also alters subjective perception. Turatto, Vescovi and Valsecchi (2007) found this phenomenon in perception of speed, reporting that a moving grating presented in an attended position was perceived moving faster than when presented in a less attended position. In the present study, we investigated the stages of motion information processing to find where attentional modulation occurred. Motion information processing consists of a stage where local motion is detected, and a following stage where integration is done to generate perception of coherent motion. We presented plaid patterns that have the same coherent motion but different components and measured the alteration of plaids' speed perception. If the attention affects speed perception in the local motion detection stage, the amount of change in perceived speed by attention in each plaid should be different. On the other hand, in the case that the attention affects speed perception in the integration stage, there should be no difference between the changed speeds of each plaid. We used the cueing paradigm to manipulate the participants' attention. After a cue appeared in left or right of the fixation, two plaids were presented in both peripheral positions simultaneously. The participants' task was to report the plaid that appeared to move faster. As a result, it was showed that speeds of plaids were perceived faster in cued positions. We then calculated the amount of change in perceived speed of each plaid pattern and compared them, and found that the amount of changed speed differed between each plaid. These findings indicate that the alteration in perception of speed by attention occurs in the first stage of motion processing, which perform local motion detection.

63.424 **fMRI responses in human MT+ depend on task and not the attended surface**

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Previous neuroimaging studies show that the effects of attention on responses in the human visual cortex depend on the physical properties of an attended surface. For example, responses in MT+ have been shown to increase when attention is directed to a moving surface relative to a static surface. Separate studies demonstrate that responses in particular visual areas are also dependent on the task being performed. For example, responses in MT+ have been shown to increase during a speed discrimination task relative to color discrimination or shape discrimination tasks. We investigated the separable effects of the attended surface and task on responses throughout human visual cortex. Participants viewed two spatially overlapping but perceptually separable surfaces of dots, one continuously moving, and one nearly static. In alternating 20-second blocks composed of two-interval forced-choice trials, the participants attended to either the moving or the nearly static field, and performed either a speed discrimination task, or a color discrimination task. Consistent with previous findings, responses in early visual areas (V1-V3) did not depend on either the attended surface or the task being performed. However, responses in MT+ did vary with task, showing greater responses during speed discrimination than during color discrimination, but did not depend on whether a moving or a nearly static surface was being attended. The same pattern of responses was demonstrated in unstimulated areas of MT+ (contralateral hemisphere). The results suggest that overall task-dependent response modulation is independent of the physical properties of an attended surface.

63.425 **Feature binding signals in visual cortex**

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The contributions of visual cortex neurons to feature binding are not well understood. A central issue is distinguishing models of feature binding in which separate feature-coding neurons are linked together from models in which binding is done by neurons that explicitly encode feature conjunctions. Here, we measured brain responses with fMRI as subjects viewed an annulus containing colored, moving dots and detected the presence of target dots defined either by a single feature (color, or direction of motion), or by a conjunction of those features. Each trial consisted of a 500 millisecond stimulus presentation, followed by a one second response period. Data were acquired in a blocked design; the blocks contained 16 trials and were separated by 25 seconds of rest. Patterns of activity during the three conditions could be distinguished with machine learning algorithms, as early as V1. Analysis of the voxel-based weights output by the classification algorithm revealed that voxels informative for classification of the conjunction task were less informative for the feature tasks, and vice versa. In other words, when subjects searched for a feature conjunction (e.g. red and down), informative cortical locations were different than when subjects searched for the same color (red) or motion direction (down) separately. This result suggests that separate populations of neurons were activated during binding relative to feature detection. A whole-brain analysis revealed involvement of parietal cortex in binding, even though no task explicitly required shifts of spatial attention. Overall, these data are consistent with a feature binding mechanism sensitive to conjunction-coding neurons in early visual cortex.

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63.426 **Spatial cueing effects in perceptual decisions of humans, monkeys, and bees**

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Although the influence of predictive spatial cues on perceptual decisions has been studied in humans and monkeys, few studies have directly compared cueing effects across species (Bowman et al., 1993). Here, we investigate the effects of spatial cueing and its interaction with target detectability in a similarly structured paradigm across humans, monkeys, and bees and compare the results to a Bayesian ideal observer. Methods: Humans and monkeys participated in the same spatial two alternative forced choice task in which a Gaussian signal of varying detectability (SNRs=0, 2.7, 4.0) embedded in white noise had to be localized. Subjects indicated the target location by making a rapid eye movement towards it. Prior to the onset of the stimulus, a brief precue was presented indicating the target location with 75% accuracy. Bees were trained to fly to one of two boxes containing a target of colored cardboard. The distractor box contained a similar piece of cardboard with a color that varied in its discriminability from the target (e.g. blue/blue vs. blue/grey). A secondary black cardboard served as a cue and co-occurred with the target on 80% of the trials. Results: Cueing effects, defined as the difference in proportion correct for validly and invalidly cued trials, were present for all three species but less than those predicted by an optimal Bayesian observer. These effects were comparable for humans and monkeys, but smaller for bees. However, consistent with ideal observer predictions, cueing effects increased with decreasing detectability of the target for all three organisms. Conclusions: Our results show that the influence of spatial cues on perceptual decisions is pervasive across species. The modulation of the cueing effect with signal strength for all three organisms is consistent with a Bayesian mechanism whereby sensory data are weighted by prior probabilities.

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63.427 **Gaze position-dependent modulation of the primary visual cortex from the eye proprioceptive representation – an offline TMS-fMRI study**

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Planned eye movements produce involuntary shifts in attention. The recent discovery of a proprioceptive eye position signal in the somatosensory cortex (Wang&al., 2007; Balslev&Miall, 2008) prompts the question whether static eye position, too, can affect visual attention. TMS over the left somatosensory cortex targets the eye proprioceptive representation, causing an underestimation of the gaze angle of the right eye (Balslev&Miall, 2008) and a pseudo-neglect for visual targets presented far versus near the perceived direction of gaze despite their equal retinal eccentricity. Namely when right eye was rotated leftwards and TMS shifted perceived eye position rightwards, visual detection increased in the right visual field and decreased in the left. When the right eye was rotated rightwards and TMS assumingly produced an underestimation of this rotation shifting perceived eye position leftwards, visual detection decreased in the right hemifield (Balslev, Gowen&Miall, unpublished). Here we used fMRI before and after rTMS over the left somatosensory cortex or motor cortex control area to investigate whether the eye proprioceptive representation is functionally connected to the visual cortex. Participants (n=11) fixated their right eye on a cross located on the screen at either to the left or right of the sagittal plane through the right eye. Visual targets appeared to the left or right of fixation at equal retinal eccentricity. In line with our behavioral results, somatosensory TMS significantly increased neural activity in a right parieto-occipital cluster (cluster $p<0.05$, corrected) in response to visual targets presented near vs. far the perceived direction of gaze. The peak voxel of this cluster was in Brodmann's area 17/18. This change in activity was specific for somatosensory TMS and was not found after TMS over a motor cortex control area. We suggest that static eye position signal influences the spatial distribution of visual processing resources by modulating visual cortex activity.

