

Vision Sciences Society



2005 Abstracts

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Poster Session A

May 6, 2005 – Friday PM

Binocular Rivalry (1-15), Biological Motion 1 (16-26), Attention, Motion, and Tracking (27-36), Faces 1 (37-50), Illusions (51-61), Scene and Layout Perception (63-79)

5:30 - 8:30 pm (Authors present 6:30 - 8:00 pm)

Hyatt Ballroom South

Binocular Rivalry

1 Negative afterimages generated during binocular rivalry show signs of weakness and signs of strength.

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In a series of experiments we investigated the interaction between binocular rivalry and static, negative afterimages (AIs). In experiment 1, one eye was exposed to a static grating that was never consciously experienced by the observer, because this grating remained suppressed in rivalry throughout the entire exposure period (the dominant stimulus itself was designed to preclude formation of an AI). As expected, the suppressed grating generated a vivid AI whose orientation could be accurately identified; not surprisingly, the strength of this AI varied with induction contrast. Surprisingly, however, Experiment 2 revealed that the strength of this afterimage was significantly weaker than the AI produced by that same stimulus when it was visible throughout the entire induction period. Suppression weakens AI formation, implying that at least some component of AI induction is cortical (Shimojo, et al., 2001, Science) and therefore susceptible to rivalry suppression, itself a cortical process. In Experiment 3, dichoptic, orthogonally oriented grating AIs were generated; flash suppression (Wolfe, 1984, Vis. Res.) was used to ensure that one of the two gratings was exclusively dominant during the induction phase. As expected from earlier work (Blake, et al., 1971, JEP; Wade, 1975, Percept. & Psychophys.), dissimilar monocular AIs engaged in rivalry, but to our surprise the AI induced by the suppressed grating subsequently predominated in rivalry following adaptation. Why does a weak AI fare so favorably in rivalry against a stronger AI? This counterintuitive finding may point to the involvement of contrast gain control in binocular rivalry, with contrast signals pooled over orientations and across eyes. This kind of gain control may, in turn, explain why rival targets differing widely in contrast can nonetheless engage in rivalry, with a relatively low contrast contestant occasionally defeating its high contrast opponent.

Acknowledgment: EY13358 & EYO7135

2 When a Traveling Wave Meets a Gap on Its Way

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During binocular rivalry, one sees perceptual waves in which the dominance of one pattern emerges locally and expands progressively. This intriguing phenomenon provides a tool by which the nature of cortical network can be probed by detailing the dynamics of perceptual waves, given a tight linkage between perceptual waves and cortical waves in the early visual cortex (Lee et al., 2004). Wilson et al (2001) proposed a model

that wave propagation is mediated by inhibitory interactions between two layers of cells, and the efficiency of propagation is regulated by reciprocal excitatory connections within each layer. With this model in mind, we attempted to estimate the efficiency of recurrent connections by assessing how the size of a gap in patterns affects the dynamics of perceptual waves. Subjects viewed a dichoptic display of a spiral annulus and a radial annulus. When a spiral grating was dominant, the contrast pulse was applied to a small region in a radial grating, resulting in a perceptual wave of a radial pattern propagating from that region. The speed of a wave was measured by a key press when a wave arrived at a region marked by nonius lines positioned 1358 away from the contrast pulse. A gap of various sizes was placed on a radial grating. Another key press indicated whether a wave propagated continuously and reached the lines allowing to estimate a threshold gap size at which the probability of waves jumping the gap was 50%. The radius of annulus patterns was varied to see how the threshold gap size is affected by the eccentricity. The threshold gap size was greater for interhemispheric waves than for intrahemispheric ones, but was constant across different eccentricities when the gap size was converted into the cortical distance on V1. The effect of gaps coincides with the known functional organization of the early visual cortex and predicts that the range or the strength of recurrent connections among neurons is homogeneous throughout the cortical surface within a given visual area.

Acknowledgment: Supported by KISTEP / M103KV010021-04K2201-02140

3 Contrast Effect of Spatial Context on Binocular Rivalry is Modulated by Eccentricity and Binocular Depth

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Spatial context influences binocular rivalry. The predominance of a rivalry target is facilitated by globally coherent stimuli (eg Sobel & Blake, 2002). In contrast, if a rivalry target is surrounded by a background, the context-contradictory target is preferred in some cases (eg Paffen et al, 2003; Carter et al, 2004). The purpose of this research is to explore the contrast effect of spatial context on binocular rivalry, and its modulation of the rival target's eccentricity and the binocular depth separation between the target and the surrounding background. We presented a square (1.5x1.5 deg) consisting of sinusoidal gratings (2.0 cpd, 100% contrast, mean luminance 50.0 cd/m², rightward or leftward slant 45 deg) dichoptically, of which the orientations were orthogonal for two eyes (Rivalry target). The rivalry targets were surrounded by a similar grating (10x10 deg), of which the orientation was identical to one of rivalry targets (Background). Thus, a rivalry target for one eye and the background were collinear gratings, and the other target and the background were orthogonal gratings. 7 naive subjects continuously reported the predominant orientation of the target grating for 180 s. In Experiment 1, the retinal eccentricity of the rivalry

target was varied at 0.0, 0.75, and 1.5 deg by manipulating the position of the fixation point. In Experiment 2, we introduced binocular disparity to the background grating, which was in front of, on, or behind of the rivalry target (crossed or uncrossed disparity 0.1 deg). Most subjects showed the predominance of the rivalry target consisting of the orthogonal gratings over the collinear gratings (spatial contrast). The contrast effect of binocular rivalry decreased as the eccentricity increased (Experiment 1) and as the background was separated in depth (Experiment 2). These results suggest that the cortical processes for spatial contrast and binocular depth perception are concerned with the predominance during binocular rivalry.

Acknowledgment: This research was supported by SCAT and The 21st Century COE Program: Intelligent Human Sensing from MEXT Japan.

4 Binocular Rivalry Can Fully Gate the Formation of Visual Phantoms

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We investigated the neural interactions between binocular rivalry and perceptual filling-in of visual phantoms to elucidate the stages at which selective and constructive perceptual mechanisms operate in the visual pathway. Binocular rivalry leads to the selective perception of one of two competing monocular stimuli, whereas visual phantom formation leads to perceptual filling-in of a large gap between two collinearly aligned gratings. We devised a novel visual display to investigate interactions between rivalry and filling-in, and measured the resulting effects in human visual cortex. One eye was shown two vertically aligned gratings (positioned one above the other) that would normally lead to perception of a visual phantom in the gap, while the other eye viewed rivalrous horizontal gratings in corresponding locations, which if viewed alone would not lead to a visual phantom. Observers reported phantom filling-in only when the vertical gratings were dominant. This behavioral result suggests that rivalry can gate the formation of visual phantoms. We monitored fMRI activity while observers viewed this perceptually ambiguous display. When observers perceived the vertically aligned gratings as dominant, increased activity was observed in retinotopic regions corresponding to the phantom location in areas V1-V3. In contrast, when the horizontal gratings became dominant and observers failed to perceive a phantom, decreased activity was found. More strikingly, the modulations in early visual cortex during rivalry were just as strong as those evoked by the non-rivalrous stimulus alternation between the two monocular displays, suggesting that rivalry fully gates the neural filling-in of visual phantoms. These results show that rivalry occurs at an earlier stage of visual processing than perceptual filling-in, and that neural activity in V1-V3 closely reflects the observers' conscious perception of the visual phantom during moment-to-moment fluctuations in awareness.

Acknowledgment: Research supported by NIH grants R01-EY14202 and P50-MH62196 to FT

5 Binocular Rivalry Is Affected By Surface Boundary Contours

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In a typical binocular rivalry (BR) display, orthogonal grating disks (vertical vs horizontal) at corresponding retinal areas induce a strong alternation wherein each disk has ~ 50% predominance. But by placing these grating disks on, say, a vertical grating background in each half-image (thus blending the vertical grating disk into the background), the alternation is vastly reduced as the horizontal grating disk claims ~ 90% predominance. We proposed that the perceptual difference between this, monocular-boundary-contour (MBC)-display, and the typical-BR-display reveals a preference for boundary contours (He & Ooi 02). Only a monocular boundary contour (rim of horizontal grating disk) exists in the MBC-display, hence its predominance, whereas binocular boundary contours (rims of the two grating disks) exist in the typical-BR-display. To

further test the proposal, Exp 1 tracked the BR dynamics of a modified MBC-display with a monocular grating disk on two types of random-dots background conditions. i) Fully correlated condition: the two half-images had the same random-dots pattern; ii) Partially correlated condition: the random-dots pattern in one half-image was flipped around the vertical and horizontal axes. It was predicted that the fully correlated condition would have more BR alternations as stronger binocular boundary contours were formed between the correlated random-dots around the rim of the grating disk and its corresponding area in the other half-image. Confirming this, we found more alternations in the fully correlated condition, while the grating disk in the partially correlated condition has a higher predominance. Besides BR's varied dynamics, the sensitivity of the suppressed area is expected to decrease. Thus Exp 2 used a probe to measure the sensitivity reduction in the MBC-display. We found a suppression threshold similar to that in other BR displays, suggesting a common (suppression) fate beyond the boundary contour processing stage.

6 Surround inhibition affects perception of center motion in a manner similar to lowering the center's luminance contrast

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Recently, it has been shown that increasing size and luminance contrast of a motion stimulus makes it more difficult to perceive its direction of motion (Tadin et al. 2003). It was argued that this was the result of surround inhibition in motion selective neurons in the human brain. The neural response to motion presented to a neuron's classical receptive field can be inhibited by presenting motion to its surround. Question: does increasing size and contrast of a motion stimulus have a similar effect on perception of motion in the center as decreasing the center's luminance contrast?

In binocular rivalry, dissimilar targets compete for perceptual dominance. Decreasing one target's contrast increases the dominance duration of the other target, leaving its own duration unaffected. We investigated whether increasing size and contrast of surround motion has the same effect on rival targets as decreasing one target's contrast.

Rivalry was instigated between a moving and stationary target. Surround motion was either in the opposite direction of the moving target, or in the same direction. Both contrast of center and surround and width of the surround were varied. Observers continuously indicated which target was perceptually dominant.

A same direction surround modulated rivalry: at high contrast (100 and 50% Michelson), increasing the size of surround motion gradually decreased the dominance of the moving target. At low contrast (5%), the decrease in dominance was constant for various widths of the surround. Interestingly, as dominance durations of the static target increased, durations of the moving target were relatively unaffected. An opposite direction surround did not modulate dominance.

This study shows that increasing size and contrast of a moving stimulus has a similar effect on perception of center motion as decreasing the center's contrast. It appears as though surround inhibition decreases the signal for center motion in a manner similar to lowering the center's contrast.

Acknowledgment: Supported by the Netherlands Organization for Scientific Research (NWO)

7 Structure-From-Motion and Biological Motion Perception Influences on Binocular Rivalry

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Previously, we showed in psychophysical experiments that rivalry between biological motion patterns under binocular conditions is different

from low-level rivalry (Beintema, Halfwerk & van Wezel VSS 2004). Biological motion patterns evoked slower alternation and less suppression than less-recognizable inverted and scrambled versions, but only at less-than-natural gait speed. We used this stimulus in an event-related fmri study to investigate the influence of higher level processing on binocular rivalry. We tested rivalling upright vs rivalling inverted walker conditions at less-than-natural gait speeds. Clear centers of activation differences were found in the Fusiform Gyrus, Middle Temporal Gyrus and Inferior Temporal Gyrus, but also in the Parietal and Frontal Lobes. Furthermore, psychophysical 2AFC experiments under monocular viewing conditions showed that a walking figure is perceived to be rotating about the vertical at low speed (as low as 1/8 of natural gait speed), especially when its recognizability is decreased. The opposite trend was found for simulated rotation of a frozen figure, which was perceived as non-rotating at higher speeds (up to twice natural gait speed), especially when it was most recognizable. Interestingly as well, structures could be perceived as rotating and being non-rigid, suggesting two independent perceptual processes. The psychophysics suggest that binocular rivalry is not only influenced by biological motion perception, but also by structure-from-motion perception. The latter might explain activity differences found in the regions that could correspond to MT+ and the more posterior located KO/LO.

Acknowledgment: supported by NWO/ALW grant 811.37.001, VIDI grant of the Netherlands Organization for Scientific Research (NWO) and the Interuniversity Attraction Poles Programme (IUAP) of the Belgian Science Policy

8 Metacontrast and Binocular Rivalry Suppression Reveal Hierarchies of Unconscious Visual Processing

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Using metacontrast, we looked at target suppression and target recovery under binocular and dichoptic viewing of stimuli, with the ability to additionally introduce binocularly rivalry suppression in the latter viewing condition. Our investigations revealed the following functional hierarchy of unconsciously processing of visual stimuli: 1) Studies of masked priming showed that a target form can be processed unconsciously at levels that already have extracted, at minimum, conjunctions of primitive orientation features such as corners and vertices. 2) Studies of target recovery, produced by using a secondary mask to weaken the masking effect of the primary mask, showed that recovery is absent or greatly reduced under dichoptic presentation of the two masks, indicating that target recovery occurs primarily at unconscious levels prior to cortical binocular activation. 3) Studies of target recovery, produced by binocular rivalry suppression of the mask, showed that the cortical mechanism responsible for metacontrast suppression, itself activated at unconscious levels of cortical processing, occurs after the cortical level of binocularly rivalry suppression. Besides allowing us to establish functional hierarchies of unconscious processing in the cortical visual system, these results also allow us to distinguish between current models of target masking and recovery.

Acknowledgment: Supported by NSF grant BCS-0114533 and NIH grant R01-MH49892.

9 Predicting the stream of human consciousness

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Is it possible to predict the rapid stream of conscious experience in another person's mind from their brain activity alone? Here we used binocular rivalry to induce frequent changes in conscious perception in the absence

of any external changes in sensory stimulation, while measuring cortical responses with functional MRI. Using information present in the multivariate pattern of responses in early visual cortex, we were able to accurately predict, and therefore track, the conscious experience of participants over periods of several minutes. During this time, multiple changes in the contents of participants' subjective experience were accurately predicted from fMRI measurements alone. Our findings show that it is possible to predict the dynamically changing time-course of subjective experience only using brain activity, in the absence of any behavioural clues.

Acknowledgment: This work was funded by the Wellcome Trust

10 Perceptual mis-binding of color and form during binocular rivalry

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PURPOSE: How are separate neural representations of color (red) and form (an oriented grating) bound together to give a unified percept (a red grating)? Dichoptic presentation of rivalrous chromatic gratings reveals perceptual mis-binding of color and form, which implies (1) color and form rivalry are resolved separately and (2) resolution of color rivalry goes beyond just color dominance and color mixture. **METHODS AND RESULTS:** An equiluminant square-wave red/gray grating was presented to the left eye and an equiluminant blue/gray grating to the right eye. After an initial period of rivalry (less than a minute), these stimuli resulted in a perceived red/blue grating. This two-color perceived grating is not consistent with previous studies of dichoptic presentation of two chromaticities, which report either binocular color rivalry or binocular color mixture. Instead, the percept is accounted for by mis-binding of the color presented to each eye with the perceived form. In experiments, observers dichoptically viewed two rivalrous stimuli for 1 minute. The visibility time was measured for three percepts: left-eye stimulus, right-eye stimulus, or two-color grating. The chromaticities of the gratings were varied to exclude opponent chromatic induction as an explanation. Three types of spatial configurations were tested to exclude optical misalignment (eye vergence) as an explanation. All three configurations gave rise to the percept of a two-color grating, regardless of the chromaticities. **CONCLUSIONS:** The experiments showed that neither classical chromatic contrast nor misalignment of the two eyes could explain the percept of a grating with both eyes' rivalrous chromaticities (e.g., a red/blue grating). These results show that color rivalry is resolved independently of form rivalry and, further, that two rivalrous colors can both be represented simultaneously but separately. "Resolution" of color rivalry is not restricted to color dominance or color mixture.

Acknowledgment: This research was supported by PHS grant EY-04802.

11 The Effect of Ocular Dominance and Interocular Rivalry on Monocular Reading Speed Under Near-Normal, Ganzfeld, and Complete Occlusion Conditions

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Purpose: Normal reading typically involves binocular processes. However, in the case of monocular reading, the non-reading eye may interfere with the processes of the reading eye depending on the nature of the input to that eye. Furthermore, this interference may differ depending on whether the eye reading is the dominant or non-dominant eye.

Method: The monocular reading speed of seventeen participants with normal vision was tested under six conditions. Three conditions tested the reading speed of the dominant eye while the non-dominant eye received patterned input, light input, or no input, and the other three conditions were similar for the non-dominant eye.

Results: No difference in monocular reading speed was found between the dominant and non-dominant eye. A significant difference was found between patterned input and light input ($p < .05$), as well as patterned input and no input ($p < .05$).

Conclusions: While dominance does not seem to play a role in monocular reading, the level of input into the non-reading eye heavily affected monocular reading speed. Specifically, patterned input in the non-reading eye negatively affected monocular reading speed while light input and no light input did not. These results support the hypothesis that patterned input in the non-reading eye would most negatively affect reading speed as reading involves the interpretation of patterned information.

12 Perceptual and neuronal dynamics of binocular rivalry flash suppression

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Asynchronous presentation of two dissimilar patterns at the same point in visual space can lead to the perceptual domination of the second pattern, accompanied by suppression of the first. This flash suppression is particularly pronounced when there is direct interocular conflict, as in binocular rivalry flash suppression (BRFS, Wolfe, 1984), or more subtle interocular differences as in generalized flash suppression (GFS, Wilke et al, 2003). Under conditions favorable to monocular rivalry, asynchronous presentation is also effective at promoting exclusive visibility when two overlapping patterns are shown to corresponding portions of the same eye (Maier et al., ECVF 2004). The dynamics of all these phenomena appear to be closely related, all possessing an increasing probability of perceptual suppression with longer 'adaptation' intervals before the presentation of the second stimulus.

Here we present neuronal activity in monkey areas V4 and MT during BRFS using various pre-flash intervals. Animals performed a fixation task while dichoptic grating patterns were presented asynchronously to the two eyes. Pre-flash intervals were varied over the range used for psychophysical testing. We found that neural responses to this presentation followed the expectations based on perception, with longer pre-flash intervals eliciting larger modulation. This was largely caused by an inhibitory response component that could only be evoked if pre-flash intervals were large enough to reliably elicit perceptual suppression. This time course of perception-related modulation was largely comparable to that observed with GFS in an accompanying study. Taken together, these observations provide evidence that the diverse phenomena of flash suppression share common active mechanisms related not to any particular stimulation condition, but more generally to perceptual organization.

Acknowledgment: Work was supported by Max Planck Society

13 Temporal dynamics of generalized flash suppression in V4

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A wide range of salient visual stimuli can be made to suddenly disappear from view following the onset of a large surrounding pattern (generalized flash suppression, GFS, Wilke et al (2003)). The interaction of two factors has previously been found to maximize the probability of perceptual suppression in the context of GFS: some kind of interocular interaction other than spatial conflict, combined with the introduction of approximately a second temporal delay between target and surround onset (stimulus onset asynchrony, SOA). In the present study we examined the neurophysiological basis of this observation by means of multielectrode recordings in area V4 of awake monkeys. Specifically, we were interested in whether the increased probability of perceptual target

suppression with longer SOAs could be explained by a decay in the firing rate of neuronal populations responding to the target. To test this, we systematically varied the time between target and surround onset between 0 ms (simultaneous onset) and 1400 ms under different ocular configurations. By subtracting neuronal activity in 'target only' trials from 'target + surround' trials for a given SOA, we found significant neuronal suppression only with the SOA times that reliably led to perceptual disappearance. Further matching perception, maximal attenuation occurred at a mean latency of about 130 ms to 200 ms after surround onset - approximating the previously measured latency to subjective disappearance in GFS. Moreover, optimal suppression was achieved with incongruent ocular target/surround configurations. These data suggest that response modulations in area V4 are closely related to perception during GFS, and that neural adaptation cannot alone account for the all-or none perceptual disappearance of the target.

14 Multistable motion rivalry - four co-localised motion directions compete with similar dynamics to binocular motion rivalry

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Following Diaz-Caneja's observation of multistable perception across the midline, Suzuki and Grabowecky (Neuron 2002) have recently studied the dynamics afforded by the increased perceptual options, including path dependence and on-line adaptation, which were equivalent whether the rivalrous exchanges perceived were formed by single-eye or mixed-eye dominance. Because the four perceptual options of Suzuki were formed by a mid-line split of the two stimuli, we investigated whether more than two discrete stimuli existing at the one point in space could individually compete for dominance. Three experienced subjects with normal or corrected-to-normal vision viewed through a stereoscope (or performed free-fusion of) two circular stimuli each containing a red pattern of moving dots and a green pattern moving in the opposite direction (Left eye Up-Down, right eye Left-Right), each with 90% coherence. Thus all four cardinal directions are represented when the patterns are superimposed. After a short period of adjustment, alternation of 4 rivalrous percepts emerged such that alternations of dominant motions were clearly visible with other motions either missing or apparently in the background. Each of the four motions demonstrated dominance durations well-fit by a log-normal distribution. Mean durations were calculated for a series of trials where the velocity of one dot motion (green horizontal) was varied from 1 to 408/sec. While interaction was clear between dominance durations for opposite motions, increasing the strength of one direction did not appear to affect durations of orthogonal directions. Transition history showed that approximately 55% of transitions were within eye and 45% between eyes, despite an equal probability model predicting 33.3% within eye and 66.7% between eye. Both interocular rivalry suppression and hemispheric switching theories would require significant modification in order to explain the data.

15 Cortical Responses to Invisible Objects In Human Dorsal And Ventral Pathways

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It is long believed that the human visual system comprises two main pathways, a ventral pathway that explicitly represents perceptual experience and a dorsal pathway that can process visual information and guide action without accompanying conscious knowledge. Evidence for this theory has primarily come from studies of neurological patients and animals. Here, we used functional Magnetic Resonance Imaging (fMRI) to measure cortical responses to invisible objects in human dorsal and ventral object-selective areas. When low-contrast stationary images of objects are presented to the non-dominant eye and high-contrast and dynamic noise

to the dominant eye intermittently, object images can be suppressed from consciousness for minutes. We found that in normal human subjects, even when they were completely unaware of the nature of visual input due to interocular suppression, dorsal cortical areas, but not ventral cortical areas, showed significant activities for different types of visual objects, with stronger responses to man-made tools than human faces. This pattern of results supports the distinct functional role of the dorsal and the ventral streams. The results also suggest that in binocular rivalry, substantial information in the suppressed eye can escape the interocular suppression, possibly traveling through the sub-cortical pathways that feed directly to the dorsal cortical regions, or through the Magnocellular pathway that is believed to be less susceptible to inter-ocular suppression.

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Biological Motion 1

16 Perception of biological motion at varying eccentricity

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Purpose: Items in the periphery are harder to see than those in the fovea. The degree of difficulty depends on the task and stimuli used. We investigated the size threshold for determining a point-light walker's direction of motion both in the fovea and in the periphery. The rate at which this threshold increases as stimuli are shown farther into the periphery is described by the eccentricity (E_2) at which a stimulus magnified to twice the size would show equivalent performance in the fovea. **Method:** Point-light treadmill walkers of different sizes were presented by method of constant stimuli at four levels of eccentricity: 0, 10, 20, and 40 degrees. Participants reported which direction the walker was headed (right or left) without feedback. **Results:** Threshold size was surprisingly small. Thus a six-foot walker's direction could be discerned at a distance of 1400 feet at the fovea and at about 85 feet at 40 degrees eccentricity. E_2 values ranged from 3.1 to 3.8. **Conclusions:** In comparison to significantly lower E_2 values for both simple and more complex form tasks, these high E_2 values suggest that the periphery is more efficient in coding complex moving patterns. It is of interest to determine whether other perceived aspects of biological motion, for example gender, have similar E_2 values.

17 Eccentricity dependency of the biological motion perception

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Accurately perceiving the activities of other people is a crucially important social skill of obvious survival value. Human vision is equipped with highly sensitive mechanisms for recognizing activities performed by others (Johansson, 1976). One putative functional role of biological motion perception is to register the presence of biological events anywhere within the visual field, not just within central vision. To assess the salience of biological motion throughout the visual field, we compared the detection performances of biological motion animations imaged in central vision and in peripheral vision. To compensate for the poorer spatial resolution within the periphery, we spatially magnified the motion tokens defining biological motion. Normal and scrambled biological motion sequences were embedded in motion noise and presented in two successively viewed intervals on each trial (2AFC). Subjects indicated which of the two intervals contained normal biological motion. A staircase procedure varied the number of noise dots to produce a criterion level of discrimination performance. For both foveal and peripheral viewing, performance increased but saturated with stimulus size. Foveal and peripheral

performance could not be equated by any magnitude of size scaling. Moreover, the inversion effect - superiority of upright over inverted biological motion (Sumi, 1984) - was found only when animations were viewed within the central visual field. Evidently the neural resource responsible for biological motion perception are embodied within neural mechanisms focused on central vision.

18 Detection of biological motion in the visual periphery

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In general, studies of peripheral vision report that spatial acuity and form perception decline rapidly outside the fovea. The course-grained information the peripheral retina provides is inadequate for form recognition. Instead, the peripheral retina provides only cues to elements in the visual field to which we might orient. With few exceptions (e.g., Thorpe, Gegenfurtner, Fabre-Thorpe, & Bulthoff, 2001), these studies employed simple or artificial stimuli such as letters and gratings. In the current study, we examined sensitivity to socially-salient stimuli in the nasal and temporal periphery. Two human movements—walking and lunging—were depicted in high-contrast point-light displays. Each movement was performed in 5 different orientations relative to the picture plane. Foils were created from each target in each orientation by randomly relocating the point-light elements comprising the target figure. On each trial, a target or foil figure was presented in one of 14 locations throughout the horizontal visual field, from 50 deg in the nasal to 75 deg in the temporal visual field. Observers were asked to discriminate the target and foil displays viewed monocularly, with their heads held stable in a chin rest. Observers were presented either the walking or the lunging targets and the corresponding foils. We recorded discrimination accuracy and reaction time. Initial analyses suggest that observers are able to discriminate alternative forms in structure-from-motion displays at the most extreme eccentricities we tested. These results suggest that the visual periphery's ability to extract motion-carried information is not limited to optic flow information.

19 The conspicuity of pedestrians at night: How much biological motion is enough?

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Most collisions between vehicles and pedestrians occur at night and inadequate visibility has been implicated as a key causal factor. Earlier research has shown positioning reflective markers to depict biological motion greatly enhances pedestrian conspicuity at night. To determine the extent to which enhanced conspicuity can be achieved with fewer biological motion elements, we measured the distance at which passengers pressed a button to indicate their confidence that a pedestrian was present. 120 university students (18-24 years) were driven along a 5.1 mile residential route using low beams. At two dark locations along the route a pedestrian (an experimenter) had been positioned to the right of the roadway. The pedestrians, who either stood still or walked in place, wore either black clothing or black clothing plus 304 cm² of retroreflective material in four different configurations (a rectangular vest; ankles; ankles & wrists; full biological motion). The mean response distance for the vest condition (23.8 m) was not significantly different from the mean response to the black condition (30.6 m). When pedestrians were walking in place, all conditions with markings on the extremities were significantly more conspicuous, with response distances ranging from 88.9 m (ankles) to 113.5 m (biomotion). Although the advantages of marking the extremities was reduced when the pedestrians were standing still, the biological motion configuration (63.2 m) and the ankles & wrists configuration (45.4 m) remained significantly more conspicuous than the other conditions. Marking the ankles only (where low beam illumination is maximal) was effective when the pedestrian was walking but was ineffective when the pedestrian stood still. These results confirm that incorporating biological

motion substantially enhances pedestrian conspicuity at night. Interestingly, our results also suggest that motion patterns alone can not explain the conspicuity advantages of biological motion.

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20 The ups and downs of point-light displays: Sensitivity to upright and inverted biological motion

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Inversion of point-light displays depicting biological motion impairs identification of the depicted action, actor, and emotion (e.g., Dittrich, 1993). This impairment arises from the discrepancy between the orientations of the observer and the display rather than from the inversion of the display itself (Troje, 2003). In the present study, we quantified the impairment by comparing the processing of upright and inverted biological motion embedded in noise in a 2-interval temporal forced-choice task. Each trial comprised a point-light biological motion stimulus depicting one of 12 possible actions, and a scrambled version of the same action. Scrambled stimuli were equivalent to biological motion stimuli in the movement of individual dots (black, 10 arc min, moving on a gray background), but the movements were disrupted in both temporal phase and spatial location. Each biological motion and scrambled display lasted 1 sec and was embedded in a mask composed of a variable number of dots. The number of masking dots was varied according to a staircase procedure to determine the maximum number of masking dots yielding 71% accuracy. Masking dots each underwent equivalent motion to one of the dots in the biological motion display. Participants (n=20) tolerated substantial amounts of noise in both orientations of the display, although thresholds for the inverted condition (63 noise dots) were significantly worse than thresholds for the upright condition (88 noise dots), $p < .01$. The results are consistent with fMRI findings that the area in the posterior STS that responds preferentially to upright biological motion also responds above the baseline rate to scrambled biological motion when the stimuli are inverted (Grossman & Blake, 2001). The findings substantiate the exquisite sensitivity of the human nervous system to patterns of human motion, even patterns that have never been experienced in the real world such as point-light displays of inverted climbing of stairs.