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63.428 **Timing of attentional selection in frontal eye field and event-related potentials over visual cortex during pop-out search**

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Attentional deployment during visual search is controlled by a distributed network of brain areas including the frontal eye field (FEF). When search is inefficient (e.g., searching for a T among rotated L's) visual activity in FEF selects the target location before the macaque homologue of the N2pc (m-N2pc), a component of the event-related potential (ERP) indexing attentional selection. However, during pop-out search tasks (e.g., a green target among red distractors) it has been proposed that bottom-up processing is sufficient to perform the task and the focusing of attention is unnecessary. While monkeys performed a color pop-out search task, we simultaneously recorded spikes from individual neurons in the FEF along with FEF local-field potentials (LFPs) and ERPs over lateral visual cortex. As expected, saccadic response time and the time of target selection for all neural signals did not vary with the set size of the array. Contrary to proposals that pop-out search tasks are performed in the absence of top-down attentional guidance, the target was selected earliest by the FEF neurons, next in the FEF LFPs, and latest in the m-N2pc. These results suggest that feedback from attentional control structures like FEF is involved in generating the macaque homologue of the human N2pc component and that the temporal cascade of selective activity is similar for both efficient and inefficient search tasks.

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63.429 **Timings of attentional "disengagement" and "reengagement" estimated with steady-state visual evoked potential**

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[Purpose] There are three processes involved in an attentional shift: "disengagement" from the previous location, "movement" to, and "reengagement" on a new location. These processes are thought to be executed in serial order. The purpose of this study was to estimate the timings of "disengagement" and "reengagement" of attention from steady-state visual evoked potential (SSVEP). SSVEP is an oscillatory brain potential evoked by a continuously flickering stimulation and it has been shown that the attention modulates the amplitude and phase of the SSVEP. [Experiment] We recorded SSVEPs for two stimuli flickered at different temporal frequencies which were presented on the left and right sides of the fixation. Participants were instructed to either (1) stay their attentional focus on the same stimulus, or (2) shift attention toward the opposite side of the stimulus after the presentation of flashing cue adjacent to either of the stimulus. We measured the time course of SSVEP modulation under the two conditions: the condition where attention is kept on the stimulus throughout the trial and the condition where attention is shifted away at a certain time during the trial. From the time course data, we estimated latencies for the onsets of the disengagement and the reengagement of attention. [Results] The estimation of the timing of disengagement and that of reengagement showed that the attentional modulation of SSVEP involved in the reengagement process is faster in time than that involved in the disengagement process. This suggests that the two processes relating to attentional shifts are executed in parallel in the human brain, rather than that attention shifts from one location to the next in the serial processes.

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63.430 **Control of memory-driven attentional bias in selective attention: Electrophysiological evidence**

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There is some evidence that visual working memory can bias selective attention by providing a competitive advantage to sensory inputs that match the contents of visual working memory. However, it is unclear whether this process is automatic or can be flexibly controlled. The present study investigated this issue by using ERP recordings, focusing on N2pc (a measure of attentional deployment) and Pd (a measure of attentional suppression). Participants were instructed to memorize the orientation of

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a colored rectangle in a memory array, and memory was tested at the end of the trial by a test array. In Experiment 1, task-irrelevant circles (probe stimuli) were briefly presented between the memory and test arrays. We found that the task-irrelevant circles matching the color of the rectangle in memory did not elicit N2pc but instead elicited Pd. This suggests that the item matching memory was detected but was suppressed before attention could be captured by it. In Experiment 2, a search-target square was presented on 50% of the trials between the memory and test arrays, requiring a button-press response. In the other 50% of the trials, task-irrelevant circles were presented, as in Experiment 1. We found that the target square elicited an N2pc, and N2pc onset latency was earlier if the target matched the color being held in visual working memory. In contrast, the task-irrelevant circles again elicited Pd if they matched the color being held in visual working memory. These results suggest that sensory inputs matching the contents of visual working memory are detected and have an advantage in competing for attention, but these inputs can be either suppressed or facilitated depending on task demands. Thus, items that match memory automatically receive priority for attention, but the actual deployment of attention is flexibly controlled by top-down factors.

Attention: Features and objects

Orchid Ballroom, Boards 431–449

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63.431 Multi-level neural mechanisms of object-based attention

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We used fMRI in conjunction with pattern classification to characterize the neural mechanisms responsible for the attentional selection of complex objects. Stimuli consisted of single faces, single houses, and blended images in which the two images were spatially overlapping. Observers performed a same/different discrimination task involving pairs of sequential stimuli. In the blend condition, observers performed the discrimination task for one object type, which required attending selectively to either faces or houses while ignoring the other object type. Functional activity patterns from individual visual areas (V1-V4, fusiform face area, and parahippocampal place area) were used to train a linear classifier to predict the object category that was seen or attended on independent fMRI test blocks. Activity patterns in both high-level object areas and low-level retinotopic areas could accurately distinguish between single faces and houses. More importantly, activity in these areas could reliably distinguish the target of attentional selection in the blended stimulus condition, across all visual areas tested. When classifiers trained on single object conditions were used to predict the attended object category in the blended condition, decoding performance was high across all areas indicating wide-ranging effects of object-based attention. Furthermore, block-by-block analysis of the strength of the object-specific attentional bias revealed a strong correlation between bias signals in object-selective areas and low-level areas. Finally, the object-specific activity patterns found for attended upright objects could effectively generalize to cases when the same object classes were viewed upside down. Results indicate that an object-selection mechanism involves a multi-level bias modulating diverse feature responses throughout the visual pathway. Selecting one of two overlapping objects involves widespread biasing of cortical activity, resulting in activity patterns that resemble the target object viewed in isolation. Such attentional filtering may be essential for flexible efficient processing in crowded and complex real-world visual settings.

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63.432 Object-Based Attentional Selection is Affected by Visual Search Strategy

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Object-based selective attention is often assumed to spread automatically throughout any object to which attention is cued. However, Shomstein and Yantis (2002, 2004) reported that object-based attentional modulation arises only when the target location is uncertain, suggesting that attention is deployed only to behaviorally relevant locations on the objects. In a previous presentation (VSS, 2006) we extended these findings by showing that contingent attentional capture (Folk et al, 1992) is object-based only when target location is uncertain. Here we examined the role of visual search strategy in object-based attention. Displays contained two rectangles with 5 RSVP streams (one at fixation and one at each end of the two objects). The four peripheral streams contained all gray letters and the central stream was either all gray (Experiment 1) or multicolored (Experiment 2). Subjects were aware that the central stream contained a red target letter (or green for half the subjects) on each trial, which they were to identify. One or two frames prior to target onset, a target-colored or nontarget-colored distracter could appear in one of the peripheral RSVP streams (same or different rectangle). Robust contingent capture was observed in both experiments, but its magnitude differed for distracters on the same versus different objects only in Experiment 1. Furthermore, performance on nontarget-colored distracter trials suggested that subjects used a temporal Singleton Detection Mode (SDM) to detect targets in Experiment 1 and Feature Search Mode (FSM) in Experiment 2 (Bacon & Egeth, 1994). Because FSM requires a more specific definition of the target-defining feature than does SDM, the present data show that uncertainty in the target-defining feature (here, during SDM) can evoke object-based attentional modulation, even when target location is certain. Thus, a more general principle of target uncertainty may guide the allocation of attention to objects.

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63.433 When two objects are easier than one: Effects of object occlusion

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According to theories of "object-based attention", it should be easier to divide attention between two attributes of one object, than between two attributes of two different objects. However, some studies find that two attributes can be compared faster when on separate objects than when on the same object (e.g., Burnham & Neill, 2006; Cepeda & Kramer, 1999; Davis & Holmes, 2005). This effect appears to occur when the whole objects can be compared more easily than component parts (Neill, Li & Seror, 2009). The present experiments investigate whether between-object superiority (BOS) can occur for partially obscured objects, via amodal completion. In the first experiment, subjects judged small notches in the ends of one or two rectangular "objects" as same or different in shape (rectangular and/or triangular). The spatial separation between the notches was equal for within- and between-object presentations. A third perpendicular object appeared to partially occlude either (a) both target objects, (b) only one target object, or (c) neither target object. Reaction times showed BOS if neither object was occluded, and also a smaller but significant effect when only one object was occluded. Surprisingly, there was no within- vs. between-object difference when both objects were partially occluded. The results suggest that BOS can occur for partially occluded objects, but amodal completion may only occur for an occluded object if cued by a non-occluded object. Follow-up experiments investigate the effects of intra-list and intra-trial cueing of amodal completion on between-object superiority. Implications for theories of object-based attention will be discussed.

63.434 The Role of Surface Feature and Spatiotemporal Continuity in Object-Based Inhibition of Return

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How is object correspondence established across dynamic changes in the world so that objects are treated as continuous entities? Correspondence could be established by spatiotemporal continuity or by surface feature continuity. We examined the relative contributions of surface feature and spatiotemporal information to object correspondence, within the context of object-based inhibition of return (IOR). In contrast to previous paradigms that depended on conscious report to assess object correspondence, object-based IOR assesses correspondence implicitly by measuring the efficiency of orienting to a previously attended object. In the present experiments, one of two colored array objects was cued, the objects moved to new locations, and participants executed a saccade to either the previously attended or unattended object. We systematically manipulated the objects' surface feature and spatiotemporal properties to measure the relative contributions of both sources of information to object correspondence. In Experiments 1 and 2, we kept spatiotemporal information consistent but either changed the objects' colors to new values (Experiment 1) or swapped the objects' colors (Experiment 2) during the change in spatial position. Object-based IOR was observed despite a color change in Experiment 1 but was eliminated in Experiment 2 when the objects switched surface features, demonstrating that surface feature continuity contributes to object correspondence in IOR. In Experiment 3, we kept surface feature information consistent but eliminated spatiotemporal continuity by removing the linking motion between the original and updated locations. Surface feature continuity was not sufficient to support object-based IOR in the presence of this type of salient spatiotemporal discontinuity. These data indicate that, contrary to the classic view that only spatiotemporal information drives correspondence operations, object persistence in dynamic displays is also computed on the basis of surface feature continuity. However, spatiotemporal features may be weighted more heavily than surface features in this paradigm.

63.435 **Attentional control settings can be object-based**

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We are able to guide attentional selection toward features that are relevant to our current goals. Recent work shows that independent features can be preferentially selected in independent locations of the visual field (Adamo, Pun, Pratt, & Ferber, 2008). The present study demonstrates that our ability to control attentional selection is even more sophisticated, such that we can select for different features of different objects, even when those objects share the same spatial location. To test whether or not participants could hold separate attentional control settings for objects that occupy essentially the same spatial region, participants viewed two object outlines (a horizontal and a vertical rectangle) that between conditions were either spatially separated or overlapped in space. Participants were instructed to press a key whenever a target color was presented within a specific rectangle, such as green within the horizontal object, or blue within the vertical object. Before the target appeared, one outline was cued with either green or blue. This cue could match the color, orientation, or both color and orientation of the subsequent stimulus. For spatially separated objects, results confirmed past results showing independent control settings for objects at different locations (Adamo et. al., 2008). Moreover, the effect was equally strong (if not stronger) when the object overlapped in space, suggesting that observers can form complex attentional control settings for different objects, even when those objects appear at the same location. A control experiment showed that this effect was not due to simple visual or response priming following a compatible cue. We suggest that these control settings are determined by the contents of visual working memory. That is, simultaneously storing the attentional control settings for "horizontal/green" and "vertical/blue" may require a memory representation of a horizontal green and a vertical blue object.

63.436 **Studying Object-Based Attention with a Steady/Pulsed-Pedestal Paradigm**

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The steady/pulsed-pedestal paradigm has been shown to be an effective manipulation of relative magnocellular (M) and parvocellular (P) activity (e.g., Leonova, Pokorny, & Smith, 2003; McAnany & Levine, 2007). However, this manipulation has primarily been used with contrast sensitivity measures. The purposes of the present study were to evaluate the effectiveness of this manipulation using a simple reaction time (RT) measure and then test previous findings showing specific influences on space- and object-based attention under M- and P-biased conditions. Cuing studies investigating object-based attention have shown the cost for shifting attention within an object is less than equidistant shifts between two objects (object advantage = within-object RTs <between-object RTs). We previously reported this object advantage is eliminated under equiluminant (P-biased) conditions because of increased within-object RTs (Boyd, Guenther, & Brown, VSS 2007). The first experiment measured simple RTs to a square target presented at center screen on a square pedestal (20% catch trials) to see if the pulsed-pedestal would cause increased RTs expected from P-biased conditions. The steady/pulsed-pedestal manipulation produced reliable differences in RTs consistent with M- and P-biased conditions with overall RTs longer for the pulsed (P-biased) compared to the steady (M-biased) pedestal condition. A second experiment tested for an object advantage using pairs of rectangular bars (tilted 45° left or right of vertical) as objects. Again overall RTs were greater for pulsed compared to steady pedestal conditions. A similar magnitude validity effect (valid RTs <invalid RTs) was found for both conditions indicating that, in general, the pulsed condition did not interfere with shifting attention. However, the pulsed condition had a greater influence on RTs for within- compared to between-object shifts. Similar to our previous study, RTs for within-object shifts increased for P-biased conditions eliminating the object advantage.

63.437 **The time course of space- and object-based attentional prioritization**

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Previous studies suggest that object-based effects are the product of attentional prioritization (Shomstein & Yantis, 2002, 2004; Drummond & Shomstein, 2008). What remains unclear, however, is whether prioritization enhances spatial locations (i.e., space-based representations) or surfaces that occupy them (i.e., object-based representations), and what effect target location certainty has on attentional allocation. In a traditional two-rectangle paradigm, the space- and object-based reference frames overlap, and therefore it is not known which representation is prioritized, or if both reference frames are prioritized to the same degree. To investigate the effects of prioritization on these representations, we used a dynamic display in which, following a spatial cue, the rectangles rotated 180º. The target then appeared either in the cued spatial location, in the same- or different-object location, or in the cued object location. This manipulation successfully separated the spatial and object reference frames by creating non-matching spatial and object locations (Becker and Egeth, 2000). To examine the time course of attentional prioritization, space-based, object-based, and cued object effects were sampled at six SOAs, ranging from 200ms to 1500ms. Space-based effects exhibited a benefit at the shortest SOA, followed by an inhibition of return (IOR). The effect size was significantly reduced as compared to static displays, suggesting that spatial prioritization and object prioritization have an over-additive relationship. We found no object-based effects at any of the SOAs. Instead, only the cued object location received the benefit of prioritization (after 200ms), much the way certainty allows for prioritization of only the target location in static displays (in both cases, no object-based effects were present). The observed pattern of results indicates that attention tracks the cued object location through the rotation, eliminating the influence of whole objects and thereby eliminating object-based effects. Taken together these results place further constraints on the mechanisms of attentional allocation.