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21 Perception of point-light biological motion at isoluminance.

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Background. Individuals are remarkably adept at recognizing the human form in action solely from the motion of the joints (Johansson, 1973). Recognition of biological motion has been shown to depend on spatio-temporal integration of the dots, though recent evidence has called into question the extent to which image motion is critical (e.g. Beintema & Lappe, 2002). These experiments examine the extent to which viewing biological motion without luminance cues, a manipulation that degrades motion sensitivity, impairs perception of biological motion. Method. All subjects were screened for normal color vision as measured by the Ishihara Color Plates. Observers viewed animations depicting either a human action (biological motion) or non-biological motion-matched controls ('scrambled motion'). Psychometric functions were measured for two-alternative forced choice discriminations on the animations embedded in four levels of dynamic noise. The dynamic noise consisted of the same motion trajectories as the biological or scrambled targets. The displays were rendered as green dots on a red background, or vice versa, and either differed in luminance or had the same perceived luminance as determined by a minimum flicker task using random dot patterns. Subjects also performed a direction discrimination task on red/green random-dot

kinematograms with varying levels of direction coherence. Results. Direction discrimination was better with the luminance cue than at isoluminant light levels, verification that subjects were indeed able to determine their point of red/green isoluminance in the minimum flicker task. Discrimination performance on the biological motion task was also better in the luminance condition than in the isoluminance condition. Conclusions. Removing luminance cues from point-light animations reduced sensitivity to biological motion. These results will be discussed in the context of the relative contributions of form and motion in biological motion perception.

22 How Much Does Biological Motion Perception Depend on Motion?

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Purpose: When presented with a single frame, naïve observers do not spontaneously recognize it as a human figure. However, non-naïve-observers can perceive biological 'motion' from a static display. Static frame conditions and conditions with poor motion quality may provide the key to discovering how much biological motion perception depends on form or motion perception. Method: Motion quality was degraded in three ways: inserting blank frames, displaying motion out of order, and decreasing the number of frames presented. Two animation conditions were used, one where blank frames were presented between each frame of the animation sequence and another where each frame remained visible until the next frame was presented. The animation sequences contained 1, 3, 6, 12, 23, or 45 frames presented over a 1.1 second period. Observers indicated whether the first or second of two presentations contained a point light walker among scrambled walker masking dots. Results: There was no difference between the two animation conditions. In the one frame condition, observers required about 25 mask dots to mask biological 'motion.' However, as the number of frames increased beyond six frames, more masking dots were required to mask biological motion. This increase was much more pronounced for animation sequences presented in order compared to those presented out of order. Conclusions: Adding motion to the display does not seem to have an effect until the motion quality is about twelve frames per second. Specifically, performance in the three and six frame conditions, where the motion quality was poor, was similar to performance in the 1 frame (no motion) condition. This suggests that under poor motion quality conditions, form perception may play a large role in perceiving biological motion and may be more useful to consider than short- versus long-range motion processing distinctions.

23 Configural processing in biological motion detection: human versus ideal observers

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Purpose: To provide evidence of visual system's configural processing in biological motion detection, by comparing human vs. ideal observers.

Method: A three-frame sequence of a 12-point human walker, as signal, was embedded in dynamic random-dot noise. In each trial subjects detected the walker in a yes-no task, with feedback. There were 10 counter-balanced blocks, 120 trials each. One of five levels of signal strength was used per block: 4, 6, 8, 10, or 12 points were randomly sampled from the 12 walker points per trial. Detection sensitivity per signal strength level was defined by the number of noise dots at 75% correct detection, in a staircase procedure (Neri, Morrone, & Burr, 1998).

An ideal observer was designed using knowledge of how the random noise dots and walker dots were generated. It assumes knowledge of the dynamic form of the walker but does not know which walker dots are present. The ideal observer made decisions based on the number of noise or walker dots located at appropriate positions, which follows binomial distributions.

Results:

When the walker was upright, subjects' sensitivity was a quadratic function of the number of displayed walker dots, a result predicted by the ideal observer. This suggests that subjects used the dynamic configurational representation of biological motion. In contrast, when the walker was upside-down, subjects' sensitivity was a linear function of the number of displayed walker dots, suggesting that subjects were unable to efficiently use the dynamic walker representation, but instead detected the signal walker based on a low-level process. The latter is consistent with the prediction by Barlow & Tripathy (1997) based on smooth motion correspondence of individual dots.

24 The Effect of Blurring on Action Recognition by Human Subjects

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Several experiments on human subjects evidenced how they are endowed with a good ability to recognize unambiguously a motor action, whilst they are not able to recognize without uncertainty an action from a single image frame representing the same action. In fact, the movement is a motion characterized by a whole spatio-temporal pattern, with specific spatial distributions of kinetic energy, and is sufficient for extracting meaningful information about 3-D shapes.

In this contribution we study how the interaction between two systems (the movement image and the cognitive system of the observer) changes when a feature of the image is manipulated. The image features were its dynamics, its shape and the spatial relationships occurring between its components. In order to investigate the effects of these features we showed to 80 students movies and slides depicting different actions, with four blurring levels (0-3), obtained through a mosaic technique that masks shape and spatial relations. The subject task was to give a verbal interpretation of the action depicted by the pattern itself. The goals of the experiment were to know if humans were able to recognize actions only getting information from dynamics, and at what shape definition level a human observer was able to distinguish two movements that showed the same dynamics but were associated to different actions.

The findings evidenced that the blurring level had a strong influence if the input pattern was a static image. So the movement carries a lot of information about the dynamics and the action that is quite independent from the objects contained in the scene. Moreover, in correspondence to the same blurring level, actions and dynamics were not recognized with the same precision, leading to a recognition of dynamics without the corresponding recognition of the associated action. This supports the hypothesis asserting the existence, within subjects, of general movement schemes operating in the recognition process.

25 Multistability of Point-Light Gait is Resolved by the Optical Flow of the Ground

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Two dimensional point-light walker displays are ambiguous in depth (Proffitt et al., 1984; Vanrie et al., 2004). Yet, observers are frequently unaware of this ambiguity (Bulthoff et al., 1998). What cues does the visual system use to disambiguate human motion? Object perception is strongly dependent upon ground cues. We therefore tested whether the ground influences the perceived direction of a point-light walker's gait. Across three studies, naïve observers viewed computer-generated displays of a point-light walker and reported whether the point-light person walked towards or away from them. In Exp 1, the point-light person was positioned above 10 points in a trapezoidal arrangement depicting a rigidly translating surface. When the points defining this ground surface translated away from observers, the point-light person appeared to walk towards the observers (82% 'toward' and 18% 'away' responses). Conversely, when this ground translated toward observers, the point-light

person appeared to walk away from the observers (70% 'away'). Thus, ground motion significantly influences the perception of gait direction. In Exp. 2, the point-light defined surface was positioned above the point-light walker's head. When positioned as a ceiling, the translating surface had significantly less impact on the perceived direction of the walker's gait. In Exp. 3, the ceiling and ground motions were placed in conflict. That is, inward ceiling motion was paired with outward ground motion and visa versa. When an ambiguous point-light walker was placed in between conflicting ceiling and floor motions, the floor motion was significantly more likely to capture the perceived direction of gait. Taken together, these results suggest that the visual interpretation of human motion depends upon the physical restrictions on that motion. Specifically, the ground constrains human motion (Gibson, 1979) and visual analyses appear to take that into account.

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26 Learning Mid-level Motion Features for the Recognition of Body Movements

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Body movements are characterized by specific sequences of complex optic flow patterns. Computational models for the perception of static shapes have demonstrated that recognition performance can be significantly improved by choosing an appropriate dictionary of mid-level shape-components (see abstract by Serre & Poggio, 2005). Preliminary results suggest that such shape-tuned units are consistent with recent physiological data collected in V4 (see abstract by Cadieu et al, 2005). We test if the visual recognition of complex body movements from optic flow might also benefit from optimized motion-component units.

METHOD: We employ a physiologically inspired learning algorithm for the optimization of mid-level motion detectors of a hierarchical model for the recognition of human actions (Giese & Poggio, 2003). In the proposed algorithm, competing units are associated with a memory trace that reflects their recent synaptic activity. The model is presented with movies showing a human action (i.e. walking): the trace from units that are behaviorally-relevant is increased while the trace from the others is decreased. Units whose memory trace falls below a critical threshold are randomly replaced.

RESULTS: When presented with movies showing human actions, the model generates a dictionary of mid-level motion-component units that lead to a significant improvement of the recognition performance. For the special case of walking, many of the units' preferred stimuli were characterized by horizontal opponent motion, consistent with a recent experimental study showing that opponent horizontal motion is a critical feature for the recognition of these stimuli (Casile & Giese, 2003).

CONCLUSION: Like for the categorization of static shapes, recognition performance for human actions is improved by choosing optimized mid-level motion features. In addition, the extracted features might predict receptive field properties of complex motion-selective neurons, e.g. in areas MT and MSTl.

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Attention, Motion, and Tracking

27 Multiple Visual Object Juggling

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Purpose: In standard multiple-object tracking experiments, Os attend to specific objects (targets) while ignoring other objects (distractors).

Typically, the targets are identified at the start of each trial. Then, all objects become identical and move about the screen. After some period of time, memory for target items is assessed. Real life is more continuous. You monitor two cars on the highway. Then a new car becomes relevant, an old one moves away, and so on. We wish to assess the ability to change the tracked set during a trial.

Method: In the critical condition, a set of identical items begins moving. Os are instructed to begin to track targets that briefly change color. They are instructed to stop tracking targets that are briefly marked with an X. This condition was compared with two others. In one condition, all targets were defined at the beginning of each trial as in a typical tracking task. In another, targets were added dynamically, once the items were moving. However, no targets were dropped during a trial. Total tracked items were never greater than four. The overall set size was eight objects. The tracking duration was twenty seconds.

Results: As soon as you see a demonstration of the display, you will know what the data must look like. Performance was very proficient in all conditions. The juggling (pick up and drop off) condition produced 88% accuracy compared to 90% when targets were added throughout the experiment and 87% accurate in the standard tracking experiment.

Conclusions: It is not necessary to establish the tracking set before the start of tracking nor even to have a fixed set. Os can proficiently add and delete items from the tracked set. In on-going experiments, Os appear to be able to do this for trials lasting many minutes.

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28 Target Tracking During Interruption in the Multiple-Object Tracking Task

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Observers can successfully track a subset of independently moving identical objects in a multiple-object tracking task, even if all objects disappear for a 300-500 ms gap. How observers reacquire targets following such a gap reveals what kinds of information they maintain for moving objects. With identical objects, only two types of information are available: location and trajectory. In Experiment 1, objects disappeared and then reappeared at one of three locations: the point of disappearance ("stay" condition), the position predicted by continued motion during the gap ("forward"), or the position predicted if the object had reversed direction during the gap ("reverse"). We found that tracking accuracy in the stay condition was superior to both the forward and reverse conditions, which were equivalent, supporting the use of location information in target reacquisition. Experiment 2 replicated Experiment 1, but with a condition in which objects disappeared one at a time. In this case, tracking accuracy in the forward condition, while still worse than in the stay condition, was now superior to that in the reverse condition. In Experiment 3, objects always reappeared in the forward position. In the motion condition, objects moved before they disappeared. In the static condition, they were stationary before the gap but reappeared in the forward position. Tracking performance was better in the motion condition. Experiments 2 and 3 support the use of trajectory information in target reacquisition. Taken together, the results indicate that the visual system maintains both types of information about tracked objects, selectively favoring one or the other in reacquisition depending on the nature of the task. More speculatively, we suggest that there may be two distinct mechanisms: one for general task-postponement during simultaneous offset (see Horowitz et al., VSS 2004), and the other for maintaining object continuity during single-object disappearance or occlusion.

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<http://vision.arc.nasa.gov/personnel/al/papers/05vss/>

29 Rapid recovery of targets in multiple object tracking

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We have previously shown that Os in multiple object tracking (MOT) experiments can successfully track objects that disappear for up to 500 ms (Alvarez et al. in press; see also Keane & Pylyshyn VSS 04). Last year, we demonstrated that Os recover those tracked objects based on some memory representation, rather than tracking amodally during the gap. (Horowitz et al. VSS 04). How quickly can targets be recovered after they reappear? Are targets recovered one by one, or simultaneously? Here we employed a version of the MOT paradigm in which Os indicated whether or not a probed object was a target with a speeded response. Eight Os tracked 4 of 8 moving gray disks. After 1000 to 3000 ms of tracking, the disks disappeared for a fixed gap duration, then reappeared at updated positions as if they had continued to move during the gap. After a stimulus onset asynchrony (SOA) of 0, 80, 160, 320, or 1280 ms, one of the disks (the probe disk) turned red until response. The gap duration was either 0 ("no-gap" condition) or 133 ("gap") ms. At an SOA of 0 ms, response times (RTs) to target disks were elevated in the gap condition relative to the no-gap condition; however, at SOAs of 80 ms and greater, there was little or no difference between RTs on the gap and no-gap conditions. In a second experiment (8 Os) that included shorter SOAs, the difference in RT between gap and no-gap conditions disappeared by 40 ms. Os can apparently recover targets within 40 ms after reappearance. This rapid timecourse argues against a target-by-target, serial recovery process. Instead, Os may be matching a single template of expected target locations to the display.

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30 Attentive tracking of multiple objects by humans and monkeys

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Human observers can attentively track 3-5 stimuli as they move along independent random trajectories among distracter stimuli (Pylyshyn and Storm, 1988; Sears and Pylyshyn, 2000). We developed a multi-object tracking task suitable for monkeys, and measured task performance in two monkeys as we varied the number of tracked and distracter stimuli. Each trial began with fixation of a central point, after which 4-8 identical stimuli appeared at equally eccentric peripheral positions. A subset of these briefly flashed, identifying them as targets. All stimuli then moved along random independent trajectories for 2-3 seconds while the monkey maintained fixation. All stimuli terminated motion at equally eccentric positions that were unpredictable from their initial positions. The monkey indicated the identities of the targets by making a saccade to each. Reward was only delivered if the monkey made saccades to all targets and no distracters. After extensive training both monkeys showed reliable tracking for two items. Humans were able to track 3-4 items when tested with the same stimuli. Initial recordings in Area V4 made with one tracked target and three distracters found that V4 responses evoked by the tracked object were on average ~20% stronger than responses evoked by the same stimulus when it was not being tracked.

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31 Further evidence for inhibition of moving nontargets in Multiple Object Tracking

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Using the Multiple Object Tracking (MOT) task involving tracking 4 targets moving randomly among 4 identical nontargets, Pylyshyn & Leonard (VSS03) showed that a small brief probe dot was detected more

poorly when it occurred on a nontarget than when it occurred either on a target or in the space between items, suggesting that moving nontarget items were inhibited. Here we generalize this finding by comparing probe detection performance against a baseline condition in which no tracking was required. We examined both a baseline condition in which objects did not move and one in which they moved exactly as in the probe detection task, but without tracking. Detection in the nonmoving control was essentially error-free, but probe detection performance in the moving (non-tracking) control task did depend on the probe location. Nonetheless, the findings reported earlier (worse detection on nontargets than anywhere else) remained after we took account of the baseline performance (using several different baseline comparison methods). Using this new baseline-control method we also showed that inhibition does not spread more than about 1.3 degrees of visual angle from the nontargets as the latter move during a tracking trial. In the present report we also describe some preliminary studies of conditions under which enhancement of targets, as well as inhibition of nontargets, may be obtained. Increasing the number and type of nontargets appeared to improve the detection of probes on targets, relative to baseline. However, we failed to find evidence that potentially distracting nontarget objects were inhibited more than clearly task-irrelevant objects, as would be expected if inhibition were a top-down process applied in order to improve performance on the main tracking task. For example, using the comparison with its matching baseline, we showed that task-irrelevant stationary items (which are never confused with targets in the tracking task) appeared to be inhibited even more than nontargets.

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32 Using multiple-object tracking (MOT) to test whether cerebral hemispheres share common visual attention resources

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Alvarez & Cavanagh (VSS 2004) showed that attentive tasks presented to left and right cerebral hemispheres appear to be carried out independently, so observers perform a pair of tasks presented to different hemispheres much better than when they are presented to the same hemisphere. We further explore this important finding by using a pair of multiple object tracking (MOT) tasks involving tracking 2 targets out of 4 identical objects, which were presented in two separate quadrants of a display. We tested whether stressing one of the two tasks by increasing its speed results in poorer performance on that task and/or the paired task when the two tasks are presented in the same hemisphere compared with when they are presented in different hemispheres. The assumption that resources for the speeded-up task could be borrowed from the paired same-hemisphere task but not from the paired different-hemisphere task leads to several predictions. An increase in difficulty of one task should result in greater performance decrement in the second task in the same-hemisphere condition compared with the different-hemisphere condition. Moreover, since resources cannot be borrowed from the second task in the dual-hemisphere condition the decrement in performance on the speeded-up task itself should be greater in the dual-hemisphere condition than in the same-hemisphere condition. We used several baseline measures to assess the degree of interaction between tasks in the dual-hemisphere presentations compared with matched single-hemisphere presentations and confirmed all the above predictions, as well as the original A & C findings, thus adding strong support to the conclusion that one hemisphere is unable to draw upon attentional resources from the other hemisphere to help with an increasingly difficult task.

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33 Object substitution masking during attentive tracking

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A recently reported form of visual masking named object substitution masking (OSM) occurs when a sparse mask such as a group of four dots is presented simultaneously with the target (Enns & DiLollo, 1997). When the mask lingers in the display following target offset, the masking can occur. Some studies reported that the masking could be observed even when the target and mask were presented at the separate position and time, and implied that the masking could be regarded as a token individuation failure between the target and the mask. We introduced a new technique to couple attentive tracking and OSM to investigate the effect of the individuation between the target and mask under the control of the locus of attention. Observers attentively tracked a disk in an ambiguous motion display of six disks. After several frames, the discs changed into Landolt-Cs. Observers were required to report the gap direction of the Landolt-C that was surrounded by the four dots mask. When the target and mask offset simultaneously, observers could respond correctly even if it was not the tracked item. Whereas, when the mask lingered at the target position after the target offset, observers responded correctly only when the target was the tracked item. That is, OSM was found. We assessed the minimum target-mask SOA that could produce the masking effect. Our initial hypothesis was that this SOA should be close to the minimum SOA between the frames in the ambiguous motion display with which the observer could attentively track one item, where we thought the visual system could individuate tokens of stimuli. Indeed the masking effect reduced around 140ms-SOA that was close to the minimum SOA for the tracking (7Hz or 143 ms; Verstraten et al., 2000). These results support the target-mask individuation failure view of the OSM and suggest that it is necessary for the effect that the target and the lingering mask are presented within the spatio-temporal attentional resolution.

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34 Cortical and Behavioral Manifestations of Dynamic Object Occlusion

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How does the visual system keep track of a moving object that temporarily disappears and re-emerges again? We investigated the nature of the tracking mechanism with two tasks. In the first, observers maintained central fixation and covertly tracked a target that translated back and forth on a constant linear trajectory at three velocities, fast (3.9 deg/s), medium (2.6 deg/s) or slow (1.7 deg/s). 'Unoccluded' trials consisted of a fully visible trajectory and 'occluded' trials were identical except for an invisible occluder that concealed the center of target's trajectory. Observers judged the target's re-emergence from behind the occluder with a button press. These judgments were highly accurate for fast and medium trajectories in both occluded and unoccluded trials, but there was increased variability in these anticipatory judgments of re-emergence during occluded slow trajectory trials, suggesting an unstable representation of the target in space across longer delays.

The second task was identical to the first except observers were not required to press a button, but only to watch the stimulus as we recorded cortical activity with fMRI. Extrastriate regions showed increased activation during unoccluded relative to occluded trials presumably related to the representation of the visible target. Additionally, we identified cortical regions that showed increased activity during periods of temporary dynamic occlusion. The right angular gyrus and posterior portions of superior temporal sulcus showed increased activation during occluded relative to unoccluded trials. Activation during occlusion may be related to maintaining an internal representation of the spatiotemporal properties of the invisible target in the visual system during attentive

tracking. These findings may shed light on the cortical mechanisms involved in the phenomenon of perceptual constancy.

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35 The upper temporal limit of attention-based motion perception is increased by an in-phase auditory stimulus

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Attentively tracking a feature (e.g. a disc) in an ambiguous radial motion display results in the perception of a clear motion direction (either clockwise or counter-clockwise, see Verstraten et al., *Vision Research* 2000; vol. 40, 3651-3664). Attentive tracking has an upper temporal limit. Here we investigate whether auditory stimulation, either in or out of synchrony with the visual stimulus can affect this tracking limit.

Two circular arrays of 10 evenly spaced discs were alternated in time and space, separated by a blank ISI. This results in successive steps of 18 degrees, and 20 attentive steps to complete one full revolution. Using the keyboard observers adjusted the alternation frequency of the two circular arrays, such that they could just attentively track a single disc for at least two full revolutions. The maximum alternation frequency at which observers could track a disc was measured for 3 main conditions: attentive tracking without auditory stimulation, tracking accompanied by an in-phase auditory stimulus and, tracking with asynchronous auditory beeps. The beeps were presented through headphones and contained no spatial information. Given the higher temporal resolution of the auditory system and assuming an auditory-visual interaction (e.g. Shams et al., *Nature* 2000; vol. 408, 788) we expected in-phase beeps to facilitate attentive tracking.

The results showed that in-phase auditory stimulation increased the upper temporal limit of attentive tracking. Moreover, out of phase beeps did not impair tracking performance. These results make it tempting to suggest that the mechanism responsible for the temporal resolution of visual attention receives facilitatory input from the auditory system.

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36 Attentional control of multi-stable aperture motion

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Ambiguous stimuli often look different in different contexts. This study measured the combined influence of visual and behavioural context on the subjective appearance of aperture motion. Subjects fixated the centre of a circularly-windowed drifting grating (2.9 deg diameter, orientation 45° clockwise from horizontal, with foveal mask), and continuously indicated the direction of perceived drift. Though many different distal motions could create the same proximal stimulation, only the vector orthogonal to the grating orientation was predominantly reported. However, adding two discrete horizontally-flanking 315° gratings (centre-to-centre separation 3.6 deg) produced spontaneous bistable switching between diagonal component motion and pattern motion, with the whole configuration occasionally appearing to drift upwards. Adding a second pair of vertically-flanking 135° gratings even produced tri-stable perception, with leftwards drift as the third mode. Thus, adding context increased rather than reduced the subjective ambiguity of aperture motion. Observers were now cued every 6 seconds to try to switch between leftwards and upwards pattern motion, by selectively attending to the vertical or horizontal configuration of three gratings respectively. Observers could rapidly switch between modes on demand, with dominance of the cued motion increasing markedly at the expense of the other two modes. However, behaviour was still constrained by stimulus factors modulating the appearance of pattern motion. As the extreme case,

little or no control was possible with just a single isolated grating. Goal-directed attention could therefore resolve the subjective ambiguity, by integrating a subset of the local motion components into a behaviourally-relevant pattern. Such selective context integration results in dramatic but voluntarily-controlled changes in the observer's subjective state.

Faces 1

37 Separate Face and Body Selectivity on the Fusiform Gyrus

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Recent findings of a high response to bodies in the fusiform face area (FFA) challenge the idea that the FFA is exclusively selective for face stimuli. We examined this claim by conducting an fMRI experiment at high resolution (1.4 x 1.4 x 2.0mm) on 9 subjects using visual stimuli in both blocked and event-related designs. Regions of interest (ROIs) were defined using data from the blocked-design runs, during which subjects viewed images of faces, headless bodies, and objects. We identified the FFA as the face-selective region on the fusiform gyrus with greater activation ($p < 0.0001$) for faces versus objects and an adjacent body-selective region with greater activation for bodies versus objects (see also Peelen & Downing, 2004). These regions overlapped in all subjects. To test whether separate and exclusive selectivities exist for faces and for bodies, we excluded the dual-selectivity voxels from further analysis, thereby creating two new ROIs, one that showed significant face but not body selectivity in the localizer, and one with the opposite pattern of body without face selectivity. On average 75 percent of voxels in the FFA were exclusively face-selective and 56 percent of the voxels in the body-selective ROI were exclusively body-selective. Our event-related data from the same subjects replicated this exclusive selectivity in each ROI: the faces-only region produced a significantly higher response to faces (1.04 PSC) than to bodies (0.44 PSC) or objects (0.39 PSC), which did not differ from each other. Conversely, the bodies-only region produced a significantly higher response to bodies (0.90 PSC) than to faces (0.55 PSC) or objects (0.56 PSC), which did not differ from each other. These results demonstrate strong and exclusive selectivities in distinct but adjacent regions in the fusiform gyrus for only faces in one region and only bodies in the other.

38 Activation in lateral occipital and fusiform cortex predicts performance in threshold face identification tasks

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Human observers can distinguish between highly similar faces in a fraction of a second. A network of cortical regions has been proposed to underlie human face processing. Areas in superior temporal (STS), fusiform (FFA), lateral occipital (OFA), as well as anterior temporal cortical regions and the amygdala are activated more strongly when observers view faces than non-face objects. Previous studies have suggested distinct roles for these areas, such as identity discrimination in the FFA and discrimination of emotional expression and/or gaze direction in the STS. However, previous studies have not determined whether these areas are critical to performing the perceptual discriminations, or whether their activation corresponds to ancillary, post-perceptual, processing (for example social processing, or multi-modal integration.) In the current study we use performance-based fMRI analysis to determine which areas show patterns of activation corresponding to successful perceptual discrimination. Subjects' thresholds were determined during a practice session utilizing a staircase procedure in a carefully controlled

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psychophysical face identity discrimination task. Presenting the stimuli at a known threshold during the fMRI data collection ensured that all changes in activity could be directly attributed to changes in internal state and not stimulus differences. We show that while areas STS, FFA, and OFA all show higher activation for faces than for a non-face blobby object, only the OFA and FFA show significantly greater activation when subjects are accurate. These findings, as well as other preliminary findings from discrimination tasks on face expression and gaze direction, suggest that areas OFA and FFA play primary roles in the basic perceptual processing of face stimuli.

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39 Severe acquired impairment of face detection and recognition with normal object recognition

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LJ, a 16-year-old male, had no history of visual difficulties prior to an incident in November 2004. After posing for a photograph preceded by red eye reduction flashes and the normal flash, LJ became disoriented and sounds were distorted. His disorientation and hearing difficulty cleared up within a matter of minutes, but his face perception has been severely impaired ever since. In the preceding years, he suffered from several spells of disorientation, including one following exposure to a strobing light. Other than face perception, LJ is unaware of any difficulties resulting from the incident. He reads and plays the piano normally. LJ is a world-class juggler, and his juggling has not suffered. He reports no difficulties with object recognition in daily life, and he has performed normally on a wide range of object tests. In contrast, LJ now inhabits a lonely world devoid of meaningful facial information. He is unable to identify few previously familiar faces, and successful identifications rely on recognition of individual features and a process of inference. He performs very poorly on tests of emotional recognition and gender discrimination, and his attractiveness ratings are atypical and unreliable. Unlike most prosopagnosics with face-selective impairments, he fails tests of face detection. When shown six Arcimbaldo faces, which consist of a collection of objects in a face-like configuration, LJ was able to see only one of the faces and he did so quite slowly. LJ also reports no facial imagery. He performed normally on several flawed face tests so he does not appear to be malingering. His difficulties with faces extend to inverted faces as well. His results indicate that face perception mechanisms are sharply segregated from object perception mechanisms, face detection is not carried out by general-purpose recognition mechanisms, and inverted face processing involves the processes used with upright faces.