63.438 **How does a subliminal cue influence object-based attention?**

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Mulckhuyse, Talsma, and Theeuwes (2007) have shown that a subliminal cue can capture attention to its location. In this study we investigated whether this kind of subliminal cue can cause object-based selection. According to the spreading hypothesis of object-based attention (e.g., Richard, Lee, & Vecera, 2008), a subliminal cue that can successfully capture attention to a specific location within an object should also cause attention to spread throughout the whole cued object. By adopting the two-rectangle method (Egly, Driver, & Rafal, 1994) and using an effective subliminal cue as in Mulckhuyse et al. (2007), we tested whether the same-object advantage (i.e., faster response to a target within a cued object than within a non-cued object) can be obtained as with the classic supra-threshold cue. The subliminal cue was a small patch appearing in one corner of the two rectangles, presented 16 ms earlier than the other patches shown in the other three corners, giving the impression that all four patches appeared simultaneously. Objective and subjective measures both indicated that participants were indeed unaware of the cue. We found that subliminal and supra-threshold cues caused different result patterns: a subliminal cue led to the different-object advantage, and the supra-threshold cue replicated the conventional same-object advantage. The fact that the subliminal cue did not lead to the same object advantage is inconsistent with the spreading hypothesis. Instead, we propose that a subliminal cue strengthens between-object links, which are coded primarily within the magnocellular to dorsal pathway that governs the visual guidance of action (e.g., Davis & Holmes, 2005; Humphreys, 1998).

63.439 **Effect of Feature-Based Cueing on Perceptual Experience**

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A growing body of research has shown that spatial attention alters stimulus appearance on a number of dimensions including contrast (Carrasco, Ling, & Read, 2004), spatial resolution (Gobell & Carrasco, 2005), and size (Anton-Erxleben, Henrich, & Treue, 2007). Here we explored whether feature-based attention would also influence perceived spatial resolution, and whether its influence would mirror that of spatial attention. Each trial began with a brief presentation of a colored cue in order to direct feature-based attention to that cue's color. Following the cue presentation, a stimulus display was presented consisting of two differently-colored Landolt squares—one of which matched the cue color on 66% of the trials. Participants performed a two-alternative forced-choice discrimination task requiring them to provide a response indicating which of the two Landolt squares possessed the larger gap. Our results suggested that the effect of feature-based attention on perceptual experience may be different than that of spatial attention.

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63.440 Feature-based attention enhances motion processing during dominance and suppression in binocular rivalry

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Goal. Feature-based attention enhances the neuronal and perceptual representation of consciously perceived visual objects. But can feature-based attention also modulate responses to stimulus properties we are unaware of? Here we use binocular rivalry flash suppression to compare the effects of feature-based attention on perceptual and eye movement responses to visual motion in the presence and absence of visual awareness. Method. Stimuli were two orthogonally oriented, leftward or downward moving sine-wave gratings presented separately to each eye through a stereoscope. We used binocular rivalry flash suppression to manipulate stimulus visibility, rendering one stimulus dominant and the other suppressed. In each trial, the speed of either the dominant or suppressed stimulus briefly increased or decreased for 50 ms. Attention was directed to either leftward or downward motion by a 75%-valid arrow cue. In two judgments observers indicated (1) whether the speed change was an increment or decrement and (2) their perceived motion direction. Eye movements were recorded throughout each trial. Results. Feature-based attention affected (1) speed discrimination and (2) motion processing. (1) Performance in the speed change discrimination task was better for the dominant than suppressed stimulus. It was also better for attended than for unattended stimuli, regardless of whether the stimulus was dominant or suppressed. These findings indicate that observers successfully deployed attention to either leftward or downward motion. (2) When the suppressed stimulus was attended, perceptual and eye movement responses were shifted towards the motion direction of the suppressed stimulus. This study therefore shows that feature-based attention can affect motion processing as assessed by perception and eye movements, even when a stimulus is substantially weakened through binocular rivalry.

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63.441 Measuring the spatial spread of feature-based attention to orientation

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Goal: Feature-based attention (FBA) enhances the processing of stimuli that are spatially coextensive with distractors that must be ignored. For some feature dimensions (e.g., color and motion), FBA increases sensitivity to the feature value that distinguishes the target – both at the target location and, remarkably, at ignored or unstimulated locations across the visual field. Several studies have demonstrated location-specific effects of attention to an oriented target that overlaps with a differently-tilted distractor, but there is little evidence for a spatial spread of orientation-based attention.

Methods: We developed a novel psychophysical paradigm to measure the spread of orientation-based attention to peripheral locations where the attended feature is irrelevant. At the center of the display, a group of leftward tilted white lines overlapped with a group of rightward tilted white lines. Each of these groups pulsed in luminance at random times throughout the trial. The primary task was to count the number of pulses in one orientation while ignoring the other. Also present in the display were groups of non-overlapping lines arranged in an annulus at 4.5° eccentricity. Half of these groups were tilted leftwards and half rightwards, and, independently, half were red and half green. Once per trial, a randomly selected peripheral group pulsed in luminance, and the observers' secondary task was to report its color. Importantly, that group's orientation was not correlated with the orientation of the central target.

Results: Performance in the secondary task was better when the peripheral target's orientation matched the orientation attended at fixation. Thus, heightened sensitivity to the attended orientation spread to peripheral locations where observers were not instructed to selectively attend and where doing so conferred no advantage. This new paradigm also allows us to investigate the spatial and temporal limits of the involuntary spread of FBA.

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63.442 The spread of attention across features of a surface

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Question Does attending to a single feature within a surface facilitate perceptual judgments about other features of that surface? Methods Stimuli were composed of two superimposed fields of dots, each associated with a color and a direction of motion. For each surface, each feature changed slowly and independently along a smooth trajectory. Surfaces thus were defined by time-varying conjunctions of motion and color in feature space. While fixating, observers tracked a single feature (color or motion) of one of the two surfaces and reported discontinuities along its trajectory with button presses. Each trial lasted 10 s and contained 0-3 such discontinuities per field. On approximately 70 percent of the trials, a single discontinuity was also introduced in the untracked feature of either surface with equal probability. At the end of a trial the number of misses and false alarms were provided, and a 3AFC paradigm was used to assess whether observers detected a discontinuity in an untracked feature, and if so in which surface. Results Observers were better at detecting discontinuities in the untracked feature when it occurred in the tracked surface compared to the untracked surface. For example, while tracking the motion of one surface, subjects were better at detecting color discontinuities in that surface compared to color discontinuities in the other surface. Conclusion Our results suggest that attending to a feature of a surface recruits attentional mechanisms associated with other features of that surface. Our preliminary results using fMRI suggest that this feature-tracking task may lead to enhanced modulation of hemodynamic responses associated with multiple features of an attended surface.

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63.443 Feature Exchange: the unstable contribution of features in the maintenance of objects moving along ambiguous trajectories

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We introduce a novel visual phenomenon in which two objects traversing distinct motion trajectories seemingly "exchange" their defining features with each other. We demonstrate feature exchange using an ambiguous motion display in which the motion of two translating objects is consistent with the objects colliding or passing through each other (Metzger 1938). We observe that when the two objects have different features (e.g., color, textures, orientations, size, faces), collisions may still be perceived, but the features appear to un-bind from one object and bind to the other. The un-binding and re-binding of the features is quite compelling and occurs with both simple (color, size) and complex (texture, faces) features. This dissociation of feature information and motion trajectory suggests a limited (perhaps non-existent) role of feature information in the spatiotemporal maintenance of object representations. In a series of psychophysical experiments, we use the occurrence of feature exchange as an empirical tool for testing this hypothesis. Methods: Observers reported whether they perceived a pass-through or collision when presented with displays in which the two objects were defined by either the same feature or by one or more different features. We compared the percentage of reported collisions on same-feature and different-feature trials. Results: Although collisions were reported when the two objects differed on one or more feature dimensions (feature exchange), the percentage of these trials was smaller than when the two objects were defined by the same features. Conclusions: Although the existence of feature exchange demonstrates that the features do not fully mediate, they do contribute to, the spatiotemporal maintenance of object representations. Feature exchange depends critically on stimulus parameters, such as contrast relative to the background, differences in relative size of the objects, and whether or not the objects overlap at the point of collision.

63.444 **Global feature-based attention distorts feature space**

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Selective visual attention is generally conceptualized to control the flow of information with respect to the task at hand. Various studies in the space-based and feature-based domain have demonstrated that the visual system achieves this via gain-control mechanisms. These mechanisms are supposed to result in an enhanced neural representation of relevant stimuli or features while irrelevant ones are suppressed. For example, attending to a specific direction of motion results in an enhanced response of those neurons whose tuning characteristics match with the attended direction, while neurons which prefer the opposite direction are inhibited. However, some models predict that attention can alter the perceived feature as well (e.g. Hamker, Adv. Cogn. Psychol., 2007).

Our study provides psychophysical evidence that global feature-based attention does indeed not simply result in a more salient representation of attended features, but that global feature-based attention is able to dynamically alter the entity of an encoded stimulus in feature space.

While subjects attended to the direction of a target random-dot kinematogram (RDK) presented in one hemisphere, another adaptor RDK was presented in the opposite hemisphere. After a certain time, subjects indicated the direction of the perceived motion aftereffect of the unattended adaptor RDK. We observed that directions close to the attended target are attracted (32 degrees on average) while directions farther away are repelled (29 degrees on average) resulting in an effective expansion of the feature space between these directions. We explain these effects by model simulations in which gain-modulations lead to distortions of the neural population responses if the adaptor direction differs from the one of the target. Furthermore, consistent with recent electrophysiological observations this model predicts changes of tuning curves for cells which are driven by these distorted responses with the consequence that more cells are recruited to process the attended feature.

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63.445 **Attention is Directed by Prioritization in Cases of Certainty**

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While some recent studies suggest that object-based attentional selection is driven by spatial uncertainty of target location (Shomstein & Yantis, 2002, 2004), other studies suggest that target-to-object relationship, rather than uncertainty, is the determining factor (Chen & Cave, 2006; Richard, Lee, & Vecera, 2008). In the present study we re-evaluate the contribution of spatial uncertainty to object-based effects as well as examine the interaction of uncertainty with target-to-object relationship. In a series of four experiments we manipulate uncertainty and target-to-object relationship to examine the extent to which target uncertainty contributes to object-based attention. Participants were presented with a series of single and multiple objects that contained "bites" (concavities), and were asked to perform a shape discrimination task in two conditions: (i) when target location was known in advance (certainty), and (ii) when target location was uncertain. In addition, the properties of the "bites" were manipulated, they were either interpreted as being part of the object or as having been placed on to the object. We observed object-based effects when target location was uncertain, and only if the targets were interpreted as being a part of the object. On the other hand, when target location was known in advance, or when the target shapes appeared to be independent of the object (i.e., not a part of it), object-based effects disappeared. These results re-instate the importance of location uncertainty in object-based attentional guidance, and suggest that object properties have to be task relevant if they are to influence object-based effects.

63.446 **Cue Position Alters Perceived Object Space**

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Brief visual cues are often used to induce involuntary shifts of attention to locations away from the center of gaze. However, it is not fully understood how displacements of the focus of attention alter visual processing and, in particular, the perceived structure of objects in the visual field. The present study addressed this question by presenting cues that were either within or outside the contour of a subsequently presented oval and measuring how cue placement altered the perceived shape of the ovals. On every trial two white dots were briefly presented as cues (50ms) at equal eccentricities along the horizontal or vertical meridian (8° or 14°). Following a 100ms ISI one of fifteen blue ovals was presented for 100ms. The ovals were centered at fixation and had horizontal radii of 5°, 11°, or 14°. The height of the ovals was +0%, ±5%, ±10% the horizontal radius. Participants responded after every trial whether the oval was wider or taller than a perfect circle. The cues were paired with ovals such that cue positions (inside/outside contour; horizontally/vertically aligned) were uninformative of which dimension of the oval was larger. There were 40 cue-oval combinations and 25 repeats per configuration. There was a significant Cue Side x Cue Configuration x Oval Height interaction showing that when the cues were located within the oval contour the percentage of taller responses increased for vertically aligned cues and decreased for horizontally aligned cues relative to when the cues were placed outside the oval contour. However, this pattern of responses was only seen for the middle Oval Heights (0% = circle) and not the most extreme (e.g. ±10%). This double dissociation cannot be explained by a simple response bias and suggests that the relative position of cues can systematically alter subsequent processing of an object's spatial structure.

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63.447 **Neural representation of targets and distractors during object individuation and identification**

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Many everyday activities, such as driving on a busy street, require the encoding of multiple distinctive target objects among distractor objects. To explain how multiple visual objects are attended and perceived, the neural object file theory argues that our visual system first selects a fixed number of about four objects from a crowded scene based on their spatial/temporal information (object individuation) and then encodes their details (object identification) (Xu & Chun, 2009, TICS). In particular, while object individuation involves the inferior intra-parietal sulcus (IPS), object identification involves the superior IPS and higher visual areas such as the lateral occipital complex (LOC). Because task irrelevant distractor objects were never present in previous studies, it is unclear how distractor objects are processed and whether they influence the encoding of target objects during object individuation and identification. In the current fMRI study, we asked observers to encode target shapes among distractor shapes, with targets and distractors defined by two different colors. If distractors can be ignored based on their color before objects are individuated and identified, then the presence of distractors should have minimal impact on fMRI responses in the inferior and the superior IPS and the LOC. However, if distractors are automatically individuated or even identified, then neural responses in the relevant brain areas should be modulated accordingly. In a third possibility, if irrelevant information is only encoded when the central processing resources are unfilled as argued by the perceptual load theory, then distractors will be processed under low but not under high target load. Consistent with the perceptual load theory, we found that distractors only affected neural responses under low, but not under high, target load. Moreover, the presence of distractors under low target load had different effects on fMRI responses in the inferior and the superior IPS and the LOC.