40 A new test for face perception

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Currently there are no effective standardized tests of face perception without memory demands. This leaves us unable to determine if face recognition impairments are caused by perceptual or memory problems. Experiments with normal subjects also require assessment of face perception abilities. To address these issues, we have created a face perception task in which subjects must order simultaneously presented faces based on their similarity to a target face. The experiment consists of twelve sets; in each set a target face is presented along with six morphed test faces that each resembles the target face to a different degree. The test faces were created by morphing the target face with another face; different proportions were used to achieve different levels of resemblance. On some sets, we created each test face by morphing the target face with a different face, thus minimizing subject's ability to see continuous feature changes. Noise was added to the test faces in order to obscure the blurring effect of the morph technique. To determine if the task involves the specific mechanisms used for face recognition, we measured effect of inversion by

presenting half of the trials upright and half inverted. Subjects committed far more errors on inverted trials than upright trials. This indicates that this experiment does engage face recognition mechanisms. The prosopagnosic we tested did not show a significant inversion effect.

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41 Priming identity in biracial observers affects speed of visual search for different race faces

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Priming an individual with one of his or her social identities has previously been shown to affect cognitive performance on math and word completion tasks. We examined whether or not priming racial identity would influence the ability to search for different race faces. In the present study, we employed, Black, White and Biracial (Black/White) participants. Biracial participants were primed with either their Black or White racial identity by being required to write an essay describing one of these racial identities. All groups performed a Black/White face visual search task for faces. Black faces were detected faster than White faces. The results also showed a racial prime effect in Biracial individuals such that the magnitude of the search asymmetry was significantly different depending on whether or not they were primed with their White or Black identity. These findings suggest that top-down factors such as one's racial identity can influence mechanisms underlying the visual search for different race faces.

42 The face system is blind and inefficient to other-race faces

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Human beings are natural experts at processing faces, with the exception of other-race faces. Despite numerous studies it is still unclear whether the so-called *other-race effect* results from changes of visual information processing depending on the race of input faces. We first investigated this question with *hybrid* faces (Schyns & Oliva, 1999) that combined a face of a specific race (Asian or Caucasian) at a coarse spatial scale with the face of the opposite race at a fine spatial scale. A condition combining faces of the same-race at the different spatial scales was included for controlling response biases. When both races were simultaneously presented in the *hybrids*, Caucasian and Asian observers were biased to perceive their own race faces, independently of scale, revealing a tuning for same-race face information. To understand which facial information observers use to classify (as 'Asian' or 'Caucasian') and recognize (face identify) same- and other-race faces, we used *Bubbles*, a response classification technique that sampled facial information across the faces (Gosselin & Schyns, 2001). Surprisingly, participants used across tasks more information to classify and recognize same- (eyes, nose and mouth) than other-race faces (e.g., eyes and nose for the classification task). Crucially, however, they exploited facial information more efficiently for same- compared to other-race faces. Altogether our results provide new insights on the other-race effect and define how the face system, calibrated with experience for processing same-race faces, flexibly optimizes its selection in the use of facial information.

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43 Influence of facial expression on binocular rivalry between two faces

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PURPOSE: How do facial expressions affect perception of a face? Previous research on binocular rivalry suggests that stimulus strength (e.g. amount of contour or luminance contrast) affects perceptual dominance and suppression of the stimulus during rivalry. Certain facial expressions may increase perceptual strength of a face because of their emotional information. We examined the influence of facial expressions on perception of faces by implementing binocular rivalry experiments. More specifically, we tested whether (a) emotional faces had dominance over neutral faces, and (b) a negative facial expression, as a result of evolutionary advantage, had dominance over a positive facial expression. **METHODS:** Three different facial expressions (happy, disgust, neutral) from two female models (i.e. a total of six faces) were chosen from Ekman and Matsumoto's (1993) Combined JACFEE and JACNeuF. Twenty-four observers viewed two faces presented on a calibrated CRT through a haploscopic mirror system. During 1-minute presentation, exclusive visible time for each face was measured. **RESULTS:** Faces with facial expressions of happiness (18 ± 2 s) and disgust (17.2 ± 1.8 s) had longer dominance duration than a neutral face (10.2 ± 1.1 s) presented to the contralateral eye. When a happy face and a disgust face were presented to the two eyes, the happy face (19 ± 1.8 s) had longer dominance duration than the disgust face (12.6 ± 1.3 s). **CONCLUSIONS:** The experiments showed that emotional information from a face could affect perceptual dominance of the face, which suggested that facial expressions could change the strength of a face stimulus. The results are inconsistent with the perceptual advantage of negative facial expressions found in searching experiments. The results suggest the presence of a positivity bias, which is consistent with previous studies demonstrating higher accuracy for the decoding of happy faces in a variety of conditions.

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44 The effect of sharpness constancy on the recognition of facial expression

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Video-sequences appear sharpness even blurred images inserted into them. This effect, called sharpness constancy (Ramachandran et al, 1974), has been demonstrated empirically. Video-sequence images are actually somewhat blurred, but they look sharp when the video is played. We have examined effects of motion information of a face on the recognition by the method of varying the degree of blur among facial expressions.

Methods: We prepared video-sequences of 2 facial expressions (happy and sad), each of which comprised 26 frames. A video-sequence of 29.97 fps was mixed alternately the half of the 26 frames was blurred by Gaussian filtering with the non-blurred frame. Video-sequences were set by 3 scales (Gaussian filter radius 0, 4, 8 pixel). Also, Blurred still images were set by ten scales (Gaussian filter radius 0-9 pixel) as comparison stimulus. 2 observers judged the perceived sharpness of the movies by comparing the movie to a blurred still image.

Results: In case that the value of blur of video-sequences was large (4 or 8 pixel), observers judged the value of blur of still image lower than the value of blur of video-sequences. However, appearance keeps sharpness when video-sequences of sad faces show than when that of happy faces show.

Conclusions: We found that sharpness constancy occurs in video-sequences of facial expression, and this effect differs among facial expressions. These results suggest that a motion detecting mechanism on the recognition of facial expression depends on the spatial frequency

component of facial expression. Two explanation of this effect are possible: 1. Motion information of a face reconstructs the high spatial frequency information. The reconstruction ratio on happy faces is larger than that on sad faces. 2. Blurred images of a video-sequence were neglected. We can easily recognize the happy face with low spatial frequency, but we are hard to recognize sad faces with low spatial frequency.

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45 'Reading' Dynamic Facial Expression in Autistic Spectrum Disorder

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Autistic Spectrum Disorder (ASD) affects about 1 in 200 individuals and is associated with deficits in social communication and reciprocity. These abilities are highly dependent upon the ability to understand others' intentions and desires by 'reading' facial expressions and eye gaze direction. Instruments developed to diagnose ASD find that the ability to follow the direction of other's eye gaze, is impaired in ASD and discriminates between these children and those with other disorders. However, experiments have found that children with ASD reduce their reaction times to a two-choice stimulus, by taking advantage of a precue in the form of an eye gaze stimulus. These studies may be problematic as they employed static images of eyes that were removed from the face, and which could be treated as symbolic stimuli. In this study, 10 children with ASD and an age-matched control group were presented with a realistic computer generated face (composite of 100 real faces) before the presentation of an imperative stimulus (an arrow). Participants were required to press a right key when a central arrow pointed right and a left key when it pointed left. A 10 degree eye-movement within the face seen for 1000ms provided consistently valid precue information. The imperative stimuli would appear 500-3000ms (random) after the face disappeared. In a second block of trials, the eye shift occurred concurrently with a smile or a frown. The smile meant that the cue was valid but a frown indicated an invalid cue. This design feature was explained carefully to the children. This experimental paradigm provides an objective and quantifiable measure of whether children with or without ASD can integrate facial expression and eye-gaze to derive intentional information.

46 Interpreting Facial Expression Following Alcohol Consumption

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Social situations are strongly influenced by the way that individuals respond to others' facial expressions, which convey a wealth of information about a person's mental state such as the mood and intentions. Ethyl alcohol is often involved as a neuropharmacological factor in such situations and alcohol has been shown to alter facial perception to make some faces appear more attractive. It therefore appears that facial expression may influence behaviour to a greater extent under the effects of alcohol. We were interested in whether ethyl alcohol altered the ability to derive intentional cues from facial observation, or inhibit responses to those cues. To explore this issue, we used a simple two choice reaction time task in 8 healthy, right handed non-smoking males of BMI = 18-21 in a double-blind, placebo-controlled crossover design. Blood alcohol levels were raised to about 0.15%. Participants were required to press a right key when a central arrow pointed right and left when it pointed left. An eye-movement within a computer-generated facial expression (composite of 100 real faces) seen for 1000ms provided pre-cue information that was always valid. The imperative stimuli would appear

500-3000ms (random) after the face disappeared. In the first block of trials ($n = 40$) the eyes within the face were made to move 10 degrees to either the right or left or remain stationary. In the second block of trials ($n = 40$), the eye shift occurred concurrently with a smile or a frown. The smile meant that the cue was valid but a frown indicated an invalid cue. Participants were told this. A second condition also explored performance when the imperative arrow appeared on the left or right of the screen rather than in the centre. The results of this study provide insights into the effect of alcohol on the behavioural response to facial expression.

47 The Effect of Motion Information on Infants' Recognition of Unfamiliar Face.

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Traditionally, face researchers mainly use static pictures. However, a number of recent studies attempted to reveal the effect of motion information in face recognition. Studies with adult participants indicate a fundamental difference in the effect of motion for familiar and unfamiliar faces (O'Toole, Roark, & Abdi, 2002). Although a facilitative effect of motion is consistently found for the recognition of familiar faces, the effect is less clear for the recognition of unfamiliar faces.

The aim of the present study was to examine the role of motion information on infants' recognition of unfamiliar faces. Several previous studies suggested that motion information promotes infants' perception (Kellman & Spelke, 1983; Otsuka & Yamaguchi, 2003), and therefore we theorized that motion information should facilitate infants' face recognition. In the present study, we compared infants' recognition memory for unfamiliar faces learned in a moving or a static condition.

A total of 24 infants aged 3- to 5- months participated in the present study. Infants were first familiarized with a smiling woman face either in the moving or static condition. The familiarization phase was fixed at a relatively short duration (30 sec). After familiarization, infants were tested using a pair of novel and familiar female faces. Both novel and familiar faces in the test phase had static, neutral expressions. Hair was excluded so that only the internal features were visible. In such a paradigm, we infer that infants have recognized the familiar face, if they show a novelty preference for the novel female face.

We found that the infants in the moving condition showed a significant preference for novel faces, but that the infants in the static condition showed no preference for either of the faces. The present results suggest that learning from moving condition promotes infants' recognition of unfamiliar faces.

48 Patterns of Developmental Advancement in 'Reading' Dynamic Facial Expression

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The ability to predict the intentions of others is a core feature of human social communication. Within the visual domain, information regarding intention is conveyed largely through gesture, facial expression and eye-gaze. Whilst there is evidence that even very young children follow eye gaze and discriminate between different facial expressions, much less effort has been directed to exploring whether children are able to integrate two sources of social-visual information to predict intention. We studied the development of this ability in four groups of children ($n=10$ for each group) aged between 5 and 12 years using a facial pre-cue paradigm. The children were presented with a realistic computer generated face (composite of 100 real faces) on a computer screen for 1000ms. After a random delay of 500-3000ms after the face disappeared, a central arrow would appear pointing left or right. The children were required to press a right key when it pointed right and a left key when it pointed left. A ten

degree eye-movement within the face provided consistently valid precue information. In a second block of trials, the eye shift occurred concurrently with a smile or a frown. The smile meant that the cue was valid but a frown indicated an invalid cue. This design feature was explained carefully to the children. The data reveal the developmental progression of responses to social pre-cues. We will discuss the findings with regard to the general maturational processes that occur within this age group.

49 DOGS, BUT NOT CATS, CAN READILY RECOGNIZE THE FACE OF THEIR HANDLER

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It should be expected that there are multiple factors that a domestic animal could use to recognize its human handler including face recognition, speech patterns, olfactory signals, and cutaneous cues. The purpose of this study was to examine if either cats or dogs are able to identify their handler using only face recognition. Shortly after weaning, twelve pure-breed beagles and twelve domestic cats were each assigned a different human handler who worked with the animal for two hours each day for six months. The animals were trained to work in a two-alternative forced choice testing apparatus and mastered many different types of pattern and object discriminations. At about 9 months of age, each animal was tested on four different visual discriminations (for 50 trials each), with both stimuli in each pair being rewarded on all trials. Stimulus pairs and results: 1) The face of the handler versus an unfamiliar face. Dogs chose the face of their handler at 88.2%, while the cats chose their handler at 54.5%. 2) The face of an animal that lived with them in the colony versus an unfamiliar animal. Dogs chose the face of the familiar dog at 85.1% and the cats chose the face of the familiar cat at 90.7%. 3) A previously learned natural scene versus an unfamiliar scene. The dogs chose the familiar scene at 89.0% and the cats chose the familiar scene at 85.8%. 4) An unfamiliar natural scene versus an unfamiliar natural scene. The dogs chose one scene at 49.8% and the cats chose one scene at 51.7%. Overall, the only significant difference between the performance of the dogs and cats was in the recognition of the face of their handlers. Neither dogs nor cats had any difficulty recognizing other animals they lived with or a previously-viewed scene. As expected, neither dogs nor do cats have any preference for two scenes that they had not previously seen. Therefore, dogs are able to discriminate their handler from another human based solely upon face recognition.

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50 Prime-mask Interactions in Unconscious Priming and Conscious Perception of Emotional Faces

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Winkielman, Berridge, & Wilbarger (in press, PSPB) report that unseen happy and angry faces influence consumptive behaviors such as drinking and the rated value of a beverage. Central to their claim is the assumption that the emotionally expressive faces were not consciously perceived. Participants in their study were shown emotional faces for 16 ms, which were replaced by neutral faces for 400 ms. These display sequences influenced beverage consumption, even though participants were at chance in their attempts to identify the emotion in the prime faces. In the present work, we asked whether perception of either the prime or the mask face was influenced by interactions between features of both faces. In phase 1, participants made speeded classifications of happy and angry masks (450 ms) that were preceded by angry, happy, or neutral primes (22 ms) at one of three intervals (22 ms, 45 ms, or 67 ms). In phase 2, participants were instructed to classify these same prime faces as either happy or angry. Prime-mask congruence had different influences in the two tasks. In the mask classification task, emotionally congruent primes led to faster responses than incongruent primes and this effect increased

with prime-mask interval. Featural similarity in the faces played no role in priming. In the prime classification task, the effect of emotional congruence interacted with featural similarity of the faces. For emotionally congruent faces, increased feature similarity improved accuracy whereas for incongruent faces it impaired accuracy. This underscores the importance of examining prime-mask interactions on unconscious influences on consumptive behavior. A second study examined the issue of task relevance in the masking of faces. We discuss the implications of these findings for unconscious action priming and conscious object recognition in the realm of rapid emotional processing.

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Illusions

51 An Illusion of Misalignment

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Purpose: To study a new Illusion of misalignment. Given a two-dimensional configuration made up of a white vertical rectangle partially occluded by a black horizontal one, so that the two extreme components of the occluded rectangle remain visible, when the figure is monocularly viewed, the two components, geometrically aligned, appear misaligned. The direction of the effect depends on the viewing eye: when the figure is observed with the right eye, the upper component appears displaced leftwards relative to the lower one; observing with the left eye, the upper component is displaced rightwards relative to the lower one. These results can be better perceived by rapidly closing and opening the viewing eye. Trained observers reported that the apparent misalignment can be perceived even when the figure is binocularly viewed. Under these conditions the direction of the illusion changes during prolonged inspections. When the figure is 90 deg rotated with the partially occluded rectangle horizontally oriented, its visible components can again be perceived misaligned, but this effect depends on the viewing angle, not on the viewing eye. When the figure is viewed front parallel with the centre at the same high of the observer's eyes, the two components appear aligned; when the figure is viewed higher than the observer's eyes, the right component appears displaced upwards relative to the left one; when the figure is below the line of the observer's eyes, the right component is displaced downwards relative to the left one. The results are essentially the same for monocular and binocular viewing, since in this case the misalignment has the same direction for both eyes. The roles of the geometrical properties of the stimuli, of their spatial location relative to the viewing eye and of the depth segregation in stereoscopic conditions were studied in five experiments. An explanation based on depth processing is proposed, and some implications for picture perception are discussed.

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52 Seeing More Than Meets the Eye - the Ghost Illusion

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When a large and a small concentric square alternate in succession with a blank separating the two, observers often report seeing one or more distinct illusory squares (or 'ghosts') in the blank field. To explore this 'Ghost Illusion', squares with black edges and white backgrounds were used, ranging between 1.0 and 3.5 degrees in size. Each square was displayed for 80 ms; the two displays alternated 5 times, with a white screen (duration 125 ms) between each display. Observers were informed

that more than one square size would appear. They were instructed to count the total number of squares differing in size that appeared, and then respond using the numbered keys. Several experiments were carried out, with twelve observers in each, and 36 trials per observer. The first three experiments tested a range of size ratios (2:1-4:1). The strength of illusion decreased only slightly as the size ratio increased. Two, three and four squares were perceived in 31%, 49% and 16% of trials for size ratio 2:1, in 37%, 39%, and 13% of trials for ratio 3:1, and in 32%, 33%, 18% of trials for ratio 4:1, respectively. Similar results were obtained when the thickness of the edges was tripled for ratio 2:1 and when the colors of the edges were distinct (red and green) for ratio 4:1. These results therefore show that the strength of the illusion persists across size ratio, edge thickness, and color.

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53 The chromatic Hermann grid illusion for stimuli equated in chroma

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A Chromatic Hermann Grid evokes the perception of illusory colored spots at the crossings of grid lines. Using a restricted range of contrasts near isoluminance, we have found that the chromatic illusion may be weaker than the equivalent achromatic illusion for grids darker than the background. Here we explore the interaction of hue and contrast in the chromatic Hermann Grid illusion for a full range of negative contrasts using a constant luminance dark grid. Because stimuli that differ in hue may also differ in saturation, we equated our stimuli for chroma.

Method. We constructed grids with 21 intersections. Grid lines were 0.18 deg wide and presented at 200 cm. 5 colors were presented at 5 negative contrasts. Stimuli were equated for chroma using the CIE 1976 uniform color space. Subjects rated the magnitude of the illusion with the highest rating referenced to a standard achromatic grid presented adjacent to the comparison stimulus.

Results. The Hermann Grid Illusion increased with contrast for all hues ($P < 0.0001$). For some observers, the colored illusion was marginally visible even without luminance contrast. At high contrasts, the achromatic illusion was stronger than the chromatic illusion for red and blue backgrounds. The hue x contrast interaction was significant for red and blue backgrounds ($P < 0.05$) but not for green and yellow backgrounds. In all cases the illusory spots appeared as a dark version of the background hue.

Conclusions. The discrepancy between the strength of the Hermann Grid illusion for red and blue grids and for luminance equated achromatic grids is even larger at high contrast levels than we found in our previous work for low contrast levels; the discrepancy was not significant for green and yellow grids. This effect of hue is unlikely to be due to differences in saturation among our stimuli since we equated the stimuli for chroma. These results will be related to Oehler and Spillman's (1981) suggestion that this illusion is mediated by R and G cones.

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54 The problem of the perception of holes and figure-ground segregation in the watercolor illusion

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The watercolor illusion is a long-range assimilative spread of color sending out from a thin colored line running parallel and contiguous to a darker chromatic contour and imparting a strong figural effect. Pinna (1987) showed that the watercolor illusion induces a figural effect with univocal depth segregation similar to a rounded volumetric surface, and a complementary background effect, that, under most conditions, appears as

an unequivocal hole. The problem perceiving a hole is related to the unilateral belongingness of the boundaries (Rubin, 1921). However, a hole is something in between figure and background. Phenomenally, the boundaries belong only to the figure and not to the background, which, as a consequence, has no shape and is invisible. When a hole is perceived, the boundaries belong to it and at the same time to the complementary region. The boundaries delineate the hole that is visible as an empty space with a shape. This work demonstrates that the watercolor illusion, due to its strong figural effect, enhances the perception of holes under conditions usually perceived as a figure or as a background. This was psychophysically tested (i) by weakening the whole figural organization through imparting motion to only some components of a stimulus, while other components remain stationary, and (ii) by creating new paradoxical cases. The results showed that, despite the common fate principle, under watercolor conditions, moving and stationary elements group, inducing strong figural and hole effects. The uniqueness of the watercolor illusion in inducing the perception of holes is considered to be due to its peculiar boundary properties - juxtaposition of at least two parallel lines creating a luminance asymmetrical gradient along the boundaries - that can be considered as a principle of figure-hole-background segregation. The results are interpreted in terms of the FACADE neural model of biological vision (Grossberg, 1994).

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55 The Pinna -Brelstaff Illusion is not optimal under self-motion conditions.

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Purpose: The Pinna-Brelstaff illusion (Pinna & Brelstaff, 2000, *Vision Research*) consists of two concentric rings of micropatterns that appear to counter-rotate when the observer moves towards and away from the image. There have been several anecdotal reports that the illusion is stronger when the retinal motion (expansion and contraction of the stimulus) is produced by self-motion rather than by expansion and contraction of the stimulus on the computer screen.

Method: Our displays consisted of two concentric rings of Gabor patches. Each micropattern was oriented $\pm\Theta$ degrees from the line that connects it to the centre of the display (Gurnsey et al., 2002, *Perception*). Nine displays were created with Θ ranging from 0 to 90 degrees. Subjects first made relative salience judgements (for all possible pairs of Θ) under both self-motion and screen-motion conditions. Subjects then judged which of two identical retinal motions--one produced under conditions of screen motion and another under conditions of self motion--produced the stronger illusion.

Results: The relative salience judgements made under conditions of screen- and self-motion produced identical dependence on Θ , with peak salience occurring at approximately $\Theta = 31$. For all values of Θ screen motion produced the more salient illusion and in several cases the difference was statistically different from chance.

Conclusions: Contrary to anecdotal reports the Pinna-Brelstaff illusion is not strongest under conditions of self-motion; if anything, the opposite is true. Therefore, there is no need to consider a role for extraretinal inputs in determining the strength of the illusion. It should be noted however that the percepts differ under conditions of self motion and screen motion. Under conditions of self motion there is size constancy but not under conditions of screen motion. Nevertheless, the extra retinal contributions leading to size constancy do not affect the strength of the illusion.

56 Magnocellular- and parvocellular-pathway processing in a novel visual illusion

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If viewed peripherally, a white disk presented in an intersection of gray alleys in a grid of black squares is not detected. Previous work showed that both retinal and cortical mechanisms contribute to this 'blinking phenomenon' (McAnany & Levine, 2005). Here, we examine magnocellular (MC) and parvocellular (PC) pathway contributions to this novel form of visual disappearance. In these experiments, grids of black squares were continuously presented 15° above and below fixation on a 46 cd/m² gray background (background and alley luminance was always equal); a white disk appeared in a randomly chosen intersection. Subjects were asked to identify which intersection (left, middle, right) contained the disk.

In one condition, the disk was presented as a 36 ms pulse, a presentation duration that favors the MC-pathway. Subjects identified the correct intersection with near-perfect accuracy in this condition. In a second condition, the disk was ramped on, held for 36 ms, and then ramped off (minimizing temporal transients, thus biasing processing toward the PC-pathway). Subjects' responses to the ramped stimulus were essentially random. A third condition was intended to saturate the MC-pathway by introducing a large luminance transient concurrent with the disk presentation (Leonova, Pokorny, Smith, 2003). To induce the luminance transient, the background and alley gray luminance before and after the pulsed disk presentation was 0.3 log above or below the 46 cd/m² gray. Contrast threshold under this condition was significantly higher than when the disk was pulsed without a luminance change.

There are two possible explanations for these results. First, the MC-pathway may be solely responsible for detecting the disk; the disk cannot be detected when the MC-pathway is saturated or ineffective. Alternatively, either pathway can detect the disk, but the PC-pathway includes processing that causes blanking in the presence of the grid.

57 The Effect of Chromaticities and Shaft Occlusion on the Magnitude of the Mueller-Lyer Illusion

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Purpose. To examine changes in magnitude of the Brentano version of the Mueller-Lyer illusion by varying the chromaticities of the shaft and arrows along the cone-excitation axes and the occlusion of the shaft. **Method.** The Brentano version of the Mueller-Lyer figure was displayed on center of a CRT monitor subtending a visual angle of 488 x 378 at a viewing distance of 45 cm. The stimulus consisted of a shaft of 15.28 and 3 arrows of 2.38 per side forming 458 angles to the shaft. All stimuli were equiluminant to the gray surround (11.6 cd/m²) except for the black stimuli. The combinations of shaft/arrow chromaticities were black/black, L-/L-, L-/L+ and L-/S- as expressed in the DKL cone-excitation space. When the chromaticities of the shaft and arrows were different, the arrows occluded the shaft or were occluded by it producing a total of 6 stimuli. The magnitude of the illusion was measured by having observers adjust the position of the middle arrow using keys on a keyboard until judged that the 2 segments of the shaft to either side of the arrow appeared equal in length. When satisfied, the observer pressed a key to indicated it. The screen turned homogeneous gray for 3 s and the next stimulus appeared. Observers made these adjustments 6 times per randomly presented stimulus. Observers were 45 naïve, normal trichromats. The magnitude of the illusion was obtained by dividing the longer by the shorter segment of the shaft. **Results and Discussion.** Consistent with the past research, stimuli with identical shaft/arrow chromaticity produced more illusion than stimuli with different chromaticities. L-/S- stimuli tended to produce more illusion than L-/L+ stimuli suggesting that the chromaticity similarity of the shaft/arrow components, not the chromaticity change along one axis, increases the illusion. When the middle arrow occluded the shaft rather than the opposite, the illusion was smaller. This is possibly because the observer can see the clear segmentation of the shaft by the middle arrow.

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58 The Windmill Illusion

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Purpose: To study a new illusion of apparent rotation. By alternatively increasing and decreasing the amount of transparency of a grey annulus superimposed to a radial arrangement of black and white circular sectors, the annulus appears to rapidly rotate. We call this phenomenon 'windmill illusion'. Phenomenology of the illusion: (i) The rotation does not belong to the boundaries of the annulus but only to its grain and matter, that appear to flow within and along the annulus area ambiguously in either clockwise and anticlockwise directions; (ii) the granular matter of the annulus emerges clearly only under transparency modulation and only if the illusory rotation is perceived; (iii) the intentional motion of the gaze in one direction (e.g. clockwise) disambiguates the illusory rotation that follows the gaze direction; (iv) the loss of transparency annuls the apparent rotation; (v) by rotating the whole stimulus while the transparency of the annulus is increased and decreased, the annulus appears to rotate in the opposite direction to the real rotation; (vi) by replacing the annulus with another shape (disk, square, vertical or horizontal rectangle) the apparent motion follows the main directions of the boundaries of the specific shape, i.e. the matter appears to flow along the horizontal rectangle and in either left and right directions; (vii) by replacing the annulus with a disk of different sizes, if the disk is smaller than the sectors, the apparent rotation belongs to the disk, if it is larger than the sectors, the rotation belongs to them, if it has the same size as the sectors both rotate but only in their matter or grain; (viii) the apparent rotation is clearly perceived under neon color spreading conditions. **Experiments:** The previous phenomenal conditions were psychophysically measured. Results confirmed previous phenomenal observations and are theoretically discussed and related to other phenomena reported in the motion perception literature.

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59 The visual system does not take global snapshots of the visual field

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In stroboscopic conditions, rotating objects may appear to move in the reverse direction. This illusion arises from an asynchrony between illumination frequency and the periodic frequency of stimulus rotation. A seemingly similar phenomenon occurs in constant sunlight, and this has been suggested as evidence that the visual system processes discrete 'snapshots' of the outside world. We reasoned that if snapshots indeed are taken of the visual field, then when a rotating drum appears to transiently reverse direction, its mirror image should always appear to reverse direction simultaneously. Contrary to this prediction, we found that when observers viewed two rotating drums, almost all illusory motion reversals occurred in only one drum at a time, not both at once. This result indicates that the motion reversal illusion cannot be explained by snapshots of the visual field, a theory popular since the advent of cinematography. Independent reversal of the two drums is also found when the two images are presented in the same visual hemifield, further ruling out hemisphere-specific snapshots. The frequency distribution of illusory reversal durations approximates a gamma distribution, suggesting perceptual rivalry as a better explanation for illusory motion reversal. In an adaptive motion-opponency system, the activity of motion-sensitive neurons coding for motion in the reverse direction might intermittently drive the perception of motion. EEG and fMRI experiments are underway to determine the neural difference between veridical and illusory motion perception.