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63.448 **Number and Area Perception Engage Similar Representations: Evidence from Discrimination Tasks**

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The present research addresses the long-standing question of the similarity between the perception of individual "count" objects ("three cats"), and continuous "mass" objects ("some sand"). Such distinctions have been important in studies of higher cognition (e.g., linguistics) and basic visual representation (e.g., ensemble features). Can mass and count be represented in a shared format? A prominent theory by Chierchia (1998; Natural Language Semantics 6, 339-405) proposes that mass and count representations share a similar format as ensembles of discrete individuals. This view, in concert with certain theories of mid-level vision (Pylyshyn, 1989; Cognition 32, 65-97), takes objects to be the foundation upon which higher cognition is built. Our study tested whether number and area perception share a visual format through sets of individuals or through noisy continuous approximations. In Experiment 1, 20 adults were presented with two sets of dots for 150 ms on each trial and were asked to evaluate which set was greater in number (see Figure 1). An additional 20 subjects saw, for 150 ms, images of 2-D blobs made up of two colors, and had to judge which color had a greater area (see Figure 2). A classic psychometric curve derived from a Gaussian subtraction model was highly correlated with the observed data for each condition (R2 > 0.90), and suggests that the representations of number and area share a similar format through noisy approximations. Therefore, the underlying representation, for vision, of both count and mass objects is not a set of discrete individuals, but a continuous Gaussian variable (or a Bayesian probability distribution). These findings speak not only to the psychophysics of area and number discrimination in adults, but also contribute to long-standing debates in lexical semantics, as well as to the relationship between vision and language and the extraction of ensemble features.

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63.449 **Representations of "Event Types" in Visual Cognition: The Case of Containment vs. Occlusion**

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The visual system segments dynamic visual input into discrete event representations, but these are typically considered to be token representations, wherein particular events are picked out by universal segmentation routines. In contrast, recent infant cognition research by Renee Baillargeon and others suggests that our core knowledge of the world involves "event type" representations: during perception, the mind automatically categorizes dynamic events into types such as occlusion, containment, support, etc. This categorization then automatically guides attention to different properties of events based on their category. For example, an object's width is particularly relevant to containment events (wherein one object is lowered inside another), because that variable specifies whether the event is possible (i.e. whether it will 'fit'). However, this is not true for the variable of height. This framework has been supported by looking-time experiments from Baillargeon's group: when viewing containment events, infants encode objects' widths at a younger age than they encode their heights -- but no such difference in age is observed for similar occlusion events. Here we tested the possibility that this type of 'core knowledge' can also be observed in mid-level object-based visual cognition in adults. Participants viewed dynamic 2D displays that each included several repeating events wherein rectangles either moved into or behind containers. Occasionally, the moving rectangles would change either their height or width while out of sight, and observers pressed a key when they detected such changes. Change detection performance mirrored the developmental results: detection was significantly better for width changes than for height changes in containment events, but no such difference was found for occlusion events. This was true even though many observers did not report noticing the subtle difference between occlusion and containment. These results suggest that event-type representations are a part of the underlying currency of adult visual cognition.

Spatial vision: Masking

Orchid Ballroom, Boards 450–461

Wednesday, May 12, 8:30 - 12:30 pm

63.450 **Visual performance fields in noise**

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Goal: Here we investigated the changes in visual performance fields with external noise to determine whether the observed asymmetries are due to sensitivity or internal noise. Contrast sensitivity (CS) varies at isoeccentric locations. Specifically, CS is higher on the horizontal (East and West) than the vertical (North and South) meridian. Along the vertical meridian, CS is higher in the South than the North (e.g. Carrasco, Talgar, & Cameron, 2001). Generally, perceptual performance is a conjoint measure of the sensitivity to the signal and the amount of internal noise. Examining CS as a function of noise contrast reveals the equivalent input noise of the visual system. This value indicates the level of external noise at which internal noise ceases to dominate signal processing (Pelli & Farell, 1999).

Method: Observers performed an orientation discrimination task on Gabors of varying contrast at four isoeccentric locations (North, South, East, and West). The Gabors were embedded in Gaussian white noise of varying contrast. We measured the 75% performance threshold for each location and noise contrast and plotted threshold versus noise contrast functions for each location.

Results: Without external noise, thresholds were lowest in the East and West, higher in the South, and highest in the North. However, as noise contrast increased, thresholds increased the most at the East and West, less in the South, and least in the North. Thus, the equivalent input noise is lowest on the horizontal meridian, higher in the South, and highest in the North. At a high enough level of external noise, the thresholds for all four locations were the same. These data suggest that the differences in processing between the two meridians and within the vertical meridian are due to variations in internal noise across the visual field.

Acknowledgement: NIH EY016200 to MC and NIH T32 EY007136 to NYU

63.451 **Orientation uncertainty reveals different detection strategies in noise**

Remy Allard[1](remy.allard@umontreal.ca), Patrick Cavanagh[1]; [1]Centre Attention & Vision, Laboratoire Psychologie de la Perception, Université Paris Descartes

Widely used external noise paradigms are based on the assumption that adding external noise quantitatively affects performance but does not qualitatively affect the processing strategy. However, we recently found evidence in a crowding task that some forms of external noise do change processing strategies at higher levels and we confirm this effect of noise on strategy here using an uncertainty reduction procedure. Specifically, we measured the impact of orientation uncertainty (fixed- versus randomized-orientation) on contrast detection thresholds of a sine wave grating in three different noise conditions: noiseless, spatiotemporally localized noise (i.e. signal and noise shared the same spatiotemporally window) and spatiotemporally extended noise (i.e. continuously displayed full screen dynamic noise). In the no-noise and extended-noise conditions, knowing the orientation of the signal to detect had little impact on performance (orientation uncertainty increased contrast thresholds by 4% and 8%, respectively) suggesting that detection was not based on an orientation recognition strategy but rather mediated by an energy-based strategy as it is generally assumed. In contrast, knowing the orientation of the signal substantially improved performance in the localized-noise condition (orientation uncertainty increased contrast thresholds by 28%) suggesting that detection was based on an orientation recognition strategy. We conclude that spatiotemporal localized external noise can qualitatively affect the processing strategy. Our results suggest that external noise paradigms should use only spatiotemporally extended dynamic noise in order to match the likely characteristics of the internal noise and avoid triggering qualitative changes in the processing strategy. These results raise questions about the validity of the conclusions of many previous studies using external noise paradigms with localized external noise.

Acknowledgement: This research was supported by a FQRNT post-doctoral fellowship to RA and a Chaire d'Excellence grant to PC

63.452 **Mutual effects of orientation and contrast within and between the eyes: from summation to suppression**

John Cass[1](johncassvision@gmail.com); [1]School of Psychology, University of Western Sydney

Previous masking studies estimate the bandwidths of orientation-selective mechanisms based on the rate at which threshold elevations decrease as a function of the angular difference between spatio-temporally overlaid target and masking stimuli, with many finding that bandwidths decrease with increasing spatial frequency. In this study we examine, in detail, the effects of relative phase, contrast, and the ocular mode of presentation (MON vs DICH) on the relationship between orientation masking and spatial frequency. Results: When relative phase was randomized across trials we observed similar masking functions to those observed previously. When relative phase was blocked, however (ie. in phase or anti-phase), monoptic thresholds increased up to ~10 degrees of angular difference, then decreased monotonically out to 90 degrees. This qualitative pattern, evident at all mask contrasts (0.5 – 64 x threshold), is well fitted by an orientation-defined Difference of Gaussian (DoG) model, consisting of narrowband summation (~5-10 degrees) combined with a broader suppressive component which becomes narrower with increasing spatial frequency. Interestingly, identical non-monotonic patterns were observed dichoptically at low mask contrasts (0.5 - ~8 x threshold). At higher mask contrasts however, the sign of the narrowband component reversed to produce what appeared to be narrowband inter-ocular suppression (Baker & Meese, 2007), whilst the broader suppressive component remained almost identical to that derived monoptically. These results indicate that human orientation channels laterally inhibit one another at a neural locus that receives binocular input, with the extent of lateral inhibition decreasing with spatial frequency. Whilst narrowband summation is evident within and between the eyes, narrowband suppression results when inter-ocular contrast differences are high, possibly to reduce inter-ocular redundancy.

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63.453 **Effects of arbitrary structural choices on the parameters of early spatial vision models**

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Typical models of early spatial vision are based on a common, generic structure: First, the input image is processed by multiple spatial frequency and orientation selective filters. Thereafter, the output of each filter is non-linearly transformed, either by a non-linear transducer function or, more recently, by a divisive contrast-gain control mechanism. In a third stage noise is injected and, finally, the results are combined to form a decision. Ideally, this decision is consistent with experimental data (Legge and Foley, 1980 Journal of the Optical Society of America 70(12) 1458-1471; Watson and Ahumada, 2005 Journal of Vision 5 717-740).

Often a Gabor filter bank with fixed frequency and orientation spacing forms the first processing stage. These Gabor filters, or Gaussian derivative filters with suitably chosen parameters, both visually resemble simple cells in visual cortex. However, model predictions obtained with either of those two filter banks can deviate substantially (Hesse and Georgeson, 2005 Vision Research 45 507-525). Thus, the choice of filter bank potentially influences the fitted parameters of the non-linear transduction/gain-control stage as well as the decision stage. This may be problematic: In the transduction stage, for example, the exponent of a Naka-Rushton type transducer function is interpreted to correspond to different mechanisms, e.g. a mechanism based on stimulus energy if it is around two.

Here we systematically examine the influence of arbitrary choices regarding filter bank properties−the filter form, number and additional parameters−on the psychophysically interesting parameters at subsequent stages of early spatial vision models. We reimplemented different models within a Python modeling framework and report the modeling results using the ModelFest data (Carney et al., 1999, DOI:10.1117/12.348473).

63.454 **On the fate of missed targets**

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Signal Detection Theory assumes no sensory threshold, that is, an internal response monotonically increasing with stimulus strength, available for decision. While a wealth of empirical observations unfailingly sustained this principle, the debate on the existence of a sensory threshold persists. An educated SDT intuition is that an identification response of a non-detected stimulus (Miss) should yield above chance performance. A high threshold theory predicts chance performance. Using a single-presentation double-task paradigm, consisting of independent detection (Yes/No) and identification (2AFC) reports, data of three highly trained observers show that orientation (±45°) as well as position (±2° eccentricity) discrimination performance for a missed Gabor patch (5 cpd) is very close to chance for criteria as high as 1.3 noise units (σ) above mean noise level (d' up to 2.5). To compare the data with SDT predictions, we make the standard assumption that observers are monitoring two independent neuronal populations corresponding to the two possible targets in a given task. A 'Yes' report in the detection task occurs when a response from any of the two populations crosses a criterion level; an identification report corresponds to the identity of the population producing the largest response ('labelled line'). Receiver Operating Characteristics of these populations were estimated using rating experiments, with the experimental results conforming to earlier reports ($\sigma = 1 + r/4$, with r the signal evoked mean internal response; Green & Swets, 1966; Graham, 1989). SDT predictions using these ROCs match observers' identification rate for Hit trials (r2=0.9) but exceed by far the measured identification rate for Miss trials (r2=0.04). While the rating data support the availability of a continuous internal response, the detection/identification data point to the fact that decision criteria in a Yes/No task are more akin to a high threshold inasmuch as they are considered to be boundaries for 'invisible' events.

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63.455 **Do illusory contours prevent spatial interactions?**

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In the third of a series of concurrent-response experiments examining decision processes in fine spatial discriminations, we have investigated the effect of creating an illusory contour between a center grating patch and a surrounding grating annulus by shifting the relative phase of the two by 180 deg. In single-response paradigms, the phase shift appears to render the two stimulus parts independent (Saylor & Olzak, 2006). Four stimuli were intermingled into a single session of 160 trials. In different conditions of the experiment, observers either made hyperacuity-level orientation or spatial frequency judgments. Both the center and surround grating patches contained a cue to discrimination; for example, left-left, right-right, left-right and right-left. Observers made two consecutive judgments, one on the center and one on the surround (order was counterbalanced across observers), rating their confidence on a 6-point scale that either Pattern A (e.g. left) or Pattern B (e.g. right) was presented in that part of the stimulus. Like previous results found with in-phase abutting stimuli and those separated by a tiny gap, independent processing was strongly rejected. Observers appeared once again to be using a complex decision strategy in which they first classified the stimulus as the "same" type (left-left or right-right) or of the "different" type (left-right or right-left), and then using the rating scale in a correlated or anti-correlated way for the two decisions. We discuss these findings in the context of General Recognition Theory (Ashby & Townsend, 1986). Saylor, S. A. and Olzak, L. A. (2006) Contextual effects on fine orientation discrimination tasks. Vision Research, 46 (18), 2988-2997. Ashby, F. G and Townsend J. T. (1986) Varieties of perceptual independence. Psychological Review, 93, 154-179.

63.456 **Orientation Dependence of Contextual Suppression Derived from Psychophysical Reverse-Correlation**

Christopher A. Henry[1], Michael J. Hawken[1]; [1]Center for Neural Science, New York University

The ability to detect a visual target can be affected, often quite dramatically, by the spatial context surrounding it. It is thought that the spatial summation and extra-classical receptive field (eCRF) properties of visual cortical neurons underlie this perceptual metacontrast masking. Orientation-dependent contextual effects have been reported in both perceptual masking and neurophysiology and it is natural to compare the two.

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We have previously investigated the tuning properties of the eCRFs of neurons in macaque V1 (Henry et al. SFN 2008). Using a subspace reverse-correlation paradigm, we measured the temporal impulse-responses of neurons to the presentation of oriented gratings in their eCRFs. In general, the eCRF stimuli suppressed the neurons' responses, most often with the strongest suppression occurring for collinear stimuli.

Here, we measured the orientation dependence of metacontrast masking psychophysically using a similar reverse-correlation paradigm. Parafoveally presented stimuli consisted of an outer annulus – the surround – and an inner patch. A vertical near-threshold contrast grating target was briefly (24 ms) and randomly presented in the inner patch at a rate of 2 Hz. A continuous sequence of gratings was presented in the outer annulus (18 total orientations, changing every 24 ms). During 1 minute blocks subjects were instructed to press a key when they detected a target grating.

Analysis consisted of correlating the randomly-presented stimuli in the outer annulus with subjects' key presses, as we did with neuronal spiking in the previous study. Subjects were less likely to detect the targets in the presence of oriented surrounds, with the most masking coming from collinear stimuli. Moreover, the orientation bandwidth of the masking effect is similar to the bandwidth measured for neuronal eCRFs. Thus, using similar approaches, we have shown that masking effects in human behavior are similar to eCRF suppression observed in macaque V1.