60 Undulation and Twist Illusions

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In the Zoellner illusion parallel lines are perceived as being tilted in a direction perpendicular to the intersecting oblique segments. The most invoked explanation of this illusion is based on the principle of perceptual enlargement of acute angles. By continuing the oblique segments so that each of them becomes a component of a zigzag path an array of parallel horizontal zigzags is created in between vertical parallel lines. Under these conditions the local geometrical properties of the stimulus are preserved. If the principle of perceptual enlargement of acute angles is valid, Zoellner's tilt should be perceived again. However, differently from what expected, the vertical parallel lines appear clearly undulated. The geometry of the illusion can be simplified by referring to parallel rectangles whose inner surfaces are filled by a zigzagged texture. Phenomenology of the undulation illusion: (i) the illusory weaves are perceived at a global viewing and have a low spatial frequency compared to the much higher spatial frequency of the zigzagged pattern; (ii) as Zoellner's tilt, the undulation illusion is enhanced by rotating the stimulus at 45 deg; (iii) the zigzags do not need to intersect the rectangles but induce undulation at long distance; (iv) the undulations of two contiguous parallel lines appear not parallel but opposite curved with concave and convex alternations; (v) By increasing the width of the rectangles the strength of the undulation increases accordingly. When a black bar is inserted in between each couple of adjacent rectangles another effect emerges: the straight bars appear twisted. If two parallel stripes are now inserted, each of them appears twisted and both intertwine. The roles of geometrical properties of the zigzags and of the parallel lines were studied in five experiments. The results suggest an explanation in terms of global visual mechanisms where eye movements play a role.

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61 New insights into 'Enigma'

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In 1981, Leviant devised a star-shaped figure that elicits rotary motion in the absence of real motion. This figure consisted of concentric sets of narrowly spaced radial lines interrupted by moat-like colored annuli. Compelling as this illusion is, there is no explanation to date. Gregory (1993) pointed out a similarity to MacKay's (1957) 'complementary' afterimage and suggested accommodative fluctuations as a potential cause. Assuming a neural correlate, Zeki et al. (1993) found PET-activation by Enigma in visual area V5. To rule out accommodation, we paralyzed the lens of one eye and still perceived the rotary motion. We then produced a long-lasting afterimage of the Enigma figure to eliminate retinal image shifts due to eye movements; the rotation on the rings continued to be seen. These results left the black radial lines as a candidate factor. When the radial lines faded from the afterimage, the rotation disappeared. Motion was present, however, when the concentric sets of radial lines were phase-shifted relative to each other obviating the need for collinear lines. Rotary motion was also seen when the colored annuli were replaced by white annular zones defined only by the ends of the radial lines. This finding suggests that the Enigma illusion may be mediated by cortical neurons responding to T-junctions. Indeed, if the radial lines were tilted in opposite directions so that they were no longer orthogonal to the annuli, the illusory motion weakened and ultimately disappeared. Similarly, if the continuous black lines were replaced with dashed lines, the illusion was abolished. On the other hand, a moderately strong rotary motion was still seen when large round blobs were added to the tips of the

radial lines rendering any "T"-like property ineffective. Even when there were no radial lines at all and just a number of black blobs dispersed over the white background, some rotary motion could still be perceived. Thus, the Enigma illusion remains enigmatic.

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Scene and Layout Perception

63 Spatial Updating and Spatial Properties in Scene Recognition

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When an observer's viewpoint of an object layout changes as a result of the movement of the layout itself, recognition performance is often poor. When the viewpoint change results from the observer's own movement, visual and non-visual information may serve to update the spatial representation, resulting in better recognition performance. The purpose of the current experiment was to evaluate the effects of non-visual updating on scene recognition while systematically manipulating the type of spatial information available (object position, object identity, or both). Subjects (Ss) learned the positions and/or identities of seven objects on a rotating table. They were subsequently presented with the layout from a novel viewpoint (due to either a table rotation or to Ss' own movement around the table) and made a same/different judgment. The results demonstrated that performance was faster and more accurate when Ss moved to a new viewpoint compared to situations in which they remained stationary while the table rotated. Further, Ss were more accurate when provided with position information combined with identity information compared to situations in which each was provided in isolation. In addition, males consistently outperformed females in all conditions except for the situations when Ss remained stationary and were provided with identity information alone, in which case females outperformed males. This pattern of results changed however when subjects were required to move, in which case, males again outperformed females. This finding supports previous evidence suggesting that females excel in tasks that have a higher verbal component (identity) compared to tasks that relate more directly to spatial features (position), in which case males excel. Further, the current results indicate that specific spatial properties have dissociable effects, suggesting that independent mechanisms are involved in the encoding and updating of spatial representations.

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64 Viewpoint independent scene recognition through a-priori instruction?

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The focus of interest of this study is whether a-priori instructions would help the participants to construct a viewpoint independent representation of a dynamic scene. Garsoffky, Schwan & Hesse (2002) showed, that the recognition of dynamic sequences is viewpoint dependent. Salomon & Perkins (1989) argued that by means of cognitive elaborations, learners can intentionally develop an abstract representation of a given content. If there's a connection between abstract representations and viewpoint independency, than it seems probable, that more elaborations induce a more viewpoint independent representation. In this study ball-races were used as stimulus material: the scenes consisted of four balls with different kinds of movement characteristics. Different types of a-priori instructions were used: (1) no instruction (no elaboration), (2) the participants were instructed to pay attention to the colors of the balls (medium elaboration) and (3) they have to focus on the overtakes of the balls (deep elaboration). After viewing the film subjects had to decide in a recognition test whether

a shown video still (different viewpoints at different points of time) was part of the seen event or not. In the first condition a viewpoint dependency effect should appear whereas in the third condition a viewpoint independent mental representation was expected. While the analysis of the hit rate showed a significant viewpoint dependency effect but no significant interaction with the instructions, the false-alarm rate showed a significant main effect for the instruction. The participants produced more false-alarms in condition 2 (colors) than in 3 (overtakes), in condition 1 (no instruction) the fewest false-alarm rate was measured. Overall the findings suggest, that instead of a single viewpoint independent representation it seems reasonable, that the participants in condition 2 and 3 have two representations one visuo-spatial and one which is more abstract.

65 The ground dominance effect depends both on the surface and its location in the visual field

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We reported (2004, in press) that when objects were in optical contact with both a ground and ceiling surface, layout was determined by ground contact (a ground dominance effect). Here we report two experiments that examined whether this effect is due to the difference in layout of ground and ceiling surfaces (whether the surface recedes in depth from bottom to top or from top to bottom in the image) or to the location of the surface in the visual field. In the first experiment the observer fixated on a central cross, with fixation controlled using a go-no-go digit identification task. A scene containing a ground surface, a ceiling surface and two vertical posts was then presented for 250 ms. Optical contact with the ground indicated that one post was closer, whereas optical contact with the ceiling indicated that the other post was closer. Either the ground surface was below fixation and the ceiling surface was above fixation, both surfaces were below fixation, or both surfaces were above fixation. Control conditions were included to examine effects of distance from fixation. The proportion of judgments consistent with optical contact with the ground surface was highest in the ground-below-ceiling-above condition (0.80), followed by both surfaces above fixation (0.70) and both surfaces below fixation (0.63). In the second experiment only one surface was presented on each trial. The proportion of judgments consistent with optical contact with the surface that was presented was generally higher for the ground surface than for the ceiling. The proportion consistent with the ground surface dropped as the ground surface was moved away from fixation in either direction, but the proportion consistent with the ceiling surface increased when the ceiling surface was moved below fixation. Overall, the results suggest that the ground dominance effect is a result of an interaction between the type of surface and its location in the visual field.

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66 Priming of Scenic Layout Measured with an Accuracy Task

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Brief exposure to a known scene activates a representation of its layout that is functional -- in a priming paradigm, brief exposure to a scene prime speeds subsequent processing of spatial relations across the scene (Sanocki & Epstein, 1997, *Psychological Science*; Sanocki, 2003, *Cognitive Psychology*). However, previous results were obtained with reaction time measures of the speed of spatial processing. Accuracy measures sometimes produce results opposing reaction time. Would analogous priming results be obtained when the target scenes are briefly presented and accuracy is measured?

Full color pictures of scenes (different arrangements of blocks) were used as primes and targets. Targets were identical to primes except for two red probe ovals superimposed on scene surfaces. On each trial, a scene prime or the control prime (the background, sans objects) was presented for 300 ms, followed by a 50 ms mask. Then the target appeared, for a duration ranging from 50 to 117 ms. Observers indicated which probe (left or right) was closer to viewpoint. Percentage correct increased with target duration,

as would be expected. When scene primes preceded the targets, accuracy was higher throughout processing time relative to the control prime. This advantage is consistent with previous reaction time results.

The scene stimuli varied from simple (1 simple object, 3 surfaces total) to complex (4 multipart, obliquely oriented objects, 24 surfaces). Complex scene targets were processed more slowly than simple scenes, although priming effects were similar across scene complexity. As in reaction time experiments, scene complexity increased processing time for targets but the scene priming process was independent of complexity. The results are consistent with a fairly automatic, broad scope scene priming process that prepares a spatial representation, followed by target processing that increases with scenic detail.

Acknowledgment: thanks Mom!

67 How Far Can You Go? The 'Extended' Utility of Scene Layout Priming

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In previous research a prime showing a small portion of a scene facilitated distance judgments even when the locations judged were in scene areas that were not visible in the prime. The prime apparently activated a representation of the scene, which was mentally extended beyond the prime's view perimeter. However, the locations tested were always adjacent to the prime area. This study examines the degree of this extension by varying the distance between the preview window and the areas tested. On 576 trials, participants viewed a partial area of each scene followed by the full view of that scene. They judged the relative distance of two items in the full scene (following Sanocki, 2002). The items were located in three different general areas: adjacent to the partial view, as distant as possible in the picture and at a medium distance. As long as the prime provided information about relevant layout, the prime induced facilitation even for judgments of the most distant locations in the picture.

68 Consistency Effects in the Perception of Briefly Viewed Scenes.

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How does knowledge about which objects and settings tend to co-occur influence the perception of briefly presented scenes? Prior research (Davenport & Potter, 2004) found that single foreground objects and their settings are reported more accurately when the object and background are mutually consistent rather than inconsistent. In four experiments, consistency effects between objects and backgrounds and between two foreground objects were examined when one or two foreground objects appeared in scenes. Participants saw each picture once for 80 ms followed by a mask and typed their response. Three questions were addressed:

1) Would an additional foreground object modulate the consistency effect? Scenes contained either a single object or two objects from the same setting. In Experiment 1, objects were reported more accurately when the background was consistent, $p < .001$. In Experiment 2, backgrounds were reported more accurately when they appeared with consistent foreground objects, $p < .001$. The number of objects did not interact or produce a main effect in either experiment.

2) Would having to report two objects and the setting reduce object-background consistency effects? In Experiment 3, two objects were always present and both objects and the background were reported. A strong main effect of consistency was present $p < .001$, and this effect was greater for backgrounds than for objects, $p < .001$.

3) Do objects in scenes influence each other? In Experiment 4, two foreground objects were either related (both from the same scene) or unrelated (each from a different scene). Objects were reported more accurately in consistent settings, $p < .005$, and when presented with a related object, regardless of the background $p < .05$. These two consistency effects were independent.

The results support an interactive processing account of scene perception. With an 80 ms glimpse of a picture, consistency information about objects and settings is available and influences report accuracy.

69 The Influence of Color on Perception of Scene Gist

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Prior research has established that scene gist (semantic category) is acquired within a single fixation. The present study used a new paradigm to investigate how quickly gist becomes available, and whether color is important in its activation. Previous studies have shown that when a scene is presented quickly, there is a natural bias to affirm having seen a semantically consistent target object in that scene and to deny having seen an inconsistent object (Hollingworth & Henderson, 1999). The Contextual Bias paradigm tracks the timing of semantic gist activation by measuring the onset of this response bias. If a scene presented for a given duration is perceived and processed to the level of gist, then subjects should be more likely to respond 'yes' to consistent and 'no' to inconsistent targets. If, however, the scene is not perceived or processed to the level of gist, then participants should respond 'yes' to both target types in equal proportions. Experiments 1-3 investigated how quickly scene gist becomes available. Results suggested that gist is available 42 ms after scene onset. Experiments 4-6 investigated the relative contribution of color and structure for very short scene durations by manipulating the color (color vs. monochrome) and sharpness (sharp vs. blurred) of the scenes. Results showed that color influences gist activation later (80 ms), and only when structure was degraded (blurred). Thus, color may play a role in rapid scene gist activation, but only when the scene's structural information is relatively more difficult to extract. Whether color influences the activation of semantic information by providing supplementary structural information (separating equiluminant regions) or by providing unique scene categorization cues is the subject of current investigations.

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70 Global statistical features and early scene interpretation

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Recent behavioral and modeling research has suggested that early visual scene interpretation may be influenced by global image properties computed by processes that do not require visual selective attention (Spatial Envelope properties of a scene, Oliva & Torralba, 2001; statistical properties of object sets, Ariely, 2001; Chong & Treisman, 2003). Global statistical properties such as the stationarity of features or the distribution of orientations have been found to co-vary with real-world scene semantic and spatial properties (Torralba & Oliva, 2003). Here we studied the extent to which global statistical features modulate the interpretation of important properties of a scene, such as its mean depth, its degree of openness and its naturalness. We show that by changing the statistics of the image features in a direction that correlates with a scene property (e.g. mean depth), one can create a scene image that, for instance, looks closer or farther away than the original scene. Urban and natural images covering a large range of mean depths were manipulated so that the global features related to a scene property (mean depth, openness, naturalness) were emphasized or de-emphasized. When presenting observers with pairs of images (one normal and one with manipulated global features), the direction of the manipulation changed the perception of the image. The effect was more striking under conditions of very fast image presentation where a scene, for instance initially perceived as an ambiguous image in term of openness, could be perceived as being unambiguously open or closed after emphasizing the global features correlated with the perception

of openness. The results of the manipulation of global features suggest that early scene perception mechanisms may very well be using global statistical features, even when the features lie.

71 Better to run than to hide: the time course of naturalistic scene decisions

Michelle R Greene (*mrgreene@mit.edu*), Aude Oliva¹; MIT

The perceptual decisions we make during the course of the day engage automatic mechanisms of scene and place recognition: navigating through the environment, searching for an object, etc. However, studies of scene understanding have focused on scene classification; a task that may not reflect what we do in our daily lives. What is the perceptual efficiency of such decisions and to what degree do low-level image features correlate with these judgments? We have selected 3 dimensions that reflect common judgments made through environmental interactions: the degree to which things can be hidden (camouflaged) in a scene, how well one can navigate and the scene temperature. 500 outdoor images were chosen from a database of 5000 images to reflect membership along these dimensions. Images were ranked along each dimension. Subject agreement in ranks was good and around 100 images per dimension were found to be prototypical (low variance at dimension extremes). There was no correlation of image ranks between dimensions, suggesting that the features used or their complexity vary. The prototype images were run in a yes/no task for each dimension with variable presentation times between 20 and 80ms followed by a mask. We found a 15% performance advantage for temperature dimension over the other dimensions at 20ms that vanished by 60ms, suggesting that image features responsible for this task (e.g. color) are available earlier than properties related to the others. Detecting a navigational route had the steepest performance gain (28%) for increasing presentation times, indicating that the relevant features become massively available between 20 and 40ms. Correctly evaluating potentiality for camouflage requires more exposure time as it had a shallower gain over presentation times, indicating an even later availability of pertinent features. We show the extent to which low-level image features are correlated with the degree of temperature, navigation and temperature in a scene.

Acknowledgment: Grateful thanks to Antonio Torralba, Molly Potter, Ruth Rosenholtz and Nancy Kanwisher for fruitful discussions.

72 Effects of Familiarity and Repetition on Memory for Real-Life Scenes with Emotional Content

Vera Maljkovic (*v-maljkovic@uchicago.edu*)¹, Paolo Martini²; ¹The University of Chicago, ²Harvard University

PURPOSE. To explore the effects of familiarity and repetition on the encoding of real-life scenes with emotional content into visual short-term memory.

METHODS. Stimuli were 64 color images of real-life scenes, 32 with positive and 32 with negative emotional content (matched for arousal). During each of 1024 trials per subject we used the RSVP procedure to present 6 pictures, 1 positive and 1 negative unrepeated and 1 positive and 1 negative repeated after an intervening image (counterbalanced across durations and repetition conditions), with durations per picture ranging from 8 to 1710 ms. Following each 6-picture stream subjects were shown 8 pictures singly (4 seen and 4 new, half positive and half negative images), and asked to judge whether the given picture was present in the stream they just saw. Accuracy data from 3 subjects that had extensive previous exposure to the image set were corrected for guessing and compared across conditions.

RESULTS. In all conditions, performance with negative images was better than with positive images at all durations. Performance with negative images benefited from repetition, as would be expected from the summation of independent events across successive image exposures. Performance with repeated positive images showed instead a deficit of

facilitation for exposures of 100 ms and above, suggesting that responses to successive occurrences of positive images are not independent.

CONCLUSION: We previously reported (Maljkovic & Martini, VSS '03) that RSVP curves for negative images are steeper than for positive images in conditions where subjects are unfamiliar with the image set. Familiarity eliminates this difference in steepness and increases the overall speed of performance for negative images. Furthermore, familiar positive images, but not negative images, seem to be affected by interference between successive exposures, in agreement with findings of selective attentional interactions using other emotional stimuli.

Acknowledgment: NIH EY13155 to V. Maljkovic

73 Lack of Interference Between Unfamiliar Real-Life Scenes in RSVP Streams

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PURPOSE. To explore the interactions (interference or facilitation) between successive unfamiliar real-life scenes in RSVP tasks.

METHODS. Stimuli were 416 color images of real-life scenes unfamiliar to the subjects. During each of 32 trials per subject we used the RSVP procedure to present 7 pictures, 1 unrepeated and 3 repeated with 1, 2 or 3 intervening images (counterbalanced across subjects), with durations per picture ranging from 13 to 1710 ms. Following each 7-picture stream subjects were shown 8 pictures singly (4 seen and 4 new), and asked to judge whether the given picture was present in the stream they just saw. All 64 naïve subjects saw all the pictures, each picture never more than twice (only in the repeated condition). Accuracy data were corrected for guessing and fitted with psychometric functions.

RESULTS. All data sets are well fitted by exponential functions. For the unrepeated condition the time constant (corresponding to 63% correct) is ~400 ms. In the repeated condition performance is virtually identical across all lags, with a time constant of ~200 ms.

CONCLUSION. We find no evidence of negative interference between repeated unfamiliar pictures at any lag. Given the exponential form of the psychometric function, the fact that the time constant differs by a factor of 2 between the repeated/unrepeated conditions suggests complete independence between successive glances at a picture (probability summation). This implies that for sequences of pictures that are *complex, not easily namable and unfamiliar* to the subject, sequential effects, such as repetition blindness and attentional blink, do not apply.

Acknowledgment: NIH EY13155 to V. Maljkovic

74 Learning scenes while tracking disks: The effect of MOT load on picture recognition

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We have a remarkable ability to recognize a large number of scenes after viewing each only briefly. This ability is significantly reduced if visual attention is diverted to a superimposed letter search task during initial encoding of those scenes (DiMase, et al, OPAM 2003). How general is this impairment? In the present study, observers performed multiple object tracking (MOT) during initial encoding. This task served to both allow attentional load to be varied on different trials without changing the display and ensure that attention was broadly distributed across the scene. Additionally, prior experiments assessed scene memory after a substantial delay. The present study uses an additional, immediate (working memory) test. On each trial, observers were asked to track 0, 2, or 4 among 8 moving disks while 3 scene photographs were successively presented behind them. After five seconds, the disks stopped moving and observers indicated the ones they were asked to track. Working memory for the scenes was assessed by the immediate presentation of a single image,

which was either one of the 3 scenes displayed during the trial or a completely new scene. Following the set of dual-task trials, long-term memory for the scenes was examined in a test consisting of half new pictures and half old pictures, one from each of the earlier dual-task trials. On the MOT task, observers performed better when tracking 2 items (72%) than when tracking 4 (95%). In the working memory test of scene recognition, performance decreased as MOT load increased (d' for track 0 = 2.27, track 2 = 1.69, track 4 = 1.40). Long-term scene memory was poorer than working memory and was highly impaired for both load conditions (d' for track 2: 0.62, track 4: 0.61) compared to the zero track condition (d' = 1.09). These findings suggest that the ability to encode and recognize scenes in working memory and long-term memory is dependent on the degree to which visual attention is available during presentation.

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75 Picture Memory Demands Attention

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Experiments using rapid presentation of large numbers of picture have demonstrated impressive recognition for pictures that have been shown for less than a second. What are the visual processes that support successful picture memory? We hypothesized that observers encode two separate components: gist and/or texture information, which might be extracted without attention, and some recognized objects requiring selective attention. **METHODS:** We compared memory for scenes, objectless textures and for scenes and textures shuffled in checkerboard fashion. Shuffling should disrupt object perception in scenes with little effect on texture perception. We used a concurrent visual search task to divert selective attention from the pictures. We hypothesized that this would block object recognition, impairing memory for scenes but not textures. Os viewed scenes and textures in single and dual task conditions. Each condition consisted of 32 training trials followed by 32 test trials. In single task conditions, Os viewed 32 pictures for 500 ms each, followed by 32 test trials where they classified pictures as old or new. In dual task conditions, Os either performed the visual search task or an auditory control task during initial viewing of the pictures. **RESULTS:** Unsurprisingly, memory for scenes was better than memory for textures or shuffled scenes in single task conditions. Memory for all stimuli was impaired by concurrent visual search, falsifying the hypothesis that texture memory would be independent of attention. Visual search imposed a greater cost than concurrent tone monitoring, suggesting a specific effect of visual selective attention on visual memory as opposed to a more general dual-task cost. **CONCLUSION:** These results indicate that successful picture memory requires the involvement of selective visual attention during encoding. They cast doubt on the notion that some aspects of picture processing can entirely escape the "bottleneck" of attention.

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76 Repeated Masks are Less Effective

Trafton Drew (*tdrew@darkwing.uoregon.edu*), Edward K Vogel¹; *University of Oregon*

When a target is immediately followed by an irrelevant stimulus, it is generally harder to accurately report than when it is presented in isolation. The concept of using target masks is pervasive, yet the underlying mechanisms that predict the efficacy of a particular masking stimulus are still not fully understood. For example, what happens when a target mask is repeated? We investigated this question using a simple target detection task. Subjects were asked to pick a target out of a circular array of 7 other non-targets. The target array was preceded and followed by a circular array of random letters. On half of the trials, the distractor arrays were identical before and after the target. On the other half, both masks were novel. We found a benefit of repeated masks. That is, target detection was

significantly better when the trial repeated the same mask twice as compared to trials when there were two novel masks. Under certain circumstances, repeated stimuli have been found to be more difficult to perceive (repetition blindness, Kanwisher, 1987) while under others there is a clear benefit for seeing the same thing twice (repetition priming, Henson et al, 2000). It is not yet clear whether the current results are due to participants being primed to the mask or 'blind' to it and it is possible that the same mechanisms may actually underlie both of these processes.

77 The Mechanism of 3D Contour Perception

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Several studies have been manifested that local contour elements extracted by orientation selective cells in early visual areas are bound together by colinear connections in order to perceive global smooth curves (e.g., Field et al., 1993, Kapadia et al., 1995). In most studies investigating this contour integration, visual elements in each stimulus are on the same front-parallel plane. Therefore obtained results by these studies depict only 2D colinear connections for the contour integration mechanism. However, our visual experiences in daily life are binocular and we usually perceive 3D contours, so it is possible that the brain has 3D colinear connections for the contour integration.

A few studies used 3D stimuli with binocular disparity to investigate further characteristics of the integration mechanism (Hess & Field, 1995, Hess et al., 1997). Though each stimulus used by them contains patches with various depths, each patch is on a front-parallel plane. In order to investigate 3D integration mechanism in detail, it is necessary to use 3D contour elements oriented in depth.

This study executed psychological experiments using 3D contour stimuli with disparity gradient to address whether the 2D colinear connections clarified by previous studies are a subset of 3D colinear connections that integrate colinear elements fit on the smooth 3D curve.

3D versions of path-paradigm experiments are performed. Two types of contours that have the same global disparity gradient are used. One type of contours contain 3D colinear line element whose disparity gradients are the same as the one of the global contour, meanwhile the other type contain elements with reversed gradient, though their absolute value is the same as the of the global contour.

The results indicated that contours represented by colinear line element in 3D space are more salient than that of non-colinear elements. This suggests that colinear connections for the contour integration are organized in 3D manner.

78 Exploring visual scenes: A cognitive ethology approach

Daniel Smilek (*dsmilek@uwaterloo.ca*)¹, Tessa van Leeuwen², Elina Birmingham², Maryam Toufani², Alan Kingstone²; ¹University of Waterloo, ²University of British Columbia

In a series of experiments we examined the subjective experience of controlling (or not controlling) the exploration of different visual scenes. The content of each scene (32.5 cm X 24.5 cm) could only be perceived through a window that revealed a subsection of the underlying picture. The window could be small (1.5 cm X 1.5 cm) and provide the highest resolution view of the picture (1024 pixels X 768 pixels); the window could be medium-size (4.5 cm X 4.5 cm) with a view of a lower resolution, more blocky image (original image coarse quantized to 16 pixels/ block); or the window could be large (9.0 cm X 9.0 cm) but with the poorest resolution (original image coarse quantized to 64 pixels/block). Participants in an "active group" controlled both the sizing and positioning of the window. They could explore a picture for as long as they liked or for only 15 seconds. Participants in a "passive group" were yoked to members in the

active group, so that passive participants could only see the picture through the window that their matched active member was controlling.

All participants were required to write a description of the picture following their exploration of each scene. After seeing all the scenes they rated on a 9-point scale: (1) how much information could be extracted from the pictures, (2) whether the viewing time was adequate, and (3) whether the movement and sizing of the window were systematic. The results showed that ratings of information extraction and viewing time were equivalent across the active and passive groups. In contrast, active participants rated the window sizing and movement as being significantly more systematic than passive participants. Together our data indicate that control and information extraction are separable in visual exploration, with control enhancing perceived systematicity but not information extraction.

Acknowledgment: The research was supported by NSERC

79 A Behavioral Handle on the Phenomenology of Scene Perception

Claudia M. Hunter (cmg56@cornell.edu), Shimon Edelman¹; Cornell University

What aspects of a scene are represented in visual consciousness? A complete account must include scene structure: its parts and their spatial relationships. One sees a tree there, a house here, and a car over there. To a first approximation, scene structure thus resolves into a collection of objects represented at relatively precise spatial locations in the visual field. If this is so, the representation must persist, even if for a short time, at those stages of the visual pathway where units tuned both to complex shapes and location are present (such as area TE). Studies of the neural correlates of visual awareness suggest that structure represented at this level should be available to conscious access. We assess the conjecture that such representations constitute the neural basis for the phenomenal reality of scene structure by examining subjects' ability to construct spatially anchored representations of scene components and maintain them over time. Subjects were shown scenes composed of photographs of diatoms randomly located on a computer screen. We varied the number of scene components, presentation time, and number of scenes intervening between a scene with a target object and the point where the target had to be recalled. Subjects indicated whether or not the designated target was in the same location as in any previous scene. In scenes with 4 objects presented for 8 s, subjects could remember the location of targets over 1 intervening scene at levels significantly better than chance. However, when the number of objects was increased to 6 and presentation time decreased to 4 s, subjects performed at chance with either 1 or 2 intervening scenes. These results indicate that scene structure - "what is where", which is what the phenomenal feeling of scene perception may amount to - is psychologically real and briefly available to conscious recall. Scene complexity has less influence on this availability than the number of scenes subjects view over the retention period.

Talk Sessions

May 7, 2005 – Saturday AM

Visual Cortex: Receptive Fields (80-86), Object Recognition (87-93), Color Channels and Processes (94-99), Eye Movements, Perception, and Action (100-105)

Visual Cortex: Receptive Fields

8:30 - 10:15 am

Hyatt North Hall

Moderator: John Reynolds

80 Contrast dependant center-surround interactions in macaque area V4

Kristy A Sundberg (sundberg@salk.edu), Jude F Mitchell¹, John H Reynolds¹, Systems Neurobiology Laboratory, The Salk Institute for Biological Studies, La Jolla, CA, USA

Visual neurons integrate information over large regions of space beyond their classical receptive fields. A stimulus presented alone in this surround region does not elicit a response, but can modulate the response evoked by a simultaneously presented center stimulus. Center-surround interactions have been studied in V1 and MT but less is known about their properties in V4. We characterized the contrast dependence of center-surround interactions in V4 of the awake monkey. On each trial two luminance-modulated gratings were presented, one within the classical receptive field and the other in the surround. The monkey fixated and performed an attention demanding multi-object tracking task in the opposite hemifield. We measured the contrast response function to the center stimulus and observed how it changed with the addition of different contrast surround stimuli. Surround stimuli generally exerted a suppressive influence on the response evoked by the center stimulus. Consistent with findings in the anesthetized monkey V1, this suppressive effect could best be characterized as a rightward shift in the contrast response function for some cells, while for other cells suppression reduced the upper asymptote of the contrast response function. Suppressive effects generally increased with the luminance contrast of the surround stimulus. Although less common, surround stimulus facilitation was also observed, with some cells showing facilitation at low center contrasts and others showing facilitation at higher center contrasts. These findings show that strong center-surround modulations are induced in V4 by a single grating in the surround, but that the nature of the modulation varies from cell to cell.