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63.457 **ON/OFF channel asymmetry or consequences of a Luminance nonlinearity**

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Hartline (1938) showed that visual information is processed by parallel ON and OFF channels that signal light and dark regions in the visual scene. Later studies have demonstrated that there are functional and anatomical differences between ON and OFF channels in the retina (Chichilnisky & Kalmar, 2002), OFF center geniculate afferents dominate the cortical representation of the cat area centralis (Jin et al., 2008), and OFF cells outnumber ON cells in the corticocortical output layers 2/3 of macaque striate cortex (Yeh et al, 2009). In psychophysics, the most convincing evidence for the special importance of dark signals was obtained from texture variation discrimination (Chubb & Nam, 2000) and attributed to the OFF channel. A different asymmetry between light and dark neural signals is caused by the compressive photoreceptor response-function, and we test whether this nonlinearity can explain some of the published ON/OFF asymmetries. We measured the salience of black versus white spots on a uniformly distributed black/white binary random-noise pattern. Reaction times for detecting one to three black spots were significantly lower than for white spots. Although white and black spots occupy physically equal areas in the background pattern, the white areas look larger --- the irradiation illusion (Galileo, 1632). When the perceived areas are equated for each observer by changing the relative distribution, the salience difference disappears. We found that the black/white salience difference also occurs when the Chubb textures are used for backgrounds, and could account for the greater influence of dark texels in their task. We were able to model the percept of the binary background by a compressive non-linearity at the photoreceptor level, so we attribute the salience differences to the non-linearity rather than to greater OFF channel sensitivity.

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63.459 **When simultaneous presentation results in backward masking**

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Collinear facilitation is an enhancement in the visibility of a target by laterally placed collinear flankers (COL). Non-collinear configuration (parallel, side-by-side, SBS) produces less facilitation. Surprisingly, presentation of COL and SBS configurations simultaneously (CROSS) abolishes the facilitation rather than increases it - a phenomenon that has not been well understood. Here we directly explored the effect of canceled facilitation in the CROSS configuration. We used a Yes/No detection task measuring the hit-reports (Phit) and the false-positive-reports (false-alarm, Pfa) for a low-contrast Gabor target embedded between flankers. We compared COL, SBS and CROSS configurations. We also recoded Evoked Responses Potentials (ERP) from the occipital cortex. The results show that Phit were higher for COL and SBS, but decreased for the CROSS configuration. Pfa were also the lowest for the CROSS configuration. Thus, the decision criterion switched from target present (Yes) in COL to target absent (No) in CROSS, reminiscent of our earlier results of suppression by backward masking. However, the amplitude of the P1 ERP component (reflecting the strength of stimulation) is not reduced for the CROSS configuration – opposing the possibility of lateral inhibition between flankers. The amplitude of the N1 component, a marker of lateral interactions, is in correlation with the reduction in collinear facilitation in the SBS configuration. Thus, the ERP results show that the abolished collinear facilitation in the CROSS is not due to lateral inhibition between the COL and the SBS flankers. Interestingly, the latency of SBS is delayed by about 10 ms compared to COL, suggesting that the facilitatory process is selectively canceled due to backward masking effect by the delayed signal from the SBS. Thus, perceptual advantage of collinear facilitation may be lost when interfered with facilitation from the sides, whereas the final perception is determined by the overall spatial-temporal integration of the lateral interactions.

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63.460 **Characteristics of dichoptic lateral masking of contrast detection**

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Purpose. Past studies show strong effects by flanks on contrast detection. A limited dichoptic study showed no net flank effect (Huang et al., 2006). Here we more extensively investigate dichoptic lateral masking. Methods. Observers: 5 adults with normal vision and 2 non-binocular, non-amblyopic (NBNA) adults. Measure: contrast detection threshold (CDT) for a sinusoid (3 c/deg, 2° diameter, vertical) in isolation and with two flanking sinusoids at 3 separations (edge to edge 0.5° overlap, abutting, 0.5° separation). Flanks: target sinusoid (normalized 1.5x and 3x flank CDT) oriented vertical or horizontal, or Gaussian blobs (2° diameter) normalized by the flank CDT. Presentations: target to dominant eye, flanks monoptic (abutting only) or dichoptic (3 separations), 2-AFC with the MOCS, and mirror haploscope with septum. Results. For the normal observers, monoptic viewing produced facilitation by collinear flanks (mean 10%±4% (95% CI)), no effect from orthogonal, and suppression by blobs (8%±6%). These effects were greater for 3x CDT flanks and this difference was not shown under dichoptic viewing. For dichoptic viewing, the overlap condition produced facilitation by collinear flanks (7%±4%), suppression by orthogonal (4%±4%), and no effect by blobs. The abutting condition produced facilitation by collinear flanks (8%±4%) and orthogonal (7%±5%), and no effect by blobs. The separation condition produced suppression by collinear flanks (9%±5%), orthogonal (6%±3%), and blobs (8%±4%). For the NBNA observers, under monoptic and dichoptic viewing all separations showed suppression by collinear flanks (14%±7%), orthogonal (10%±8%) and blobs (8±4%). Conclusions. Dichoptic integration of contrast across space is similar to the known monocular mechanism: facilitation by flanks slightly overlapping or abutting the target, and masking only via spatial channels (blobs had little effect). However, an exclusive dichoptic mechanism is suggested: flanks suppress rather than have no effect when separated from the target. Dichoptic integration is further supported by the suppression shown by the NBNA observers.

63.461 **Shape discrimination in migraineurs**

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Migraine is a disabling condition for which the underlying neuronal mechanisms remain elusive. Patients with migraine often experience visual hallucinations (aura) and have been shown to exhibit subtle differences in visual processing compared to non-migraineurs interictally. Deficits have been reported under conditions including metacontrast masking and motion perception.

We compared masking effects in migraineurs and headache-free controls using a shape discrimination task, thought to involve processing in extrastriate cortical areas. Observers had to detect subtle deviations in cir-

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cular contour shapes (radial-frequency patterns [RF]) in the presence of a larger contour mask. Thresholds - defined as the amount of radial amplitude (sharpness of the contours corners) required to discriminate perfect circles from pentagon-like shapes (RF 5) - were determined using a staircase procedure. The mask, a RF 5 pentagon shape with an amplitude 16 times its detection threshold, was presented at 5 stimulus onset asynchronies (SOA): 0ms (simultaneous), 66.7ms, 100ms, 133.3ms and 250ms. Tests (1-deg radius) and mask (1.5-deg radius) were shown for 25ms. The cross-sectional profile of the contours was given by a fourth derivative of a Gaussian with a peak spatial frequency of 8 cpd. Luminance contrast of all stimuli was 0.9. Nine migraineurs with aura, 9 migraineurs without aura and 10 headache-free controls participated.

Confirming typical masking effects, all subjects showed raised thresholds between SOA 66.7-100ms compared to simultaneous presentation of mask and test shape (SOA=0ms).

While migraineurs without aura performed almost as well as the control group, migraineurs with aura had higher thresholds for all backward masking conditions (SOA>0), with peak difference occurring at SOA 66.7ms (p=0.036). This finding could reflect a general difficulty for migraineurs with aura to detect shapes in a distractive environment which might be due to a hyperexcitability in migraineurs with aura.

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