Acknowledgment: Support Contributed By: NSF Graduate Research Fellowship (K.S.), NIH Training Grant in Cognitive Neuroscience (J.M.), NEI Grant 5R01EY13802 (J.R.)

81 Habituation reveals cardinal chromatic mechanisms in striate cortex of macaque

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Psychophysical studies assign special status to three post-receptoral mech-

anisms of color vision: two color-opponent ones capturing red-green and yellow-blue variations, and a non-opponent one capturing achromatic variations. The distinctiveness of the cardinal mechanisms is most clearly revealed by habituation to chromatic modulation, but their locus has been unclear. Chromatically opponent neurons in LGN do not habituate, so the mechanisms must arise in cortex, yet the preferred color directions of striate cortex cells are very broadly distributed, with no clear preference for 'cardinal' directions. The present study exploited habituation to chromatic modulation to reveal the possible existence of very early cortical mechanisms tuned to the cardinal directions. In V1 of anesthetized macaque we characterized the chromatic tuning of neurons that responded to isoluminant modulation, before, during and after prolonged exposure to an isoluminant stimulus whose chromaticity was modulated in time about a fixed white point. Test stimuli were defined by modulation along eight color vectors within the isoluminant plane. For every neuron habituation to a stimulus modulated along its preferred color direction reduced responsiveness. For a neuron whose preferred color direction was on or near one of the cardinal axes, habituation to modulation along any direction brought about a proportional reduction in responsiveness to all directions of modulation. For a neuron whose preferred color direction lay between the two cardinal axes, habituation to modulation along either axis brought about a loss of responsiveness that was greatest on or near that axis. The specificity of habituation suggests that it occurs in V1 prior to combination of inputs from different classes of LGN neurons in the input layers or in the thalamocortical synapse.

Acknowledgment: supported by NIH grants EY 04440 and EY 13079

82 Adaptive motion integration and antagonism in visual area MT

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Neuronal responses to stimuli within the classical receptive field (CRF) of area MT can be modulated by stimuli in the CRF surround. This modulation is usually characterized as antagonistic. However, we have found that, under some circumstances, motion in the surround is integrated with that in the CRF (Huang et al. 2004, SFN Abs. 935.13). In that experiment, one contour of a moving square (208 across) was centered in the CRF, with the rest of the square in the surround. Squares translated diagonally in one of four directions. Due to the aperture problem, the motion of the contour within the CRF was in one of only two directions. Directional tuning was established by responses to moving gratings within the CRF. We found that MT responses to a given motion in the CRF were stronger when the square (and hence features in the surround) moved in a preferred relative to a less preferred direction. MT responses thus reflected the global motion of the square and this required CRF-surround integration rather than antagonism.

To determine the role of stimulus configuration in surround modulation,

we replaced the contour passing through the CRF with a circular patch of dots having the same velocity as the local motion of the contour. We compared the surround modulation observed for these stimuli with that elicited by intact squares. The unambiguously moving features in the surround were identical for the two stimulus types. As before, we found that CRF-surround interactions for intact squares were integrative. However, with moving dots in the CRF, surround modulation became antagonistic: neuronal responses were weaker when surround features moved in a preferred relative to a less preferred direction. Integrative and antagonistic modulations were both delayed relative to RF responses. These results demonstrate that surround modulation in area MT is adaptive and can switch from antagonistic to integrative depending upon visual context.

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83 Principles of Neural Shape Coding in Area V2

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To find the neural code for shape in extrastriate visual area V2, we have taken a nonlinear regression approach. We recorded from single neurons in area V2 of awake, fixating macaques while stimulating with a large sample of natural scenes (10,000 to 50,000), flashed rapidly in the receptive field and surrounding area. We then characterized the stimulus-response mapping function for each neuron using a neural network. The neural network determined which natural image features were important for each cell, and revealed nonlinear interactions between these features. It also provided a model that could be used to predict each neuron's response to new stimuli. By applying a visualization procedure to the network, we extracted the stimulus dimensions to which each neuron was tuned.

We find that most V2 neurons show excitatory tuning for a single, dominant Gabor-like feature, as found in previous studies that used sinusoidal gratings as stimuli. However, in almost all cases, this dominant excitatory tuning is modulated significantly by excitatory and/or inhibitory tuning to other orientations and spatial frequencies. There are two major trends. First, spatial frequencies that share the dominant excitatory orientation are usually also excitatory. This suggests that V2 cells pool across spatial frequency to enhance the representation of edges and break camouflage. Second, other orientations are usually inhibitory, and these inhibitory interactions occur across a range of spatial frequencies. This suggests that previously reported tuning of V2 cells for crossed and curved stimuli reflects an interaction between a dominant excitatory peak and complex patterns of tuned cross-orientation inhibition.

84 Neurons in MT Compute Pattern Direction by Pooling Excitatory and Suppressive Inputs

Nicole C. Rust (rust@cns.nyu.edu)^{1,2}, Eero P. Simoncelli^{1,2}, J. Anthony Movshon¹; ¹Center for Neural Science, New York University, ²HHMI

Cells in MT are tuned for the direction of moving stimuli. In response to a superimposed pair of sinusoidal gratings (a plaid), component direction selective cells (CDS) respond in a manner predicted by summation of their responses to the constituent grating stimuli. In contrast, pattern direction selective cells (PDS), are tuned for the two-dimensional velocity corresponding to a rigid displacement of the plaid, consistent with the way we perceive these stimuli. To investigate the computation of pattern direction, we used a spike-triggered analysis to characterize the responses of individual MT neurons in terms of a linear weighting of signals elicited by sinusoidal gratings moving at different directions and speeds. On each trial, each of a large set of gratings was assigned a random phase and one of three contrasts: 0, C/2, or C. We recovered a linear weight for each stimulus dimension by computing the mean contrast of each grating before a spike (the spike-triggered average or STA). The arrangement of the positive and negative weights of the STA predicted whether the cell responded with pattern or component selectivity. Specifically, strong, broadly tuned inhi-

bition in PDS cells suppressed responses to the individual plaid components, resulting in tuning for the direction of plaid motion. In CDS cells, such suppression was weak or absent. These results, which are consistent with the predictions of Simoncelli & Heeger (1998, *Vis. Res.*), suggest that broadly tuned null direction suppression (motion opponency) plays a fundamental role in computing pattern motion direction in MT.

85 Imaging the Dynamics of Orientation Tuning in Visual Cortex

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A debate surrounds the question of whether the orientation tuning of neurons in primary visual cortex (V1) is sharpened by intracortical circuitry. Such sharpening would be apparent in dynamical changes in orientation tuning during a response. Extracellular measurements have argued for such changes (Ringach et al., 1997), but intracellular measurements have found otherwise (Gillespie et al., 2001). We sought to resolve this question by measuring the responses of an entire population rather than those of individual neurons. We imaged voltage-sensitive dye fluorescence in layers 2-3 in V1 of anesthetized, paralyzed cats (imaged areas: ~30 mm²; sampling rate: 110 Hz). We established the orientation preference of each pixel from responses to flickering gratings (8 orientations). We then presented random sequences of static gratings (40 ms) with one of four phases and one of four orientations (Ringach et al., 1997). Reverse correlation analysis yielded the responses to each grating at each instant in time. We summarized these data by plotting the average response of each pixel as a function of its preferred orientation relative to the stimulus. These responses were well fitted by a Gaussian function. Responses rise 40-50 ms after stimulus onset, reach their maximum after 80-100 ms, and return to baseline after ~150 ms. Tuning width shows no sign of sharpening. It remains largely constant at ~40 degrees (half-width-half-height), a value somewhat larger than the ~30 degrees measured intracellularly (Gillespie et al., 2001). An analysis restricted to pixels with particularly sharp orientation tuning yielded similar results. We conclude that the orientation selectivity of neurons in the superficial layers of primary visual areas is constant through time. This result argues against the hypothesis that orientation selectivity is sharpened through intracortical circuitry.

86 Modeling neuronal response dynamics and cross-correlation in V1: a comparison of architectures that use anti-phase feedforward inhibition and isotropic lateral inhibition

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Recently, two architectures have been studied that explain some response properties of layer 4 simple cells in V1: one has anti-phase feedforward inhibition (Troyer et al, 1998 *J Neurosci* 18:5908-27), the other has isotropic lateral inhibition (McLaughlin et al, 2000 *PNAS* 97:8087-92). Differences in connectivity between excitatory and inhibitory neurons in these models suggest that their response dynamics should differ for oriented stimuli that shift suddenly in phase or orientation. Also, spike train cross-correlograms (CCGs) should differ in the models. I implemented both types of architectures and configured them to have realistic tuning curves for drifting sinusoidal gratings. Both have three populations of neurons: LGN cells and cortical excitatory and inhibitory cells. Each cell was modeled as a conductance-based integrate-and-fire unit. Realistic temporal dynamics were used for AMPA, NMDA, and GABA_A synaptic conductances. The response dynamics of model units were tested with oriented sinusoidal stimuli that changed abruptly between the preferred state and one of opposite phase, orthogonal orientation, or zero contrast. Model output was compared to data obtained earlier in the macaque (Bair et al, 2002 *J Neurosci* 22:3189-205). The anti-phase inhibition model was more consistent with the macaque: a stimulus transition from opposite to preferred phase produced a substantial additional delay of response onset. The models were also compared in terms of CCGs for pairs of neurons. The striking difference in CCGs for the models suggests experiments in V1 to deter-

mine which architecture is more realistic. However, in both models, details of temporal dynamics and CCGs depended strongly on parameters. The models have been developed within a general framework that accepts arbitrary visual stimuli and returns spikes and intracellular voltages. An online interface to the modeling framework is available at www.imodel.org to allow public testing of the models.

Acknowledgment: Supported by the Royal Society USA Fellowship

Object Recognition

8:30 - 10:15 am

Hyatt South Hall

Moderator: Moshe Bar

87 Object and shape processing in the human Lateral Occipital Complex

Joakim K Vinberg (joakimv@stanford.edu), Kalanit Grill-Spector; Stanford University

The human lateral occipital complex (LOC) has been implicated in object perception (Grill-Spector 2003), shape perception (Kourtzi & Kanwisher, 2001) and also in segmenting salient regions (Stanley & Rubin, 2003). However, previous studies have used shaped stimuli and have not dissociated between these processes. Here we asked whether the LOC processes objects, shapes or salient surfaces?

To examine whether the LOC is involved in surface-segmentation we contrasted activation to segmentable and unsegmentable random dot stereograms. Segmentable stimuli contained two depth planes, and unsegmentable stimuli contained random disparities. To examine whether LOC is involved in shape processing we contrasted activation to trials that contained a shaped aperture in the front surface (aperture condition) to segmentable depth planes. Finally, to examine the role of the LOC in object processing we contrasted activation to trials containing an object above a surface to the aperture condition. Shape contours were identical for the object and aperture conditions. Nine subjects were scanned on a 3T scanner and were asked to respond if the fixation was on the front or back surface. To test the generality of our findings, the same subjects participated in a second experiment in which we presented analogous stimuli composed of moving dots.

In both experiments, the aperture and object conditions elicited a significantly higher response in LOC than two surfaces or random noise. Further, activation to two surfaces was not significantly higher than to random noise. These results suggest that the LOC is not involved in processing of salient surfaces, but rather in shape and object processing. In addition, we observed a hierarchical processing of shape along the ventral stream: posterior regions (LO) responded more strongly to objects and shaped apertures than to surfaces or noise, while anterior regions along the fusiform responded more strongly to objects than shaped apertures.

88 Integrating information about real-world objects across eye movements

Daniel A. Gajewski (dan@eyelab.msu.edu), John M. Henderson¹; Michigan State University

Eye movements are needed to bring objects from the periphery to the fovea so that visual details can be resolved. What information about an object is maintained and integrated across a saccade? In the parafoveal preview paradigm, participants direct their eyes to a peripherally presented object that is replaced during the saccade with a to-be-named target object. Preview benefit is the difference in naming latency when the preview and target object is similar versus dissimilar. The present study determined the relative contribution of visual information versus identity and name priming in the generation of preview benefits using full-color

pictures of real-world objects and a nonrepeating stimulus set. Previews and targets were from the same basic-level category and viewpoint but varied in visual similarity. Preview benefits were observed for identical, visually similar, and visually dissimilar previews compared to meaning-less-object and different-object controls. These effects were observed despite the fact that items were not repeated. The magnitude of the preview benefits did not differ between preview conditions, suggesting that the visual component is abstracted away from surface-level features. A second experiment measured object identification from the peripheral preview alone. An items-based analysis then examined the preview benefits in Experiment 1 as a function of the proportion of trials the item was correctly identified in Experiment 2. Preview benefits increased as items were more readily identified in the periphery, but parafoveal identification explained only 10% of the preview benefit variance. Preview benefits also emerged for items that were correctly identified in the periphery by only 20% of the participants. The results suggest that identity and name priming play a minor role in the generation of preview benefits in this context, and that the majority of the effect is driven by activation at the level of abstract visual object descriptions.

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89 The Contribution of Context to Visual Object Recognition

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We see the world in scenes. In spite of the infinitely diverse appearance of these scenes, they typically include contextual associations that make the identity of the objects therein highly predictable. Such associations can give rise to context-based expectations that might benefit recognition of objects within the same setting. For example, seeing a fork will facilitate the recognition of contextually related objects such as a knife and a plate. Building on previous work (Bar, 2003; Bar & Aminoff, 2003), we propose a mechanism for rapid top-down and contextual contributions to object recognition: A blurred, low spatial frequency representation of the input (e.g. a beach scene) is projected early and rapidly from the visual cortex to the prefrontal cortex (PFC) and the parahippocampal cortex (PHC). In the PHC, each image activates an experience-based 'guess' about the present context (i.e. a context frame). This information is then projected to the inferior temporal (IT) cortex, where it triggers the activation of the set of object representations associated with the specific context (e.g., a towel, a beach chair, a beach umbrella, a sand castle). In parallel, the same blurred image activates information in the PFC that subsequently sensitizes the most likely candidate interpretations of the target object in IT (e.g., a mushroom, an umbrella, a beach-umbrella, a desk-lamp, a tree). The intersection, in IT, between the representations of the objects associated with the particular context and the candidate interpretations of the target object results, in typical situations, in a reliable selection of a single identity (e.g., a beach-umbrella). This representation is then refined and further instantiated with the gradual arrival of high spatial frequencies. We will outline the logic and discuss behavioral and neuroimaging data that support various aspects of the proposed model.

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90 Cortical Interactions in Top-Down Facilitation of Visual Object Recognition Through Low Spatial Frequencies

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Recently Bar (2003) proposed a mechanism for triggering top-down facilitation during visual object recognition where a low-spatial frequency ver-

sion of an input image is rapidly projected from occipital visual areas to the orbitofrontal cortex (OFC). Using this blurred representation, the OFC activates predictions about the most likely interpretations of the input image in the temporal cortex. This top-down projection facilitates recognition by significantly reducing the number of candidate objects that need to be considered.

For the OFC to facilitate recognition, differential activity would have to develop earlier there than the corresponding activity in the temporal cortex. Using magnetoencephalography (MEG), we have revealed that both recognition-related and spatial-frequency related activity in the OFC do develop 50 ms earlier than in the fusiform gyrus, within the temporal cortex. However, is this early OFC activity a result of early projections from the occipital cortex? Does it result in a direct projection from the OFC to the temporal cortex? And are these interactions governed by low-spatial frequencies? We have analyzed the MEG data using phase-locking statistics to test trial-by-trial covariance to determine whether the relevant regions communicate during object recognition.

The results support early communication between the occipital and orbitofrontal cortices. Occipital activity preceded OFC activity, thus indicating this is a feed-forward interaction. Furthermore, the OFC subsequently phase-locked with the fusiform gyrus, with OFC activity peaking before fusiform activity, signifying a feed-back projection. Additionally, significantly stronger phase-locking was found between the OFC and fusiform for low-pass than high-pass filtered images, indicating that this back projection is associated with low-spatial frequencies. These results confirm our hypotheses and lend critical support to our top-down model of object recognition. Supported by R01 NS44319.

91 The representation of shape in individuals from a culture with limited contact with regular, simple artifacts

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Many of the phenomena underlying shape recognition can be derived from an assumption that objects are represented as an arrangement of simple, regular, 2D or 3D geometrical shapes, such as circles, squares, bricks, and cones. The shapes, termed *geons*, are distinguished by contrasts of nonaccidental properties (NAPs), such as curved vs. straight or parallel vs. not parallel, that are invariant with orientation in depth. The detailed neural connectivity that enables this capacity is believed to develop out of early experience with the visual world. But what comprises this experience? By one assumption, a rich experience with extended contours—a characteristic of all naturally varying (i.e., non laboratory) visual worlds—would be sufficient to develop the appropriate representations. An alternative assumption is that the tendency for *geon*-like representations derives from our immersion in a manufactured world. Would individuals from a culture with only minimal exposure to developed-world artifacts show the same kinds of perceptual representations as those evidenced by typical artifact-immersed laboratory subjects? Would they, instead, have greater sensitivity for distinguishing among highly irregular shapes, such as bushes? The Himba are a people in northern Namibia with little contact with the regular, simple artifacts so prevalent in the daily life in developed societies. Their language includes few of the terms for the simple shapes and shape characteristics (e.g., "parallel") common in languages in developed societies. Similar to Western observers, the Himba showed greater sensitivity in distinguished shapes differing in NAPs compared to metric properties (i.e., quantitative variations such as aspect ratio or degree of curvature that do vary with rotation in depth). Moreover, the Himba's sensitivity to variations in shape similarity in distinguishing both simple regular shapes and highly irregular blobs resembled that of Western observers.

<http://www.eri.harvard.edu/faculty/peli/index.html>

92 Transformation from position-specific to position-invariant coding of objects across the human visual pathway

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Recent fMRI studies have shown that object categories can be distinguished based on the differential patterns of activity that they evoke in ventral temporal object areas (Haxby et al., 2001) and also retinotopic visual areas (Cox & Savoy, 2003). These results raise the question of whether successful object classification depends on neural representations of local low-level features or position-invariant properties of objects. We investigated if activity patterns in early visual areas and anterior ventral areas can effectively discriminate objects across changes in location. Subjects viewed stimuli from 8 different categories (e.g., chairs, faces, houses) in the left and right visual field. We performed correlational analyses to evaluate if different object categories could be reliably classified by comparing activity patterns on individual test trials to those observed on training trials. Activity patterns in areas V1-V3 were highly effective at classifying objects when training and test stimuli were presented at the same location (~75% correct, chance 50%), but unable to classify objects reliably across changes in location. These results indicate that successful classification of objects presented at a single location may not necessarily indicate neural selectivity for object categories. Higher visual areas (V3A and V4) were equally effective at classifying objects presented in the same location or across locations (~70% correct), indicating that position-invariant coding of object properties emerges at a remarkably early stage in the human visual pathway. Finally, anterior ventral areas also showed position-invariant classification with even higher levels performance (87% correct), consistent with the notion that ventral areas are important for flexible position-invariant coding of objects. Our results reveal a transformation across the human visual pathway, from position-specific coding of low-level features to position-invariant coding of object properties.

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93 Behavioral and physiological effects of backward masking and microstimulation in inferior temporal cortex of the monkey

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Activity of neurons in inferior temporal (IT) cortex is thought to be critical for the recognition of visual objects. Recently we showed that short trains of electrical microstimulation in IT can selectively bias monkeys' choice behavior in a recognition task. To examine the detailed temporal dynamics underlying these effects, we conducted combined behavioral and single unit recording during a classification task with backward masking. This paradigm allows the precise examination of the relationship between behavioral and neuronal sensitivity to visual patterns as a function of presentation time. Unlike previous studies, we compared the monkeys' behavioral and neuronal responses at the same time, replicated for new stimuli across multiple sessions. We found that for the shortest stimulus onset asynchrony (SOA) between target and mask (10ms), monkeys' performance fell to chance. At the same time we found a decrease of response amplitude for preferred target image in IT neurons, which was evident at response onset. As SOA was increased from 10ms and 60ms, neuronal and behavioral sensitivity quickly plateaued, but ROC analysis revealed that single unit sensitivity did not always match the monkeys' behavior. Guided by these findings, initial microstimulation studies using this paradigm indicate that electrical stimulation can affect choice behavior for preferred targets that are masked within 60ms. These results suggest that populations of IT cells very rapidly create a neuronal representation that can be used for recognition, and that microstimulation during this period can influence this process.

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Color Channels and Processes

10:30 - 12:00 pm

Hyatt North Hall

Moderator: Steve Shevell

94 Structure of Colour Space derived from Three Different Tasks

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Categorical colour perception could originate from either physiological (universal) or linguistic (relativist) constraints. Both positions assume perceptual and linguistic colour categories to be isomorphic yet a flexible relationship of mappings may exist from which different categorical organisation could arise

We tested this hypothesis by asking 40 English-speakers with normal colour vision to sort or name 140 Munsell chips (20 hues each at 7 values) over three tasks: 1) a Free Sorting Task (FST) with an unlimited number of categories; 2) a Constrained Sorting Task (CST) where the number of categories was limited to 8; and 3) a Constrained Naming Task (CNT) using 8 basic colour terms.

Data was analysed using cluster analysis and multidimensional scaling to identify colour categories and to derive a two-dimensional model of colour representation. The grouping of 68.6% of the samples obtained for 8 clusters is identical across tasks. The main difference was accounted for by the existence of a luminance-based pastel category (grouping of value 9 chips) in the CST, and a turquoise hue category in the FST replaced by the orange hue category that was present in the CNT.

In addition, representation of the 20 hues (averaged across the 7 values), draw the Munsell hue circle along a Red/Green and Yellow/Blue dimension. Large inter-points distances corresponding to category boundaries varied across tasks, with the exception of the largest common distance (5PB-10PB). Finally, the estimated collective consensus of category organisation was 69.2% for the FST, 73.8% for the CST and 85.4% for the CNT.

Structure of the colour space is independent of the task, but inter point distance variations generate differences in colour category mappings. Furthermore, constraints imposed by colour naming produce the strongest collective consensus to fulfil successful communication.

95 Chromatic Assimilation Measured by Temporal Nulling: Interaction Between the *l* and *s* Pathways

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BACKGROUND & PURPOSE The perceived color of an object depends on the context of other lights in view. This study considered neural processes that mediate chromatic assimilation, which is the shift in appearance toward nearby light. Assimilation was measured separately in the *l* and *s* chromatic pathways, and then jointly with an inducing light causing assimilation in both *l* and *s*. This tested whether assimilation resulted from independent *l* and *s* responses. **METHODS** The spatial frequency and chromaticity of context were chosen to optimize assimilation. Instead of directly measuring the appearance shift caused by context, light that induced assimilation was modulated in time, thereby causing a time-varying shift in test-area appearance. The magnitude of induced assimilation was quantified by the amplitude of temporally varying nulling light presented in the test area in counter-phase to the induced assimilation. The observer's criterion was a temporally steady test area; no color judgment was required. **RESULTS** Experiment 1 verified the temporally varying

inducing light caused assimilation rather than contrast in the test area. Experiment 2 quantified the separate magnitude of assimilation in the *l* or *s* pathway alone. These measurements were compared to the assimilation expected from optical factors (including chromatic aberration) and showed that a neural process contributed to chromatic assimilation. Experiment 3 used an inducing chromaticity that caused assimilation in both *l* and *s* simultaneously. An asymmetric interaction was found: assimilation in *s* depended on inducing stimulation in the *l* direction but assimilation in *l* did not depend on *s*. **CONCLUSIONS** Chromatic assimilation cannot be accounted for by optical factors affecting the retinal image. The neural process of assimilation is characterized by a specific interaction between the *l* and *s* pathways, which implies assimilation cannot be understood by considering each pathway independently.

Acknowledgment: Supported by PHS grant EY-04802

96 A comparison of the BOLD fMRI response to achromatic, L/M opponent and S-cone opponent cardinal stimuli in human visual cortex: I. perceptually matched vs contrast matched stimuli

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Aims: Our primary aim was to compare the responsiveness of the different visual cortical areas to stimulation of the two cone opponent systems and the achromatic system. The appropriate contrast metric for the comparison of color and luminance sensitivity is unknown, however, and so our secondary aim was to investigate whether equivalent fMRI responses of each cortical area could better be predicted from perceptual matches (in multiples of detection threshold) or a direct contrast match (in cone contrast).

Methods: MR images were acquired on a 4T Bruker MedSpec. Stimuli were sinewave counter-phasing rings (2Hz, 0.5cpd) cardinal for the selective activation of the L/M cone opponent (RG), S cone opponent (BY) and achromatic (Ach) systems. In different scans, stimuli were matched either at 25x detection threshold or in cone contrast (6%). We performed both stereotaxic and region of interest analyses on early visual areas (V1-V4v, and hMT+).

Results: For stimuli presented in multiples of detection threshold, BOLD responses in areas V1, V2, V3/VP and V4v are greatest for BY stimuli and weaker for both RG and achromatic stimuli, with the BY response significantly higher than the RG. For the same stimuli matched in cone contrast, the RG and BY response is similar in these areas. The averaged color response (RG & BY) was no different from the achromatic response with the exception of V1, which had a greater averaged color than achromatic response.

Conclusions: Perceptual visibility is not a good indicator of cortical activity across the RG, BY and achromatic mechanisms. fMRI BOLD signals are better predicted by cone contrast. Regardless of the metric, our data suggest a similar response to color (averaged RG & BY) and achromatic stimuli in V2, V3, VP and V4v. V1 shows a greater response to color, particularly with the cone contrast metric. Areas hMT+ and V3A do not follow these patterns and are discussed in a related abstract (Dumoulin et al).

<http://www.cs.dartmouth.edu/>

97 First-order color vision is slow; second-order color vision is fast

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Shapiro and colleagues (journalofvision.org/4/6/5 and [3/9/313](http://journalofvision.org/3/9/313)) have developed a class of visual stimuli capable of separating the visual response to 1st-order information (i.e., chromaticity or luminance) from the response to 2nd-order information (i.e., chromatic or luminance contrast). The basic version of the stimulus consists of two physically identical

disks, one surrounded by a dark annulus and the other by a light annulus. When the luminance levels of the disks are modulated sinusoidally in time, the 1st-order information from the disks modulates in phase, while the 2nd-order information modulates in antiphase. At 1 Hz, observers can track both the 1st- and 2nd-order information, creating the paradoxical impression that the disks modulate in antiphase but become light and dark at the same time. Analogous stimuli can be created for color. Here, we show that for both chromatic and luminance lights, the 2nd-order response predominates at higher temporal frequencies. This effect is not likely to be due to luminance artifacts since the intentional addition of luminance into the chromatic modulation eliminates the antiphase appearance. Further evidence for a fast chromatic contrast response comes from a novel experiment in which observers match the perceived modulation rate of a chromatically flickering light on a chromatic background (no contrast reversal) to the same light on a mid-white background (contrast reversal). Lights on the white background appear to modulate at twice the frequency of lights on the chromatic background, indicating the presence of a rectified chromatic contrast response. We propose the presence of two chromatic responses (1st and 2nd order). Chromatic thresholds are determined mostly by the 1st-order response; therefore, the 2nd-order chromatic response can be observed only at super-threshold levels. Luminance thresholds appear to be determined by a 2nd-order response. We will discuss the implications for color coding in the visual cortex.

98 More Evidence for Sensorimotor Adaptation in Color Perception

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Previous experiments using half-split colored spectacles had shown that color perception can be modified after exposure to new sensorimotor contingencies linking color change and eye saccades. The spectacles tinted a large part of the visual field, consequently creating strong non-homogeneity in the adaptation of peripheral retina. The present replication, involving only the central retina, avoids this problem and permits more precise control of the retinal stimulation. The method used is also simpler, can be easily replicated and allows more flexibility in the further study of the effect.

In the present experiment, adaptation trials involve the successive presentation of two patches, first on the left then on the right or the opposite, the left patch being always red and the right patch green. After 40 minutes of adaptation, yellow patches presented in a test stage seem to become redder when the eyes move rightwards and greener when the eyes move leftwards. When the eyes are kept fixed during the adaptation stage, creating a strong non-homogeneity in retinal adaptation, no effect is found. This ensures that, if present, such pure retinal adaptation cannot explain the present effect. A third experiment shows a dependency of the effect on the eye saccadic movement and not on the position on the screen, i. e. on the position of the eyes in the orbit.

These results confirm the involvement of sensorimotor mechanisms in color perception.

99 Induction from a chromatic pattern that cannot be seen

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BACKGROUND: Patterns with regions alternating between two chromaticities can induce large shifts in color appearance (Monnier & Shevell, 2003, *Nature Neuroscience*). Reliable shifts occur even with patterns having S-cone contrast of only 10%. Here we consider whether an inducing pattern with contrast so low that it cannot be perceived still induces color shifts.

METHODS: In a preliminary experiment, threshold for S-cone contrast in a pattern was measured by a 2AFC staircase procedure. A non-signal inter-

val contained 2 identical uniform achromatic backgrounds, presented side by side. A signal interval contained one uniform achromatic background and one patterned background (3 cpd) with inducing circles alternating between higher S-cone (toward purple) and lower S-cone stimulation (toward lime). In the main experiment, a centrally located test ring was inserted in all the backgrounds. The chromaticity of the test was chosen from previous work that showed strong induction from high contrast S-cone patterns. The task was to choose the interval in which the two backgrounds were different.

RESULTS: With the test ring in the patterns, each of 4 observers could reliably distinguish the signal from the non-signal interval at an S-cone contrast too low to be detected in the preliminary experiment without the test ring.

CONCLUSIONS: A test ring within an inducing pattern with S-cone contrast can be distinguished from a test ring within a uniform background, even when contrast in the pattern is below threshold. The results are consistent with an induced color shift from a chromatic pattern that cannot be perceived.

Eye Movements, Perception, and Action

10:30 - 12:00 pm

Hyatt South Hall

Moderator: Mary Hayhoe

100 Activity in Monkey Lateral Intraparietal Area Reflects Saccade Direction, Saccade Latency, and Target Identification During Free Visual Search

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Most physiological studies of saccadic eye movements and visual search reward animals for making specific eye movements, and withhold reward when they make incorrect eye movements. However, in ordinary visual behavior there is no such thing as a wrong eye movement. Instead, monkeys and humans scan the visual environment with saccades, using the eye movements to facilitate visual perception. In this study we permitted free eye movements during a visual search task, requiring the monkey to report a feature in the environment and allowing the monkey to make saccades at its own pleasure. We then examined the role of the lateral intraparietal area (LIP) in the generation of these more naturalistic saccades. The monkeys had to report the orientation of a target among an array of distractors by making a non-targeting hand movement. After the stimuli appeared, the monkeys were free to explore the array and they often made multiple saccades with their initial saccade going to a distractor. LIP activity was modulated by both the stimulus significance and the direction of the saccade. Neural activity distinguished between saccade targets and non-targets 86 ms after the array appeared, whether or not the saccade was made to the search target or to a distractor. This neural discrimination time correlated with saccade latency, suggesting that LIP could contribute to the selection of the saccade target. Neural activity in LIP also distinguished between a distractor in the receptive field and the search target in the receptive field on trials in which the first saccade went away from the receptive field. This discrimination occurred 111 ms after the array appeared, a time after the selection of the saccade target, but well before the beginning of the saccade. These data suggest that the processes of selecting a saccade goal and distinguishing the search target from distractors during visual search may run in parallel and both can be seen in LIP before a saccade.

Acknowledgment: National Eye Institute, James S. McDonnell Foundation, Whitehall Foundation

101 Neural Correlates of Subjective Spatial Bias in Macaque Posterior Cingulate Cortex

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Despite the obvious importance of subjective preferences for guiding decisions, their neural substrate has rarely been investigated. Both people and animals often demonstrate strong aversions or preferences for options with uncertain rewards, making risk preference an attractive model for probing neural mechanisms underlying subjective valuation and decision-making. Here we show that monkeys systematically preferred the risky target in a visual gambling task, in which they chose between two visual targets offering the same mean reward but differing in reward uncertainty. Neuronal activity in posterior cingulate cortex (CGp), a brain area linked to visuospatial orienting and reward processing, was enhanced by the illumination of risky targets in their response fields. On a trial-by-trial basis, CGp activation was better predicted by preferences for the risky target than by target reward value and was independent of arousal-linked changes in reaction time or saccade metrics. CGp activity thus reflects subjective bias for a particular visual target location, rather than the objective rewards associated with it. These data implicate subjective scaling of CGp activity in the decision processes guiding visual orienting.

Acknowledgment: NEI, Klingenstein Foundation, EJLB Foundation

102 Attentional Capture for Potential Collisions Gated by Task

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In natural behavior fixation patterns are tightly linked to the ongoing task. However, it is not known how task control interacts with image properties. How do task driven systems deal with unexpected salient stimuli? Previously, we studied the effect of potential collisions with pedestrians on gaze distribution of Ss walking in a virtual environment. Ss often failed to fixate pedestrians on a collision path, suggesting that potential collisions do not automatically attract a fixation, unless the observer is actively monitoring for pedestrians in peripheral vision. In this study we increased the saliency of colliders by increasing their speed by ~25% during the collision period, compared to the previous condition where they only changed direction. About 10% of pedestrians on a non-colliding path changed onto a collision course for 1 sec, and then returned to the original, non-colliding path. If peripheral vision is constantly monitored, or the deviation attracts attention, this should be revealed by a fixation. In one condition Ss were instructed to follow a virtual pedestrian leader, and in another condition, to walk at their natural pace. Ss are most likely to fixate pedestrians in the first 2 secs after they appear, during which time, in non-leader trials, Ss fixate normal (non-colliding) pedestrians about 58% of the time; speeding colliders are fixated about 88%, and non-speeding ones about 68% of the time. However, this difference was not maintained for the remaining 3 secs that pedestrians are typically in the field of view. Thus speeding colliders have added power to attract attention only when observers are likely to fixate pedestrians in general. This interpretation is supported by the results in the leader condition where the probability of fixating normal pedestrians in the first 2 secs is reduced to 30%, to 37% (speeding), and to 31% (non-speeding colliders). Thus a competing task diminishes the ability of the speeding colliders to capture attention.

Acknowledgment: NIH grants EY05729 and RR09283

103 SEF microstimulation reorders spatial memories in a convergent manner

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Saccadic eye movements can be elicited by microstimulation of the supple-

mentary eye field (SEF), an area on the dorsomedial surface of the frontal lobe. In contrast to the frontal eye fields (FEF) and the superior colliculus, saccades evoked from the SEF are often convergent: stimulation causes saccades to a single final target, or termination zone, from many initial eye positions. Because recent work suggests that the SEF may also play a role in the control of sequential movements, we explored the effect of microstimulation on monkeys' ability to remember and execute a sequence of two saccades.

While a monkey fixated a central target, two peripheral locations were cued in sequence. After a memory delay, the animal was required to make a saccade to those two locations in the same order as they were cued. Six pairs of targets were used in each experiment. During the delay, we microstimulated the SEF at currents below the threshold for evoking saccades, typically at 50°A. At 23 of 34 sites (68%), this stimulation biased the order in which animals saccaded to the targets --- the animals made saccades to the two cued locations, but in the wrong order. Saccade metrics and latencies were not affected.

The direction of bias was systematic: stimulation biased the animals' responses such that the final endpoint of the set of saccades was contraversive. Furthermore, across different pairs of targets, biases were convergent: the final endpoints favored by stimulation lay near one another. This data relates the prior observed roles of the SEF in convergent saccadic movements and sequential movement control.

104 Perceive the slow but pursue the fast - eye movement during shape-from-motion (SfM) with ambiguous stimuli

Mani Nezhad (nezhad@gmail.com), Arash Motamed¹, Bosco S Tjan¹; University of Southern California

Feature correspondence across time determines the perceived 3D shape of a moving stimulus. We investigate the role of smooth-pursuit eye movement in perceiving shape-from-motion (SfM). Since a moving target is needed to engage smooth pursuit, we reason that points foveated during pursuit corresponds to fixed points on the perceived 3D shape, thus revealing the correspondence established by a subject.

Seven Ss maintained, per instruction, one of two percepts induced by a rotating ellipse during ninety 16sec epochs. The ellipse, a line drawing 20° tall with an aspect ratio of respectively 0.4, 0.7, or 0.8, was rotated 0.125 rev/s in the image plane around a point 1.7° off the center along the minor axis. Eye movement was measured using a head-eye tracker. Eye positions and velocities during smooth pursuit was extracted by imposing a speed limit of 25°/s.

The dominant percept is a tilted disc rolling circularly on an invisible frontal plane, with little sliding. This solution of the correspondence problem minimizes the total perceived stimulus motion (Rokers, Yuille & Liu 2004). We found that, when asked to maintain this dominant percept, Ss often pursued the imaginary regions in the featureless interior of the disk that has a high perceived speed. Far fewer tracking was found in the geometrically symmetric regions of the disk where the perceived speed vanished. When asked to maintain the percept of a rotating ellipse in the image plane, Ss often pursued one of the two regions on the contour where velocity component along the normal direction is the highest. In sum, Ss pursue imaginary or physical regions with higher perceived speed, while the dominant percept corresponds to an SfM solution that minimizes the perceived stimulus motion and thereby also minimizes the perceived speed of the tracked regions.

Acknowledgment: USC Undergraduate Research Program Grant (BT)

105 Cognitive Saccadic Suppression: Number Comparison is Suppressed During Leftward Saccades

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It is well known that visual sensitivity is reduced during saccadic eye movements (i.e., saccadic suppression). Recent research has shown that saccades suppress some cognitive processes as well. For example, Irwin and Brockmole (2004, Psych Science) reported that saccadic eye move-

ments interfere with dorsal-stream tasks such as judgments of object orientation but not with ventral-stream tasks such as object recognition. Because saccade programming and execution also rely on the dorsal stream, Irwin and Brockmole hypothesized that cognitive saccadic suppression might occur as a result of dual-task interference.

Judging whether one number is larger or smaller than another is a dorsal-stream task that relies especially on the right parietal cortex (Dehaene, 2003, *Cognitive Neuropsychology*). In the current experiment, subjects judged whether a two-digit number was greater than or less than 65 while making no, short, or long saccades. RT to make this judgment increased with saccade distance, but only when the eyes moved from right to left. Saccade velocity decreased under these same conditions, suggesting that not only did saccades interfere with cognitive processing, but cognitive processing interfered with saccade execution as well. Because the right parietal cortex is instrumental in generating leftward saccades, these results provide further support for the hypothesis that cognitive suppression during saccades occurs as a result of dual-task interference within the dorsal stream.

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Poster Session B

May 7, 2005 – Saturday AM

Attentional Blink (106-117), Hand Movements 1, (118-131), Motion 1 (132-154),
Performance (155-173), Spatial Vision 1 (174-192), 3D Space Perception (193-201),
Target Mislocalization (202-208), Contours/Form Perception (209-221)

8:30 am - 1:30 pm (Authors present 12:00 - 1:30 pm)

Municipal Auditorium

Attentional Blink

106 Illusory Motion Attenuates the Attentional Blink

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Attempts to report the identity of two temporally closely spaced 'targets' leads to a phenomenon known as the 'attentional blink' (AB; Raymond, Shapiro, & Arnell, 1992). The AB has been replicated many times, though a number of experimental situations have emerged where the phenomenon does not occur. Recently, one such report by Olivers and Nieuwenhuis (in press) revealed that, with only the addition of a non task-demanding musical background, the AB is largely attenuated. The authors contend that music creates an 'attentional state' that reduces the dual-target interference to which we refer as the AB. In the present experiment, we sought to determine if 1) the background must be auditory, at the same time creating a cross-modal stimulus condition, and 2) if there might be a spatial attentional component. In three conditions we required different groups of participants to perform an AB task at the centre of the display. The AB task required two black digit targets to be identified from within a non-target distractor stream of black letters. In two of the three groups, we created an apparent motion background with a field of dots moving in one group away from the central AB task and in the other group toward the central task. In the control group, the same number of dots remained stationary. The control group revealed a normal AB, recovering by 450 msec. In contrast, both 'motion' background groups revealed an attenuated AB, with the greatest attenuation occurring in the 'moving outward' condition. We argue that 1) the effect shown by Olivers and Nieuwenhuis is not limited to an auditory background (and thus may be shown within- as well as between- modalities), and 2) is sensitive to a spatial attentional manipulation such as is created by the illusion of apparent motion. We speculate that ours and the original effect shown by Olivers and Nieuwenhuis may be due to the background task attenuating an unnecessary over-allocation of attention to the first target.

Acknowledgment: Wellcome Trust

107 Working memory and the attentional blink

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After successful identification of a target item (T1) in a Rapid Serial Visual Presentation (RSVP) task, identification of a second target (T2) is typically impaired for approximately 500ms (the 'attentional blink', AB). Although several models of the AB exist, a common element is an attention demanding stage, where a durable representation of T2 in working memory (WM) fails to occur due to ongoing processing of T1. So what effect do ongoing working memory processes have on the AB? Whilst

previous work (e.g. Akyurek & Hommel, to appear) has shown that concurrent WM tasks impair overall performance, no modulation of the AB effect has been found. This study investigates the effect of WM encoding processes on the AB using a hybrid WM/AB task. Subjects performed an RSVP task (T1-faces /T2-scenes, identity judgement) whilst maintaining two objects from a WM array; one was coloured red and the other green (e.g. a car in red, flower in green). The WM task involved matching a greyscale image (test image) to one of the items from the array. The test image was always one of the array items (e.g. the car). The item in the array to be matched against the test image was determined by a cue colour (red or green) that occurred either prior to the RSVP stream, or coincident with T1. For example, an array with a car in red and an apple in green followed by a green cue means the apple (green item) is to be matched to the test image. Results show that compared with presentation of cue colour outside the RSVP stream, concurrent presentation of the colour information with T1 increased the magnitude of the attentional blink. Follow up experiments show that this effect is not simply due to a low-level perceptual change, e.g. altered target contrast. These results inform the attention critical components of working memory processes.

Acknowledgment: The Wellcome Trust, UK

108 Information About a Spatial Cue Survives the Attentional Blink

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If two targets are presented in rapid sequence, the first target (T1) is usually perceived easily and accurately. Identification of the second target (T2), however, is impaired while the system is busy processing T1. This second-target deficit, known as the attentional blink (AB), is most pronounced at short inter-target lags and decreases rapidly, vanishing at lags beyond about 700 ms. A question asked in several earlier studies is whether all aspects of the blinked items are lost, or whether some information is preserved during the period of inattention that is the hallmark of the AB. In the present study, we asked whether information about a spatial cue presented after T1 but before T2 can survive the AB. To this end, we used a rapid serial visual presentation (RSVP) of distractor items consisting of black upper-case letters. Inserted in the stream of distractors were a white letter (T1) and a search array (T2). The search array contained 11 rotated Ls on an imaginary clock face, as distractors, and the letter T - tilted either to the left or to the right - as the target. The observers' task was to report the white letter, and then to decide whether the T was tilted to the left or to the right. T2 could appear at lag-1, lag-3, or lag-7 (90, 270, or 630 ms after the onset of T1). In Experiment 1, we used a 100% informative cue (a small square patch) to signal the location of the tilted T. This cue always appeared at the same time as the item (either T1 or a distractor) preceding T2. In Experiment 2, we used the same cue but this time it was non-informative. In both experiments, we obtained a

significant AB deficit and, more importantly, a significant facilitatory effect of the cue. These results show that information about a spatial cue can survive the AB.

109 Decision, awareness and false alarms in the attentional blink - a psychophysiological study

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The attentional blink (AB), a refractory time following correct identification of a target item T1 within a sequence of rapidly presented visual stimuli, results in impaired ability to identify a second target T2. However evoked response potentials (ERPs) indicate that the visual information is at least partially processed though controversy exists about the degree to which the P300 which is associated with working memory, is inhibited. The present study used psychophysics and electrophysiological techniques to examine conscious awareness of T2 within RSVP sequences of variable length comprising Navon figures with T1 6 characters from the start and T2 (if present) 6 characters from the end of the sequence with regard to the likelihood of error (false alarms), in 10 young adult participants. Null trials (50% of trials with no T2) matched the T2 containing trials in all other aspects. Event-related potentials (ERPs) were measured from scalp sites to clarify the effect of the AB on perceptual awareness using the P300 component of the ERP. Additionally, the association between T2 detection accuracy and the ability to differentiate between the presence and absence of T2 was examined. No P300 was observed during the AB, however an enduring negative waveform was generated in its place. The false alarm rate made in null trials followed a similar pattern to T2 accuracy in dual-target trials, with false alarm rate increasing with trial length, indicating that as the number of items increased, expectancy of presence of T2 increased and criteria for certainty decreased.

110 Interactions between spatial and temporal attention: An attentional blink study

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This experiment investigated interactions between spatial and temporal attention using an attentional blink (AB) procedure. The target letter, defined by color, was presented amongst distractor letters in a rapid serial visual presentation (RSVP) stream. The probe was a light dot that could occur in various positions in relation to the RSVP stream i.e. close or further away. The probe could occur at various stimulus onset asynchronies before and after the target. The effect of the probe's spatial and temporal distance from the target was compared in single- (respond only to the probe) and dual-task (respond to the target and probe) conditions. Results are considered in relation to the spotlight, gradient and selective tuning models of visual attention.

111 Target Detection Triggers a Slow Attentional Response in the Attentional Blink

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Observers often miss the second of two targets presented in rapid serial visual presentation at a stimulus onset asynchrony (SOA) of less than 500 ms (the attentional blink, AB; Raymond, Shapiro & Arnell, 1992). However, when a distractor that shares a visual feature (e.g., color) with the targets precedes T2, the AB is substantially reduced, suggesting that there is a delay in initiating processing of T2 that is overcome by the cue (Nieuwenstein, Chun, Hooge & Van der Lubbe, submitted). Here, two questions are addressed: (1) does cuing occur when the cue matches the category instead of a visual feature of the targets, and, if so, (2) does cuing depend on whether observers notice the cue. To this end, I used a three-target procedure in which the third target (T3) was presented 67, 134, or

202 ms after T2, which thus served as a cue for T3. T2 could appear either during or after an AB triggered by T1 (i.e., at SOAs of 268 or 670 ms). In a control condition, T2 was omitted. Performance for T3 was analyzed as a function of T1-T2 SOA, T2-T3 SOA, and the success of T2 identification. The critical comparison was between T3 performance when T2 was omitted versus when it was presented but not reported. The results showed that T3 report was unaffected by the AB when it was preceded by an unreported T2 (e.g., T3 report increased from 48% when T2 was omitted to 78% when T2 was presented but failed to be reported). When T2 was identified, however, T3 performance was found to decrease across the T2-T3 SOA, indicating that identification of T2 triggered a new AB. The results confirm an important role for cuing in overcoming a sluggish shift of processing from a first to a subsequent target, even when the cue is an unreported intervening target.

112 The Meaning of the Mask Matters: Evidence of Conceptual Interference in the Attentional Blink

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A rapid serial visual presentation (RSVP) experiment is reported that investigates the role of conceptual interference in the attentional blink. Subjects were presented with RSVP streams that contained 5 stimuli: Target 1, T1+1 distractor, Target 2, T2+1 distractor and a symbol mask. Target 1 was always a green letter, Target 2 a red letter and the distractors were either white letters or digits. The stimuli were presented in font typically seen on the face of digital watch. Thus, 'S' and 'O' were identical to '5' and '0'. This allowed us to present streams that were featurally identical yet conceptually different: Two letter targets followed by distractors that were either recognised as '5' and '0' or 'S' and 'O'. The results demonstrated that the attentional blink was substantially attenuated when subjects were told the distractors were digits rather than letters, providing evidence that conceptual interference plays a role in the attentional blink.

113 Testing the two-stage competition model of the Attentional blink: competition or a cost in distractor rejection?

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When observers try to identify two successive target items (e.g., letters) in a rapid stream of distractors (e.g., digits), accuracy for the second target is impaired for inter-target lags of 100-500 ms. This is the well-known attentional blink. Yet, when the same stream of items is presented more rapidly (e.g., 50 ms/item), accuracy is higher for the second target than the first when they appear in succession. To account for both of these findings, Potter et al. (2002, JEP: HPP, 28,1149-1162) proposed a two-stage competition model in which the first target is detected in a first stage, but whose representation remains labile until it can be transferred to a more stable second stage in which conscious identification is possible. We tested this model by varying the types of distractors preceding the first target. Experiment 1 replicated the finding that second target accuracy varied directly with three different inter-target intervals (53, 107, 213 ms/item). Accuracy for the first target improved as the interval was shortened, whereas second target accuracy decreased. In Experiment 2, we omitted the stream of distractors that preceded the first target and found that first target accuracy was no longer impaired at the shortest interval. This finding is contrary to the claim that first target accuracy is decreased at fast rates of presentation because of its labile representation. Experiments 3 and 4 tested alternative explanations for these findings, including forward masking of first target by the leading stream of distractors and task switching from a "rejection mode for leading distractors" to an "acceptance mode for targets." The findings strongly support the view that perception of items in a rapid stream is governed by multiple factors. These include attentional switching (Kawahara et al., in press, Psychological Research)

and object-substitution masking (Di Lollo et al., in press, Psychological Research).

114 The Attentional Blink and Automatic Orienting

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When a visual target (T1) is masked it can produce an interference on the identification of a second masked target (T2) for at least half a second (the attentional blink, AB). The exact role of target masking in the attentional blink is still unclear. Previous evidence suggests that the AB is enhanced when T2 is masked by interruption and reduced when T2 and its mask have a common onset. Four studies contrasted the effects on the attentional blink of masks which temporally overlap targets (common-onset masking) and those that follow the targets (delayed-onset masking). Study 1 showed that common-onset masking can be obtained with centrally presented stimuli when the mask is spatially close to the target and lasts longer than the target. Study 2 showed that the AB was much reduced when a common-onset mask was used at T2 compared to a delayed-onset mask. Study 3 showed that the same effect can be obtained when a common-onset mask is used at T1, i.e. an AB was produced when a delayed-onset mask is used at T2 but a much reduced AB with common-onset masking of T2. Study 4 showed that the delayed-onset mask must be a new visual event to produce an AB. These results show the importance of mask timing on the AB and suggest that the attentional blink depends critically on automatic orienting of attention to a new visual event.

115 The Role of T1 Masking at Short Lags in The Attentional Blink

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The Attentional Blink (AB) paradigm demonstrates that when instructed to detect two targets presented in a rapid visual stimuli stream, the second target (T2) is often undetected if presented 200-500 ms post onset of the first target (T1). However, if T2 is presented immediately after T1, in the conventional lag-1 position (100 ms stimulus onset asynchrony (SOA)), no performance deficit occurs. This finding, called Lag-1 Sparing, is believed to occur when T1 and T2 are encoded as parts of the same perceptual episode. The presence of a mask between T1 and T2 appears to be crucial for producing T2 deficits; a condition not met when T2 appears in the lag-1 position. Here we examine the role of T1 masking for Lag-1 Sparing. Our results indicate that inserting a T1 mask during the typically uninterrupted SOA between T1 and T2 prevents Lag-1 Sparing. Furthermore, interrupted presentation of successive targets lowers T2 performance across all lag positions. Results suggest that Lag-1 Sparing does not simply occur because T1 and T2 appear in close temporal proximity. Rather, Lag-1 Sparing requires an absence of intervening distracter information.

116 Subliminal task-irrelevant motion signals more severely disrupt RSVP task performance than supraliminal signals

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A widely believed consensus is that stronger task-irrelevant signals more severely disrupt task performance. If true, task-irrelevant signals that are too weak to be visible (subliminal) should less disrupt task performances than stronger supraliminal signals. To test whether this is the case, the subjects (n=16) were instructed to perform an RSVP (Rapid Serial Visual Presentation) task at the center of the display while ignoring a peripheral motion display. The degree of coherence in the motion display was varied from trial to trial (0, 5, 10, 20, 50, or 100 %). To our surprise, the RSVP task performance was the worst when the task-irrelevant motion coherence was as low as 5%. The results are at odds with the widely believed consensus. After the main experiment, we conducted another experiment to determine the coherent motion subliminal threshold. The same group of subjects as in the main experiment was instructed to report perceived coherent motion directions at various degrees of coherence (4AFC). The

performance with the motion coherence at lower than 7.7% was around the chance level (25%) for all the subjects and therefore 7.7% is regarded as the motion coherence subliminal threshold. This result indicates that the 5% coherent motion, which most severely disrupted the RSVP task performance, was actually subliminal. One possible explanation for this apparently paradoxical result is that since the attentional system did not 'notice' subliminal signals, the system was not triggered to filter the signals out. As a result, the subliminal signals might have more severely disrupted the task performance than supraliminal signals, which the attention system could 'notice' and filter out.

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117 The Attentional Blink Reflects the Time Course of Token Binding, Computational Modeling and Empirical Data

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A previously published computational model of the Attentional Blink (Wyble and Bowman, 2004) has given rise to predictions about the time course of the U-shaped T2 performance curve that is characteristic of the AB. Specifically, we posit that the blink curve is a hallmark of limitations in the temporal resolution of the binding of working memory tokens to types. In our model, lag-1 sparing results from a temporal window approximately 150 msec in length during which multiple items can be bound to the same token. Recovery of the blink occurs when a second token becomes available for binding.

In testing these predictions, we have performed two AB experiments. The first experiment compared the shape of AB curves for RSVP streams in the style of Chun and Potter (1995), presented at either 10 or 20 items/sec. If the AB is the result of temporal processes, the shape of the curve should be constant with respect to time. In our data, the blink curves had the same shape with respect to the time lag between T1 and T2, not the number of items. Specifically, in the faster presentation stream, we observed lag-2 sparing, maximal depth at lag 6 and recovery by lag 12.

Our second experiment involved presenting subjects with a letter pair for each of T1 and T2. If sparing involves binding T1 and T2 into a single conglomerate token, there should be a high percentage of binding errors at lag 1, in which one element of T1 is swapped with one element of T2. This prediction was confirmed, subjects made many binding errors at lag-1, and returned to baseline levels of error by lag-2.

This work details our continuing efforts to use the AB paradigm to explore the temporal structure of working memory. These data support our theoretical position that the AB stems from limitations in the consolidation of working memory tokens. We present these data in the context of a previously published connectionist model of the AB.

<http://www.kyb.tuebingen.mpg.de/>

Hand Movements I

118 Fixating for Grasping

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In a grasping task, Johansson et al. (2001) found that subjects look at the position to which the finger tips are guided. However, in their experiment, only the contact position of the thumb was visible. We investigated what happens if the contact positions of both finger and thumb are visible. We recorded eye and finger movements. In a first experiment, subjects always grasped with the index finger at the top and the thumb at the bottom of a flat shape that was mounted on a horizontal bar. In order to see whether a

salient feature of a shape would affect the fixation positions, we presented an (asymmetric) cross in 4 orientations (with the crossing of the bars representing the salient feature). In order to see whether gaze is attracted to the position where the finger has to be guided relatively precisely, we presented a triangle in two orientations that subjects had to contact at the base and at the pointed top (i.e., a higher required precision to contact the top than the base). We found that the crossing of the bars cross attracted the gaze whereas the top of a triangle did not. A prominent result was that subjects fixated above the center of the shape. In order to distinguish between subjects fixating the upper part of the shape versus being attracted by the index finger, we mounted a square and a triangle in two orientations on a vertical bar. We asked subjects to grasp first with one hand and then with the other so that the shape remained constant but the contact positions of the index finger and thumb were reversed. Subjects still looked above the center. In addition, the gaze was attracted to the index finger for the triangle but to the thumb for the square. We conclude that both features of the shape and the grasp affect gaze location. The exact location depends on the specific circumstances.

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http://www.cog.brown.edu/Research/ven_lab/index.html

119 Eccentric head and eye positions affect proprioceptive pointing

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To perceive the location of a stationary object to be constant, visual system should estimate head and eye positions as well as the retinal image position. Although previous studies indicated that eye position affects perceptual direction of a stimulus (J.Lewald, 2000), the effect of head position on the perceptual direction is not systematically shown. In this study, we investigated the effect of static positions of head and eye and movement of head on proprioceptive pointing.

Subjects put on a helmet that could be rotated about the vertical axis. Seven green light emitting diodes (LEDs) were arranged from 15 degree left to 15 degree right at eye level on a cylindrical surface (radius 0.5 m) in front of the subject and a red LED was mounted below the central green LED on the surface. In a trial, first, one of the green LEDs (randomly selected) was presented and subject fixated it. After two second from the onset of fixation point, a red LED was presented and subjects responded the perceptual position of the red LED using an unseen pointer with both hands. In one condition, subjects made the head movement before the response. In another condition, subjects kept their head directed to one of the three positions (15 degree left, center or 15 degree right).

The direction of pointing bias was opposite to that of the position of eye-in-head. This result is consistent with the previous study (J.Lewald, 2000). Moreover, the direction of pointing shifted to opposite to that of the position of head-in-space. These pointing errors generated by head and eye positions were simply added when both head and eye positions were eccentric. The results suggest that the error is not due to the position of eye-in-space but the individual positions of eye-in-head and head-in-space.

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120 Obligatory Attention To Action Goals

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Some of the neural substrate underlying visuo-motor coordination contributes to the interpretation of action intentions of others. In monkeys this 'mirror neuron system' consists of about 30% strictly congruent neurons (they code both the action goal [e.g., grasping an object] and the means for achieving it [e.g., with a precision grasp]) and about 60%

broadly congruent neurons (they also fire when observed and performed grasp differ). Here we provide behavioural evidence consistent with rapid and automatic operation of strictly congruent mirror neurons during action simulation in humans.

Observers viewed pictures of object pairs (one large and the other small) in front of a hand that briefly adopted either a power or precision grasp. After a random delay (variable from 0-450 ms), a target appeared unpredictably over one object (e.g., a power grasp was followed equally often by a target over the small/incongruent or large/congruent object). After both 200 ms and 300 ms delays, observers detected targets faster near the object that would be picked up with the previously shown grasp, indicating rapid and spontaneous action simulation. In Experiment 2, 21 new observers saw grasp postures that were only 20% predictive of the star's location (e.g., a power grasp was followed in 80% of trials by a target over the small object). They attended to the grasp-incongruent object within 100 ms following grasp cue offset, indicating strategic cue use. After 300 ms, however, attention was at the grasp-congruent object, indicating that action simulation overruled temporary grasp-object associations.

These results show that observers rapidly infer the goal object of another person's intended action and direct their own attention to it. The ability to interpret different grasps in this way implies the presence of strictly congruent mirror neurons in the human brain.

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121 Adaptation to Reversing Prisms: Pointing in Patients with Right-parietal Damage

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Right parietal patients can show errors in pointing to targets in the contralesional (left) visual field (unilateral optic ataxia (OA)). It is unclear if these errors are due to deficits in visual or motor coordinates. To test this, we trained stroke patients and age-matched controls to point at remembered visual targets while looking through left-right optical reversing prisms. Targets appeared briefly to either the left or right of a central fixation point. Baseline accuracy was tested with 2 blocks of 20 pointing trials (10 to the left and 10 to the right). Subjects were then adapted with 11 blocks using the reversing prisms, followed by 2 blocks without the prisms (recovery phase).

If 'OA' errors remained fixed in visual coordinates, reversing vision would reverse the errors left to right. If the errors were fixed in motor coordinates, they should not be affected by the prism task. Eight patients with right parietal (and other) damage were tested, but only one, with damage localized to the right superior parietal lobule, showed baseline inaccurate pointing to the left (but accurate right pointing). This patient quickly learned the prism task and showed a pattern of pointing that was more accurate and symmetric over-all, but with slightly greater errors for right pointing. Surprisingly, when the prisms were removed, this adapted pattern then reversed (i.e., errors were once again greater on the left, but far less than the original baseline errors). Symptoms of a left visual field 'neglect' (i.e., failure to respond to the stimulus) also stayed fixed in visual coordinates in this subject as well as another. In general, these results support the idea that posterior parietal cortex encodes the visual goal of the movement (upstream from the vision-to-motor transformation) rather than the downstream motor command. Our results also suggest that learning this reversal promotes the development of alternative pathways that might be useful for rehabilitation.

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122 Neural Activity in Monkey Parietal Area 7a During Reaching and the Effects of Prism Adaptation

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Visuo-motor transformation was studied in macaques by recording from neurons in parietal cortex and studying behavioral performance during a reaching task. In this task the monkeys had to reach to a target (white square) that appeared in one of 9 different locations (3x3 matrix) presented on a touch screen. The monkeys had to fixate the target, which dimmed by 10% to indicate the launch, and then to reach out to touch the target fast and accurately. After touching the target, the monkeys were required to hold their finger on target for 1.5 s. Once the monkeys achieved a high level of performance, 5? or 10? shifting Fresnel prisms were applied to create a mismatch between visually perceived and actual target location. With the prisms, behavioral adaptation and its time course was analyzed. Monkeys adjusted their reaching movements within a few hundred trials but large inter-individual variations were found too. Across multiple recording sessions, the adjustment periods decreased. After prism removal, monkeys showed a transitory after-effect in the opposite direction of the shift induced by the prism. Electrophysiological recordings were made from neurons in area 7a of posterior parietal cortex (PPC). This area plays a crucial role in visuo-spatial transformation from a retinotopic to a head-centered coordinate system, and is likely to be involved in visually guided reaching movements. Single cell responses (>100 neurons) were recorded from single units in area 7a. Temporal (activity changes during specific stages of the task) and spatial (9 stimulus positions) aspects were analyzed. Increased activity was associated mainly with the launch of the hand and only a few cells showed saccade related changes. In about one third of the cells analyzed, these responses were independent of spatial position; in another third, the responses were modulated with location of the reach position.

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123 Calibration of shape perception used to guide reaches-to-grasp

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In this study, the use of shape perception to guide reaches-to-grasp objects was investigated. The goal was to determine whether shape perception could be calibrated in this context. The participants reached to grasp cylindrically-shaped objects so as to span either the width or the depth with their index finger and thumb. The trajectory of reaching and grasping was measured and the terminal grasp aperture (TGA) was used to evaluate use of perceptual information. TGA occurs at the end of a reach but before the hand has contacted an object. In Experiments 1 and 2 (baseline data), we investigated whether occluding vision of the hand would affect reaches-to-grasp object width or depth. The results showed that TGA varied reliably with width and depth, and there was no effect of the occluded hand. Normally, one reaches to grasp width or depth, not width then depth. In Experiment 3, we investigated whether TGA covaries with width and depth when width and depth are grasped successively in a single reach. The results showed that they did. Experiment 4 replicated Experiment 3 with the addition of random probe trials in which participants grasped virtual objects (no actual contact). The results showed that such probe trials were the same. In Experiment 5, we investigated whether use of perceived shape could be recalibrated by distorted haptic feedback. Participants were given progressively distorted haptic feedback about shape and recalibration was tested by probe trials.

124 Patterns of Developmental Advancement in Visually-Controlled Goal Directed Action

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Through development children become increasingly expert in their ability to modify their motor responses according to changing visual information. An important aspect of this may be the ability to apply learnt rules to modify goal-directed actions operating under direct visual control. We studied development of this ability in four groups of children (n=10 for each group) aged between 5 and 12 years. Electromagnetic tracking equipment was used to document the kinematic features of aiming movement throughout its course from commencement to interception. The experiment consisted of 20 baseline trials and 60 further trials. For the baseline trials recorded before and after the experimental block, the child was required to move 25cm from a starting location to a stationary target 2cm in diameter (that the child knew would remain constant). A red target turning green was the signal to move. The experimental block consisted of four randomised conditions. Condition 1 consisted of 10 constant trials identical to baseline. Condition 2 consisted of 20 trials where the target 'jumped' either 10cm to the left or 10cm to the right, 10ms after movement commencement, Condition 3 consisted of 10 trials where the target turned red after the movement started, signalling the requirement to stop moving. In the fourth condition of 20 trials a blue distractor target appeared either 10cm to the left or right of the central target that remained as the central target. This paradigm revealed the developmental course of countermanding ability, online visual feedback correction capability and the aptitude to ignore distracting stimuli. The baseline trials allowed us to explore developmental patterns in strategy adoption when uncertainty is introduced within a movement task. The data shed light on the development of skilled visuomotor behaviour and constitute one of the most comprehensive descriptions of skilled movement development within this age group.

125 Task constraints alter prehension movements qualitatively and quantitatively

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A fundamental skill in everyday living involves reaching out and picking up an object (prehension). A fundamental issue in cognitive neuroscience is how movements vary in response to task requirements. It is important to address: (i) what lawful relations exist between task constraints and behaviour; (ii) which relations are stable across tasks; (iii) does behaviour change lawfully with task alteration? We asked participants to reach-and-grasp objects under different experimental conditions (n = 6 per condition). The participant's preferred hand moved to objects of different grip surface size (1, 2, 3cm) and object width (3, 5 and 7cm) placed at different distances (20, 30, 40cm). In condition 1, participants were allowed to touch the table off which the target objects were to be lifted. Movements showed the 'classic' prehension pattern and object distance was the only variable that predicted duration. In condition 2, participants were not allowed to touch the table whilst lifting the object and were required to generate fast, normal and slow movements. Object distance and grasp surface size predicted movement time whilst the spatial and temporal characteristics of the movement could be predicted from task constraints that affected the need for and use of visual feedback. In condition 3, participants had to secure a grasp without touching the table or moving the object when moving fast, normal and slow. In condition 3, prehension was found to consist of two components: (i) an initial component (IC) during which the hand reached toward the target while forming an appropriate grip aperture, stopping at (but not touching) the target object; (ii) a completion component (CC) during which the finger and thumb closed on the target. Across tasks the qualitative and quantitative aspects

of prehension were governed by the task constraints that affected the need for and the use of visual feedback.

126 Movement planning in a rapid 'foraging' task: Maximization of expected gain in strategy selection?

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We investigated how human subjects plan a sequence of rapid movements in a foraging-like task and compared performance to an optimal model based on maximum expected gain. On each trial, three targets (disks) carrying monetary rewards coded by color were presented for 1600ms in fixed locations on a computer screen. The subject had to choose which targets to attempt to hit and what sequence to attempt them in. The key challenges for the subject were, what sequence to choose and whether to try for all three targets. The key question for us was, do subjects select the sequence that maximizes their expected gain?

To compare subjects' performance to optimal, we have to first measure how accurately they can execute each possible sequence of length 2 or 3 on three targets. The experiment consisted of two sessions. In the first session, four naïve subjects were trained until their performance was stable. We then measured each subject's performance for all 12 possible sequences of lengths 2 or 3. We refer to the targets as A,B,C. The dependent variable was the probability of hitting each target (pA, pB, pC) and is a function of sequence. It might be (.9,.9,.3) for sequence ABC but (.9,.1,.6) for sequence ACB. The sequence ABC offers the higher probability of hitting all three targets but, if C is made valuable enough, the sequence ACB has higher expected gain. In the second session, the values of the targets were altered by amounts that varied from trial to trial. Subjects were told the values of the color-coded targets before each trial and were free to choose any sequence they wished. The values in the second session were chosen so that an ideal mover maximizing expected gain would change sequence for some value combinations. Two out of four subjects varied their movement sequences so as to maximize expected gain. The other two subjects exhibited highly consistent strategies across different reward values but did not maximize expected gain.

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127 Combining priors and noisy visual cues in rapid pointing

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Statistical decision theory suggests that optimal decisions (or actions) combine: (1) *prior information* (the probability of world states), (2) *likelihood* of world states given sensory data, and (3) the consequent gains or losses. Previously (Trommershaeuser, Maloney & Landy, *JOSA A*, 20, 1419-1433, 2003), we asked subjects to rapidly point at visual targets in the presence of neighboring penalty regions, with known payoffs/penalties. Performance was nearly optimal, indicating subjects fully account for (2) and (3). Can subjects optimally integrate likelihood and prior information in a rapid pointing task (assumed, but not tested, by Koerding & Wolpert, *Nature*, 427, 244-247, 2004)?

Methods: Subjects pointed and were rewarded when a target was hit within 0.7 s. Target location was chosen randomly from a Gaussian prior distribution. The mean location of the prior varied across trials. On each trial, first the prior was displayed as a bright Gaussian blob, with crosshairs at its mean. Next, the blob was replaced by random dots chosen from a distribution centered on the target location. The variance of this target-dot distribution controlled the visual information for the target location (the likelihood (2)), and was varied across trials. The target area was not explicitly displayed; hits on the screen within 7.5 mm of the mean of the target-dot distribution were rewarded.

Results: An optimal movement planner combines the prior and likelihood by aiming at the weighted average of the estimated location of the centroid of the set of target dots and the center of the prior. The weights should be inversely proportional to the respective variances. As predicted, endpoints regressed systematically toward the prior as target uncertainty increased. The data are compared with predictions of the optimal movement planner based on (a) perfect centroid calculation, and (b) a likelihood function determined in separate random-dot-localization experiments.

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128 Sensory-motor choices among configurations with variable expected gain

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In motor tasks with explicit rewards and penalties, humans choose movement strategies that maximize expected gain (Trommershaeuser et al., 2003, *JOSA*, 20, 1419). Here, two experiments were performed to explore the link between human movement planning under risk and human decision making. In both experiments, subjects were instructed to rapidly touch a target region while trying not to hit a nearby penalty region. Each target hit yielded a monetary reward; each penalty hit yielded a monetary penalty. Late responses were penalized. In the first experiment (N = 6), the time between stimulus display and the start signal for the pointing movement was varied (start signal 0 ms, 400 ms or 1000 ms after stimulus display). In the second experiment (N = 5), subjects had to rapidly point at one of two simultaneously displayed stimulus configurations, each consisting of one target and one penalty region. In some trials, the two configurations differed with respect to penalty value and spatial arrangement of the reward and penalty region. In the first experiment, subjects' movement end points and performance remained unaffected by variations in stimulus presentation time. In the second experiment, subjects' movement end points did not differ from the distribution of movement end points in trials with only a single configuration (control experiment). In trials with two configurations, four of five subjects showed a preference for the configuration with higher expected gain. Overall performance was suboptimal for three out of five (right-handed) subjects due to a higher preference for the stimulus configuration presented in the right half of the screen (81% to 72% across the overall balanced design).

Thus, human movement strategies remained stable (and optimal) across variable presentation times and for selection movements among multiple configurations. The choice among configurations with different expected gain was sub-optimal due to the constraints of the motor system.

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129 Evidence for Differential Weighting of Egocentric and Allocentric Cues in Delayed and Real-Time Actions

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Converging lines of evidence suggest that the presence of non-target landmarks affects the performance of delayed target-directed movements (Diedrichsen et al., 2004; Sheth and Shimojo, 2004). In the present experiment, we examined the effects of non-target landmarks on the accuracy and precision of delayed and immediate target-directed pointing movements. In our experiment, the landmarks were present just prior to and during the presentation of the target; they were never present during the execution of the movement. Constant and variable errors were significantly lower for delayed pointing when landmarks were present during encoding as compared to when they were absent. With absolute errors, a landmark-advantage was evident even for immediate actions. The locus of this 'landmarks benefit' appears to be in the target-encoding phase because we never re-presented the landmarks after target

presentation. We suggest that, when available, allocentric cues are combined with egocentric information, and thus serve to improve the accuracy of the representation of target location. In addition, we suggest that the relative weighting given to egocentric and allocentric representations is a function of the time-course of the movement task, with allocentric representations becoming more useful and egocentric representations less useful as the movement is delayed.

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130 The role of the visual feedback on the pointing behavior

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Purpose: When we point an object with a finger, the control of the arm and finger may be conducted by using a feedback loop involving vision, but it could be carried on solely by motor system without visual involvement especially when we point a target very quickly. To clarify the mode of control, or the involvement of vision in pointing behavior, we measured and compared the accuracy of pointing in conditions with and without visual feedback.

Method: Eight right-handed students participated. They were asked, to point a target (as quickly as possible) using their right hand. The target was a small dot displayed on a screen 228 cm away from the subjects. The target was on the medial plane of subjects' eye height. The points actually pointed by subjects were measured from the image projected on the screen by a small laser pointer that emits red light and affixed to the subjects' forefinger. There were two conditions. In one, feedback condition, subjects could see their arm and hand through the green glasses as well as the target. In the other, no-feedback condition, subjects saw only the target through a head mounted display connected to a video camera. They could not see their arm and hand. The location and the size of target were the same between the two conditions. In either condition, subjects did not have feedback from the point projected by the laser pointer since they wore either green glasses or head mounted display to prevent seeing the point. Each subject had 20 trials for both conditions.

Results: The accuracy was generally worse in the no-feedback condition than in the feedback condition. In addition, there was a systematic deviation towards right in the no-feedback condition. These results, together, demonstrate importance of visual feedback in pointing behavior.

131 The Last Moment for a Change in Pointing Direction

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Past evidence has shown that new visual information can induce online changes to a reaching trajectory, even during rapid movements (e.g. Saunders & Knill, 2004). Perturbations have typically been used to estimate the time required to incorporate feedback. We investigated the effect of new visual information on motor outcome. We made small visual perturbations of target location and measured endpoint accuracy. The perturbations could occur at different times during the reach. The target, a high contrast white dot subtending 0.58, appeared initially at an eccentricity of 88 and then disappeared for 67ms. On half the trials, the target reappeared at the same location and for the other half, it was shifted laterally by an amount (~0.58) that was easily visible on every trial. The direction of the shift was varied across blocks. The time of perturbation was measured from the subject's initiation of a pointing trial by a key press. The perturbation could occur early in the reach (110ms after trial onset), at an intermediate time (180ms) or late in the reach (250ms) in separate blocks of trials. Subjects made a rapid point to the target and were given negative feedback if their response was too slow (>500ms); average movement time across subjects was 430ms. For early or intermediate perturbations during the movement, subjects were able to adjust their

pointing trajectory so that there was a substantial difference between the mean of their points to the perturbed and static targets. For a late perturbation, subjects were unable to change their motor plan, because there was no difference between means for the perturbed and static targets. Subjects adopted an interesting strategy to cope with late perturbations. They pointed to the centroid of the two possible locations, thereby 'hedging their bets' about the likely location of the target. We conclude that subjects need about 250 msec to complete a shift in their planned hand trajectory in response to a visual perturbation.

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Motion 1

132 The effects of spatial-frequency and contrast ratio manipulations differ with dioptic and dichoptic viewing of Type 2 plaids

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Purpose: Recent research has supported a Bayesian model of motion combination for the perception of moving Type 2 plaids. When one component grating provides a more reliable motion signal than the other, perceived direction of the plaid is biased in the direction of the more reliable grating. Greater reliability of a grating may be achieved by increasing its spatial frequency (SF) or its contrast relative to the other grating. This predicts a bias of plaid motion toward the grating with higher SF or greater contrast. These biases were investigated under dioptic and dichoptic conditions. **Methods:** Naïve subjects viewed Type 2 plaids with gratings drifting in directions separated by 15 deg and speeds differing by a factor of sqrt(1.5). Either the SF ratio or contrast ratio of gratings varied from 0.54 to 1.84 in logarithmic steps. Stimuli were viewed dioptically or dichoptically. Subjects adjusted a pointer in the direction of perceived drift. **Results:** Under dioptic conditions, perceived drift of the plaid pattern was biased in the direction of the grating with the higher SF or greater contrast. When gratings were of equal SF or contrast, plaid direction was perceived between the vector-sum and the intersection of constraints (IOC) directions. Under dichoptic conditions and contrast manipulation, perceived plaid direction was biased in the direction of the component with greater contrast. However, there was little effect of SF ratio manipulation on the perceived direction of plaid motion with dichoptic viewing. Additionally, under dichoptic conditions, when gratings were of equal SF or contrast, plaid direction was perceived at the vector-sum direction. **Conclusion:** Although motion information is combined across eyes in dichoptic viewing, the motion combination rule seems to differ from dioptic presentation. Constraint lines weighted by reliability seem important for dioptic viewing, but vector-sum weighted primarily by contrast seems important in dichoptic viewing.

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133 The timing of space constancy during smooth pursuit eye movements

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The present study is concerned with the problem of compensation for smooth pursuit eye movements, especially with the timing of this compensation. When the eyes are engaged in a pursuit movement, a stationary background moves on the retina on the opposite direction. The visual system compensates for this retinocentric motion, recovering the stability of the visual environment. The compensation is incomplete, giving rise to the Filehne illusion, in which a stationary background is perceived as moving slightly in the direction opposite to the pursuit.

How long does it take to the visual system to compensate for those eye movements? Although this issue has received some attention in psychophysics (Stoper, 1967, Mack and Herman, 1978) and in neurophysiology (Haarmeier and Thier, 1998, Hoffmann and Bach, 2002, Tikhonov et al., 2004), little evidence of time evolution of compensation has been presented.

Recently, we have introduced a new technique to study the time evolution of compensation in the case of motion detection (VSS 2004). We found that in as little as 150 ms following stimulus appearance, motion is detected with respect to an allocentric reference frame; earlier, only motion in a retinocentric frame is detected. Thus, in the case of motion detection, compensation is in place by 150 ms.

Here, we ask whether the time evolution of compensation is specific to motion detection or whether it generalizes to other visual tasks. In the first experiment, we measured the time course of the Filehne illusion for extremely brief durations. In the second experiment, we study whether manually displacing the pursuit target—which reduces the time lag between target and eye movements—has an effect on the time course of compensation.

134 Anisotropic center-surround antagonism in visual motion perception

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Center-surround receptive field organization is an integral part of visual motion processing. These antagonistic structures, specifically those in MT area, are believed to be crucially involved in motion perception. Recently psychophysics has been exploited to demonstrate the perceptual consequence of center-surround motion opponency. Suppressing surround of the functional receptive fields, possibly in the area MT, renders the motion of a large high-contrast Gabor patch more difficult to discern. Since spatial antagonism (e.g. in MT) shows anisotropy at the neuronal level, it would be surprising to psychophysically clarify if and how anisotropic center-surround interactions are reflected at the behavioral level. In the first experiment we used large high-contrast elliptical Gabor patches and subjects were required to report its direction of motion. Stimulus duration threshold was significantly lower when the axis of elongation in the Gabor patch was perpendicular to the motion direction. This superiority effect was removed for elliptical Gabors with low contrast, small size or radial motion. These counterintuitive results could be fully explained by assuming two suppressive regions, which bilaterally surround an elongated functional receptive field. In the second experiment we used large high-contrast skewed Gabor patches and again measured the motion discriminability. Subjects had substantial difficulty in discriminating the motion signal when the motion direction was opposite to the direction of skewness in the Gabor. Low-contrast Gabors did not show such asymmetry in detection of motion directions. The results indicate that suppressive regions tend to spatially shift in the opposite direction of the Gabor's motion and, thus, providing a heterogeneous inhibitory surround with more strength in a single region on one side of the functional receptive field. The overall findings suggest some important conjectures to be addressed electrophysiologically.

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135 Speed history effects of visual stimuli

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In natural environments the speed of moving objects continually changes. To successfully interact with such objects it is useful to not only focus on the ongoing speed, but to also take speed changes into account. In the present study we were interested in whether area MT - the main motion area in the primate brain - represents not only information of the ongoing

speed of a visual motion stimulus but also reflects recent stimulus speed history.

We recorded from MT neurons from macaque monkeys during visual stimulation. The stimulus consisted of random dots moving into the preferred direction of the neuron. Stimulus speed changed smoothly over time (either linearly accelerating (condition 1) or decelerating (condition 2)). Both conditions contained the same actual speeds, but the speed history differed.

We found that the responses of most MT cells were influenced by the recent speed history of the visual stimulus. One main finding was a change in tuning width: The speed tuning was narrower when the stimulus was accelerating than when it was decelerating. This suggests that the system is less sensitive to speed changes when the stimulus smoothly decelerates. We investigated this in a psychophysical experiment with human subjects by determining detection thresholds to speed changes in a smoothly accelerating or decelerating stimulus. The results confirmed the prediction: during smooth deceleration, sensitivity was lower than during acceleration.

In summary we found that the recent stimulus speed influences the speed tuning properties of MT neurons and the speed perception of human subjects. This is further evidence that the visual system does not represent snapshots of the ongoing visual stimulation but integrates information over time. This integration is beneficial for survival in an ever changing environment.

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136 Signal latencies in motion perception during sinusoidal smooth pursuit

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Smooth pursuit eye movements change the retinal image motion of objects in the visual field. The visual system therefore has to take the eye movements into account to produce a veridical motion percept. According to the classical linear model of motion perception during smooth pursuit the perceived velocity depends on the sum of a retinal motion signal, estimating the retinal image velocity for a given object, and an eye movement signal that estimates the eye velocity. Errors in motion perception during smooth pursuit, such as the Filehne illusion and the Aubert-Fleischl phenomenon, can be explained in terms of the relative size of these signals. However, little attention has been paid to the temporal relationship between the two signals. If the eye velocity is not constant, differences between the latencies of the two signals will also produce perceptual errors. We therefore tested whether the signal latencies differ and what their perceptual consequences are. Participants judged the velocity of a sinusoidally moving random dot pattern, viewed during smooth pursuit of a sinusoidally moving target. In Experiment 1, the phase relationship between the dot pattern and the pursuit target was manipulated and in Experiment 2 we varied the motion amplitude of the dot pattern. In addition we examined whether positional cues affected performance by including a condition containing limited-lifetime dots. The relative signal size and phase difference of eye movement signal and retinal motion signal were estimated by fitting the classical linear model to the data. The model described the data well for most observers. The phase difference between the two signals turned out to be quite small, with perceptual errors mainly caused by differences in signal size.

137 Direction-of-Motion Discrimination is Facilitated by Visible Motion Smear

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Purpose. Recent evidence indicates that motion smear can provide useful information for the detection and discrimination of motion (Geisler, 1999; Burr & Ross, 2002). Because the extent of perceived motion smear decreases with the density of stimulus elements (Chen et al., 1995), we used random-dot (RD) targets of different densities to evaluate the contribution of perceived motion smear to direction-of-motion discrimination. **Methods.** RD stimuli with densities of 1, 2, and 10 dots/sq. deg were presented monocularly for 200 ms at a velocity of 4, 8, or 12 deg/s. To measure direction-of-motion thresholds, stimuli were presented in 7 near-horizontal directions and subjects reported whether the motion of the target included an upward or a downward component. Thresholds were defined as the change in the direction of motion that corresponds to 1 SD on the fitted psychometric function. On separate trials, subjects adjusted the length of a bright horizontal line to match the extent of motion smear that was perceived on each presentation of the RD targets. **Results.** In agreement with Chen et al. (1995), the extent of perceived motion smear decreased systematically with RD density. For velocities greater than 4 deg/s, direction-of-motion thresholds increased (from approximately 1.0 to 1.8 deg) with the density of the RDs in the stimulus. Across all combinations of velocity and RD density tested, the direction-of-motion thresholds correlated significantly with the extent of perceived motion smear ($r = -0.90$; $p < 0.001$). **Conclusions.** Despite the opportunity for increased summation as RD density increases, our results indicate that direction-of-motion discrimination worsens. This outcome is consistent with the conclusion that direction-of-motion discrimination is facilitated by visible motion smear.

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138 Motion Sensitivity and Fixation Variability along Individual Meridians.

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Purpose. Murakami (VR, 2004) reported a relationship between motion sensitivity and the variability of fixational eye movements in normal observers and concluded that retinal image motion during fixation is discounted perceptually. In this study, we investigated whether sensitivity to motion along specific meridians is limited by the variability of fixation in the corresponding meridian. **Methods.** Random-dot motion was presented in an array of 8 blurred patches, spaced equally around an imaginary circle with a 10-deg diameter. The observer fixated monocularly at the center of the circle. On each trial, all of the random dots in each patch translated for 500 ms in a common direction: right, left, up, down, clockwise, or anti-clockwise. Motion thresholds were defined as the velocity of horizontal, vertical, or rotary motion that yielded 50% correct judgments. Variability of fixation was specified as the SDs of horizontal, vertical, and torsional eye velocity for 168 half-sec samples, measured using a search coil. **Results.** In agreement with Murakami, the average thresholds for horizontal and vertical motion in 11 normal subjects correlated significantly ($r = 0.67$, $p = 0.025$) with the average SDs of horizontal and vertical eye velocity. However, no correlation existed between motion thresholds and the SDs of eye velocity when the results were not averaged across meridians ($r = 0.019$). Further, no relationship existed *within* subjects between motion thresholds and the SDs of eye velocity in corresponding meridians. **Conclusions.** One explanation of our results is that the visual system discounts retinal image motion produced by normal fixational eye movements, based on the average variability of eye velocity across meridians. If so, then discounting the retinal image motion from eye movements cannot account for the anisotropic motion

thresholds in congenital nystagmus, unless the discounting process operates differently in subjects with meridionally impaired fixation.

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139 A contribution of early motion systems on stream-bounce perception.

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The stream-bounce stimulus induces a bi-stable motion perception (Metzger, 1934). In this phenomenon, two identical moving objects with trajectories crossing each other are perceived either as streaming through (stream) or colliding and bouncing off (bounce). Although this phenomenon is often related to a high-level motion processing, we explored a possibility of earlier contribution by examining the effect of inter-stimulus interval (ISI) which supposedly disrupt energy based detectors (Braddick, 1974).

Method: The stimulus comprised two moving white discs (1 deg diameter) on gray background. Each disc moved on one of two linear motion paths that inclined 30 deg from perpendicular i.e. 60 deg angle between the two trajectories. The motion was 9-frame apparent motion with 2 deg displacements and a fixed SOA of 120 ms. The two trajectories met at the center and the 5th disc shared a position, i.e. only one disc was presented there. ISI was manipulated in 6 steps from 0 to 100 ms and duration covaried accordingly to make SOA 120 ms. Subjects were asked to judge whether motion appearance was 'stream' or 'bounce' with a 2-AFC method.

Results and Discussion: The response rate that 'stream' was perceived at 0 ms ISI was calculated for each subject. As a result, response rates were higher or lower than chance for 6 of 7 subjects. That is, although there was a strong individual difference in preferred percept, each subject had a dominant perception. Next, we calculated the response rate that 'dominant perception' was reported (dominant rate) in each ISI condition. Regardless of the initial dominance type, dominant rate decreased as ISI increased and the dominance reversed at the largest ISI (100 ms). These results indicate that motion perception with the stream-bounce stimulus is sensitive to ISI, and thus suggest strong contributions of Fourier-type early motion detectors (Adelson & Bergen, 1985).

140 Influence of Optic Flow Field Restrictions and Fog on Perception of Speed in a Virtual Driving Environment.

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Contrast is known to affect perceived speed, and it has been suggested that one of the reasons for difficulty in driving in fog is impaired speed judgments resulting from the contrast reduction caused by the fog (Snowden, Stimpson, & Ruddle, 1998). However, fog also reduces the area of the field from which image motion is available, in addition to contrast reduction in the near visual field. In this study we investigated the influence of reduced spatial structure from the flow field on perceived speed in a virtual driving environment, and compared this with the effects of fog. To simulate fog we used a model that reduces contrast exponentially with distance, rather than the spatially uniform reduction in contrast used by Snowden et al. To examine the effects of reduced spatial structure we removed road texture and line markings, and changed the density of roadside objects. These manipulations substantially reduced perceived speed, but exponential mist or fog had only a small effect. This was true both in the immersive environment with a head mounted display, or when subjects viewed the scene on a monitor. Thus the

reduction in area of the field from which optic flow information is available, rather than contrast reduction, is at least partially responsible for reduced ability to judge speed of self-motion in foggy conditions. In addition the data suggest a role of optic flow in judgments of speed of self-motion in natural environments, in addition to the roles previously suggested for flow, such as control of heading and control of braking.

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141 Thresholds for Detection of a Moving Object by a Moving Observer.

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When an observer moves through a scene, both stationary and moving objects project moving images onto the retina. For observer motion in a straight line, the image motion for stationary objects forms a radial pattern. How do moving observers detect a moving object in the scene? In theory, observers could identify objects whose speed or direction of motion differs significantly from that of the other objects in the scene. We tested how large an angular deviation is needed to detect a moving object in a radial optic flow field. We also examined observers' abilities to detect an object moving at an angular deviation from a deformation field, to test whether global pattern information contributes to this detection process. In each trial, observers viewed a scene that consisted of 25 white circles moving on a black background in either a radial or deformation flow pattern. In half the trials, one of the circles, the target, moved with an angular deviation from the radial or deformation pattern. Observers pressed a key to indicate whether or not this target circle was present in a trial. We measured the percentage of correct responses for angular deviations of 10, 15, 20, 25, 30 and 45 deg, and trial durations of 0.25, 0.5, 0.75 and 1.0 sec. For the radial pattern, the average threshold (75% correct) for the 9 observers tested was 20.7 deg for the 0.25 sec duration and decreased to 13.6 deg for the 1.0 sec duration. For the deformation pattern, the thresholds were much higher, at 35.4 deg for the 0.25 sec duration and decreasing to 29.0 deg for the 1.0 sec duration. Because the local rate of change of motion direction is the same for the radial pattern and the deformation pattern, this result implies that observers make use of global pattern information in addition to local motion cues when detecting a moving object within a radial optic flow field.

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142 Motion perception is differentially effected by the transient and sustained components of spatial attention.

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Many have suggested that spatial attention has 2 components: The slower, voluntary Sustained Attention (SA), and the faster, involuntary Transient Attention (TA). Whether these two components are separate mechanisms operating in a different manner, or just different instantiations of the same mechanism is still unclear.

To study the effects of TA on motion perception observers in one task had to rate the quality of motion perception elicited by an apparently moving line, and to indicate in another task the motion direction of an apparently moving rectangle. A peripheral cue (a bar) known to attract TA to the target location, or a neutral cue (6 bars) specifying that the target could appear in any one of the 6 possible locations, preceded the target. The results indicate that TA degrades motion perception. Motion rates and direction discrimination were lower with the peripheral than the neutral cues. This degradation was found even with a color-singleton cue, identical in all aspects to the neutral cue apart for the color of the bar above the target location, ruling out any 'interference' interpretations of the results. These results are consistent with other findings regarding TA and

temporal processes and support the hypothesis that TA favors parvocellular over magnocellular activity.

This attentional degradation disappears, however, with SA cues. In two additional experiments, centrally presented cues preceded the apparently moving rectangle. One cue was an arrow pointing at the target location. The other was a face gazing at the target location. In both cases, no attentional degradation of motion perception was found, and a small facilitation was evident with spatial displacement larger than 1°. This is consistent with previous studies showing that SA either improves motion perception or does not affect it (especially with small displacements). The differential effects of the two components of spatial attention support the view that TA and SA are indeed two different mechanisms.

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143 Motion transparency in combined first and second order stimuli

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Two superimposed luminance gratings of identical orientation and opposite direction of motion are seen as moving across one another (i.e. moving transparently) only if they are of different spatial frequencies (SF). Identical SF gratings produce counter-phase flicker. This suggests that opposite motions cancel each other within SF channels. Here we show that transparent motion is perceived with two superimposed gratings of identical orientation and SF, when one component grating is a first-order stimulus, whilst the other is a second-order stimulus. More precisely, this stimulus is the sum of two identical dynamic 2D noise carriers, one subject to luminance modulation (LM) the other subject to contrast modulation (CM) by a sinusoidal envelope (SF = 4.6cpd, temporal frequency = 1.6Hz). The perception of this stimulus is examined in a 2AFC task. Participants were presented with a LM+CM stimulus, where the motions of the component gratings were either in the same or opposite directions. The amplitudes of the CM and LM gratings were varied (10% - 22.5% and 5% - 25% contrast, respectively) and participants were asked to choose the interval containing transparent motion. Results show that the amplitude of the LM component affects the CM amplitude required for the perception of transparency: higher LM amplitudes require higher CM amplitudes before transparency is seen. In a second experiment, participants adapted to a transparent LM+CM stimulus. Following adaptation, participants showed elevated contrast detection thresholds when the direction of motion of a translating CM or LM test grating was identical to that of the corresponding component of the adaptor. These findings support the idea of separate pathways for the detection of first and second-order motion. However, the observed contrast dependency suggests that these pathways are not wholly independent. Our results further suggest that second-order information may aid the segmentation of multiple motion signals.

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144 Speed differences increase the number of transparent motion signals that can be detected simultaneously

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Transparent motion occurs when multiple objects move through the same region of space without total occlusion. Previous work demonstrates that when direction differences are the only cue to transparency, observers can detect no more than two transparent motion signals simultaneously. This limit appears to occur because transparent motion detection requires coherence levels much higher than those required for uni-directional motion. If this is the case, it should be possible to increase the number of signals that can be detected by increasing their signal intensities. We increased signal intensity by distributing processing of the signals between

two speed-tuned global motion systems. Because these systems perform signal-to-noise operations independently, dividing the signals between them increased the effective intensities by decreasing the amount of signals processed by each system. Observers were required to indicate which of two temporal intervals contained the greatest number of transparent motion signals. Simultaneous processing was ensured through brief durations (200ms) and comparisons between n and $n+1$ signals, eg. 3 vs. 4. With no speed differences, observers could detect no more than two transparent signals. When some signals moved at a low speed and others at high speeds, up to three could be detected. Thus, by raising the effective signal intensity, the number of transparent motion signals that could be processed simultaneously was increased. This is consistent with the signal-to-noise processing basis of the transparency limit. However, were signal intensity the sole constraint, the addition of speed differences should have allowed the representation of up to four signals. The fact that the limit could only be extended to three indicates further limitations on transparent motion processing.

145 The contribution of low-level motion systems in multiple object tracking

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Purpose: We examined contribution of low-level motion systems to the asymmetry between the upper and lower visual fields in multiple object tracking (MOT) performances. He, Cavanagh & Intriligator (1996) suggested the asymmetry originated from attentional resolution (high-level visual processing), but it is not clear whether low-level motion systems contribute to the asymmetry. To clarify this point, we conducted MOT experiments where ISI (inter-stimulus interval) for motion stimuli was varied. The operation of spatiotemporal filters for low-level motion systems is supposedly disrupted with longer ISIs (Braddick, 1974). If the asymmetry between the upper and lower visual fields is affected by ISI, it could be argued that low-level motion systems are at least partially responsible for the asymmetry. On the other hand, if there is no effect of ISI, the asymmetry is attributed more to higher-order motion systems. **Method:** Nine moving green disks were presented in the area of 6×30 degrees visual angle on a CRT screen. The ISI for apparent motion was varied in 5 steps between 0 and 200 ms. The motion stimuli were presented either in the upper or lower visual field. The color of 2 out of the 9 disks changed to red at the beginning of a trial to designate tracking targets. Subjects were asked to track the targets while keep fixating on a marker at 10 degrees above or below the center of the area for a 7 sec period. At the end of each trial, subjects reported the disks that they acknowledged as targets. **Result:** As ISI increased, the MOT performances decreased in lower visual field, while the performances in upper visual field were little affected. These tendencies thus resulted in smaller magnitudes of asymmetry for longer ISIs. **Conclusion:** These results strongly suggest that the asymmetry comes from the advantage in MOT task for the lower visual field that is related to the characteristics of low-level motion systems.

146 Second-order motion alone does not convey ordinal depth information.

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There is convincing evidence that in addition to temporal variation in luminance, the perception of motion can be mediated by temporal changes in contrast. The characteristics of contrast based second-order motion processing are well documented; however, what this information is used for is unknown. Hedge et al. (2004, *Journal of Vision*, 4-10) argue that second-order motion provides a signal for ordinal depth. While their results are consistent with this proposal, they do not show that second-order cues alone are sufficient to support this percept. In the following

experiments we test the hypothesis that the percept of depth ordering in the displays used by Hedge et al. (2004) is due to the presence of luminance based motion cues or high-level figure-ground cues. Here, we asked observers to judge the relative depth of two regions within a rectangular stimulus using solely second-order motion cues, and/or high-level configural (ie. figure-ground) cues. The stimulus consisted of a temporally resampled binary texture moving relative to a mean luminance matched background. Observers were asked to indicate which surface (upper or lower) they perceived as being 'nearer'. Our results show that when given second-order motion cues in isolation, observers rely on high-level configural cues. That is, their percept of depth ordering is determined by the location of the textured regions, e.g. when the texture was located in the upper portion of the stimulus, observers reported the upper region to be nearer on 70% of the trials ($n = 11$), and vice versa. When both regions of the display were filled with temporal noise with different element sizes this configural cue was eliminated and the near/far percept oscillated about 50%. These results show that second-order motion signals *in isolation* do not support depth ordering. To obtain reliable relative depth percepts from second-order motion additional cues such as accretion/deletion and common motion are needed.

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147 Perception and discrimination of global flow speed reveals motion coding

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In order to perceive motion accurately, an observer must perceive both speed and direction. We investigated whether speed and direction are processed separately or together by measuring the perceived speed and speed discrimination thresholds for global flow stimuli (e.g., Watamaniuk, Sekuler & Williams, 1989). If speed and direction are processed together, then increasing the range of directions in the global flow stimulus should impact perceived speed and speed discrimination thresholds.

Observers viewed random dot cinematograms in which each dot moved with a constant step size from frame-to-frame and randomly chose its direction each frame from a distribution of directions (frame rate = 60 Hz). To measure perceived speed, observers were presented with two stimuli in each trial where the standard contained dots that moved in a single direction (upwards) and the comparison contained dots that moved in a range of directions spanning 90° or 120° with a mean direction of upwards. The speeds of the standard were 6, 9, 12, and 15 deg/sec. The speed of the comparison varied from trial to trial according to a one-up, one-down staircase that converged on the point of subjective equality. To measure speed discrimination, the method of constant stimuli was used and observers were presented with a single stimulus on each trial and asked to judge if the stimulus moved faster or slower than the implicit mean speed. Thresholds were measured for four mean speeds, 6, 9, 12, and 15 deg/sec, and for stimuli spanning three different direction ranges, 0° (all dots moved in a single direction), 120° and 360°.

Results showed that perceived speed of global flow decreased as direction bandwidth increased and that speed discrimination was poorer (higher thresholds) when direction noise was added to the stimulus. Taken together, these results lend support to the idea that speed and direction are processed together.

148 Perceived direction of drifting Type 2 plaids is biased toward higher-reliability component

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Purpose: The perceived direction of moving Type 2 plaids is usually intermediate between the veridical intersection-of-constraints (IOC) direction and the errant vector-sum direction. Our recent analysis of a

Bayesian model of motion extraction predicts that when one of a plaid's component gratings gives a more reliable motion signal than the other component grating, perceived direction should be biased toward the grating with the more reliable motion signal. This predicts that perceived direction is either a monotonic or nonmonotonic function of relative reliability, depending on baseline direction percept. Reliability can be manipulated, for example, by contrast or by spatial frequency (SF). We have been accumulating evidence in support of these predictions. Methods: Naïve subjects viewed Type 2 plaids whose component gratings drifted in directions separated by 15 deg and whose speeds differed by a factor of 1.5. We manipulated duration, aperture diameter, baseline spatial frequency, and baseline contrast. We also manipulated the ratio of the gratings' SF and of their contrast. Subjects pointed an arrow in the direction of perceived drift. Results: When the gratings were of equal SF and equal contrast, perceived direction was close to the IOC direction or vector-sum direction, depending on baseline manipulations, as predicted by the model. When the gratings were of unequal SF or unequal contrast, perceived direction was biased toward the grating with more reliable motion signal, as predicted, whether reliability was manipulated via contrast ratio or SF ratio. Conclusions: The results consolidate confirmations of predictions of a Bayesian computational model of motion extraction that suggests that IOC and vector-sum directions, as well as directions beyond vector-sum, can arise from a motion analysis that weights motion signals according to their reliability. These predictions arise from strictly computational rather than physiological considerations.

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149 The effect of luminance texture on MAEs.

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Previous research on motion perception has found that static luminance texture produces an increase in the perceived speed of moving stimuli. The experiments discussed here study the influence of texture on another aspect of motion perception: the motion aftereffect (MAE). In Experiment 1, we measured static MAE duration in three conditions: 1- luminance modulated gratings to which no texture was added 2- luminance modulated gratings to which static texture (static luminance noise) was added 3- contrast modulated noise. Our results demonstrate that adding static luminance texture to a drifting luminance-modulated sinewave grating greatly diminishes static MAE duration and can even completely eliminate the static MAE. Our results also show that no difference in static MAE duration occurred between luminance-modulated gratings to which static luminance texture was added and contrast-modulated noise. This suggests that the failure of contrast-modulated texture to elicit a static MAE may not come from a fundamental difference in the processing of first- and second-order motion, but from the luminance texture inherently present in these second-order stimuli. Our results and the static MAE are discussed in a Bayesian context in which adaptation creates a shift in the prior's center in the direction opposite to the direction of adaptation and texture is used as a landmark. This is consistent with a recalibration and error-correcting account of the MAE. In Experiment 2, we studied the effects of texture characteristics on the MAE by notch-filtering the luminance noise in Fourier space. Preliminary data show that filtering out high pass information along the axis of motion produces longer MAE durations, but that filtering out high-pass information along an axis orthogonal to the axis of motion does not. This is consistent with the proposal that the visual system uses luminance texture in the assessment of motion.

150 The Dynamic Motion Aftereffect is Driven by Local Motion Adaptation

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The motion aftereffect (MAE) takes two forms - the static and dynamic MAE. Differences in their characteristics point to separate mechanisms underlying the static and dynamic MAE (dMAE), leading to speculation that they reflect neural adaptation in areas V1 (which encodes local motion) and MT/V5 (which encodes global motion), respectively. We tested whether the dMAE is driven solely by adaptation of global motion detectors, or whether local motion detector activity contributes to the effect. Our first experiment measured the speed tuning of the dMAE. Observers adapted to two displays on either side of fixation - a random dot pattern moving upwards, and a noise pattern in which all dots took a random walk (0% motion coherence). Following adaptation the stimuli were replaced with a 0% motion coherence and a 35% motion coherence stimulus moving upwards, respectively. The task was to judge which stimulus - the resultant dMAE or the 35% motion coherence stimulus - had the greater apparent speed. Dot speed was identical in both the adapting and test stimuli, and observers were tested over a range of speeds. The results revealed an inverted U-shaped speed tuning function. We repeated the experiment, but this time kept dot speed in the dMAE test stimulus constant while varying speed in the adapting stimuli and vice versa. If perceived speed of the dMAE is driven solely by adaptation of global motion detectors, then speed of the adapting stimulus - but not the test stimulus - will be responsible for the MAE's speed tuning. This is because the adapting stimulus is rich in global motion information. The test stimulus, on the other hand, does not contain any global motion information, but is rich in local motion information. Our data reveal that dMAE speed is determined solely by the characteristics of the test stimulus. We conclude that the dMAE is driven by neurons involved in local-motion processing, activity that is primarily associated with area V1.

151 Temporal Dynamics of the Motion Aftereffect

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Staring at a moving display for a few seconds generates a long-lasting aftereffect in the opposite direction. We are interested in the temporal dynamics of motion aftereffects when the test stimulus is presented at various speeds. Due to the end of the aftereffect being a very subjective and delicate event to determine, we provide a new method to estimate the duration of the motion aftereffect. Participants adapted to random dot kinematograms (RDKs) for a period of 5 seconds. To reduce eye movements, two RDKs were placed on either side of the fixation point, moving in opposite directions (e.g. outwards motion). Following a brief interval, the adapting stimuli were replaced by test stimuli whose direction was identical (outwards) but whose speed was a fraction of the adapting speed. If the speed was small, the perceived direction of the test stimulus was initially opposite to its physical direction (inwards) and slowly reverted to the true direction (outwards). We prompted observers to repeatedly judge the perceived direction of the test stimulus in order to estimate the time of reversal. We took this time of reversal as our measure of the duration of the motion aftereffect, and estimated these durations for various test speeds. We found that the duration of the aftereffect depended on the speed of the test surface. Specifically, the slower the speed of the test stimulus, the longer the aftereffect lasted. In summary, we present a new method of investigating the motion aftereffect which offers a robust estimate of the temporal dynamics of the aftereffect.

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152 Effects of Surface Depth Order on Motion Aftereffects

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After adapting to transparent bidirectional motion at different depth planes, one perceives transparent motion aftereffects (MAE) with a test pattern containing the same two depth planes (Verstraten et al., 1994). We investigated whether this motion adaptation is specific to absolute disparity or to the relative depth order of surfaces. Observers adapted to

two superimposed populations of dots that were moving in opposite directions (left and right) in different depth planes (approximately -11 and +11 arc min). In experiment 1, the MAE test contained two planes of randomly moving dots presented at various absolute disparities (-29 and -6; -23 and 0; -11 and 11; 0 and 23; 6 and 29 arc min). Observers' task was to report the MAE direction in either the front or back surface, which was cued by a tone. The results indicated that the MAE was influenced by the depth order of surfaces. When the target surface was in front, observers more often reported the MAE in the direction opposite to that of the front adapting surface than the back. Even with the maximum depth difference tested between adapting and target surfaces (18 arc min), this effect was observed in 78% of trials. In experiment 2, we used a more objective method to quantify the MAE dependent on the surface depth order. During the test, the target surface consisted of dots coherently moving orthogonal to or slightly tilted towards either of the adapted motion directions. Observers were asked to report the direction of the tilt. Replicating experiment 1, the tilt of the motion in the front surface was biased towards the MAE of the front adapted surface. When the target surface was presented exactly in-between the two adapting planes (zero disparity), the amount of biased tilt was 1 - 3 deg. MAEs appear to be sensitive to the contingency between depth orders of adapting and test surfaces. The results imply that some motion information is coded with respect to depth-order of surface planes.

153 Decoding motion direction from activity in human visual cortex

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Although it is generally assumed that the human visual cortex has motion-direction-selective units analogous to those found in animals, the neurophysiological evidence is scarce. Functional neuroimaging has revealed motion-sensitive areas in humans by comparing responses to moving and static stimuli (or dynamic noise), but is thought to lack the resolution to probe into the selectivity to particular motion directions. Here we show that ensemble patterns of fMRI voxels in human visual areas (V1-V4 and MT+) exhibit robust direction selectivity that allows for accurate prediction of motion direction, when information from weakly direction-selective voxels is combined with optimal weights. We performed conventional fMRI scans (3T scanner, voxel size 3x3x3mm) while subjects viewed random dots moving in 1 of 8 directions in each 16s block. A linear decoder was trained to classify voxel intensity patterns induced by different motion directions by optimizing the voxel weights using linear support vector machines. Then, the decoder was evaluated with independent test data. Using 800 voxels from areas V1-V4, the decoder produced predictions peaking sharply at the correct direction (RMSE of 4 subjects, 64 deg). Area MT+, in which fewer voxels were available (~100 voxels), showed a prediction performance similar to those obtained using the same number of voxels from each of the areas V1-V4. This contrasts our findings from separate studies, in which area MT+ showed markedly poorer orientation selectivity than areas V1-V4 (Kamitani & Tong, VSS/SFN 2004). Our results demonstrate that human visual cortical activity is indeed selective for different motion direction. More generally, the multi-voxel decoding analysis provides a powerful new method to characterize feature selectivity in specific areas of the human brain, and can provide an important bridge between animal and human neurophysiology.

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154 Image generator resolution and motion quality

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During computer image generation, a synthetic environment is projected onto a view plane internal to the computer. This continuous, space-time

image is sampled in space and time. To minimize spatial aliasing, IGs implement procedures that serve as low-pass presampling filters, in cycles/pixel. The cutoff frequency in cycles/m typically varies with image location. In a continuous space-time image representing constant-velocity motion over a flat, textured surface, the temporal frequency of a given spatiotemporal frequency equals the dot product of the 2D spatial frequency and the viewpoint velocity, in cycles/m and m/s, respectively. A given spatial frequency, in cycles/m, thus has the same temporal frequency throughout the image. In the display of a corresponding computer-generated motion sequence, some of the spatial frequencies may be temporally aliased (i.e., have a spurious, lower temporal frequency). However, in parts of the image, aliased components are likely to be eliminated by the resolution and concomitant spatial-presampling filter of the IG. Here we assessed effects of IG resolution on perceived motion quality during simulated flight over flat, textured terrain. The resolution was either 4 or 1 arcmin/pixel. In the first two experiments, observers indicated the spatial extent of poor quality motion for flights of different altitudes and speeds. In the third experiment, observers selected the maximum speed for good quality motion and the minimum speed for poor quality motion within small windowed views of the terrain. As predicted, the higher of the two IG resolutions resulted in poor quality motion (a) over more of the image for a given speed and altitude and (b) at a lower speed for a given ground distance. However, whereas poor quality motion and temporal aliasing coincided for the lower resolution, the pattern of results suggests that the passband of the human visual system was the limiting factor for the higher resolution.

Performance and Attention

155 Lasers as a warning signal to communicate with aircraft

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A new laser signal for communicating with aircraft is being developed to warn aircraft against entering metropolitan area air defense identification zones. The purpose of this experiment was to determine the irradiance and laser characteristics (color and frequency) of effective warning signals in simulated day and night scenes. Ten subjects, half of whom had flight experience, viewed six types of laser exposures (3-Hz and 10-Hz green beams, 3-Hz and 10-Hz red beams, and red and green beams alternating at 3 Hz and 10 Hz) superimposed on either a day or night scene. Laser irradiances varied over a 5.25 log unit range for each condition and over an irradiance range of over 2.2e-11 W/cm² to 2.0e-5 W/cm². While performing a concurrent visual tracking task, subjects were required to decide whether each laser beam presented to them was an effective warning signal. RMS error was measured on the tracking task to evaluate disruptive irradiance endpoints. The results showed that, for night scene conditions, laser exposures at approximately 4.0e-8 W/cm² were rated as a 50% probability of warning. For the simulated day scene, irradiances of more than 7.0e-8 W/cm² were required. A 90% probability of warning was achieved at irradiance levels of 8.0e-7 W/cm² at night and 1.5e-6 W/cm² for a simulated day scene. Red-green alternating exposures were more likely to be rated as warning signals than red only or green only exposures. While all the subjects exhibited similarly shaped functions, the variability between subjects for a 50% probability of warning varied over about 2.5 log units. Flicker rates of 10-Hz were a little more effective than rates of 3-Hz as warning signals. Specific disruption on the tracking task due to the laser exposures occurred above 4.0e-6 W/cm² and 1.0e-6 W/cm² in the day and night conditions, respectively. These results suggest the characteristics of a laser signal required to convey warning in flight and the results should be scalable to normal daytime irradiances.

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156 The effects of exposure to a 532 nm (green) laser on the visibility of flight symbology.

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Visible laser light is a potential hazard to flight control because it creates glare and after-images that can interfere with the visibility of flight symbology. Two components of visibility are detection and identification (ID), but previous research has only measured the effects of laser exposures on detection. Our aims were to determine the potential of a 532nm laser to disrupt flight control by characterizing effects on detection and ID of flight symbols and if results could be fit by a glare model. Glare effects were assessed by measuring detection and ID thresholds for 6 flight symbols with and without laser illumination present. Symbols varied in size and were presented for 500ms on a dark background. The laser exposure level, 14 W/cm², was eye-safe, but known to produce significant glare. Exposures lasted 10s and were repeated every 5s while subjects completed an adaptive threshold procedure. Glare recovery was assessed by measuring the time required for subjects to respond to the appearance of symbols when the laser was turned off. The laser glare significantly elevated detection and ID thresholds. On average, symbol brightness had to be increased from 0.3 (baseline) to 165 and 315 cd/m² to achieve detection and ID thresholds, respectively. The degree to which detection, but not ID, thresholds were elevated was dependent on stimulus size and fit well with model predictions of contrast threshold as a function of the location of symbol outer edges (eccentricity) from the center of the glare source. Response times to the appearance of symbols after a laser exposure did not differ from baseline. Exposure to safe levels of 532nm laser radiation can cause significant glare as evidenced by the need to increase the average intensity of the flight symbols by 500X for detection. Glare had an even greater effect on ID thresholds which required symbol intensities more than 1000X baseline levels. In contrast to the glare effects, the exposure did not cause prolonged after effects.

157 Vision Assessment of Older Drivers for Relicensure

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Background: Older drivers have a high crash rate and this may be linked to vision changes with age. This study aimed to (i) compare older driver fatality rates across Australian states to determine whether crash rates were related to vision re-licensing procedures (ii) determine which visual tests Australian optometrists perform on older drivers presenting for visual assessment for licence renewal. Methods: State based age- and gender-stratified numbers of older driver fatalities for 2000-2003 were obtained from the Australian Transportation Safety Bureau database. Poisson regression analyses of fatality rates were considered by renewal frequency, adjusting for possible confounding variables of age, gender and year. All practising optometrists in Australia were surveyed on the visual tests they conduct in consultations relating to driving and their knowledge of vision requirements for older drivers. Results: For drivers aged 60-69 years, states with mandatory vision testing had a 25% (95% CI 0.32-1.77) lower fatality risk than those with no vision testing upon re-licensure. However, for drivers aged 70+ years, fatality risk was not significantly related to vision re-licensing strategies (RR=1.17, CI 0.64-2.13). Nearly all optometrists measured visual acuity as part of a vision assessment for re-licensing, however, only 20% routinely performed automated visual fields on older drivers, despite the Medical Standards for Licensing advocating automated visual fields as part of the vision standard. Conclusion: Vision assessment for re-licensure has a positive impact on driver fatality rates for those between 60-69 years, however, the primary test of vision is visual acuity. Optometrists, who play an important role in older driver assessment, do not routinely measure visual fields on their older patients. Additional research should be undertaken to identify better visual

predictors of older driver risk that can be easily implemented at re-licensure.

158 Dissociating attention from required processing time

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Longer processing times are often associated with a larger attentional demand. Using the inattention blindness paradigm (IB) by Mack and Rock (1998), Moore, Grosjean, and Lleras (2003) provide an operational definition of attention that may not be consistent with this idea. In their studies, a main task can be affected by a background pattern, and in a critical trial it is examined whether the participant is inattentionally blind to the background. If the participant cannot report the background but the main task is still affected by it, then it is said to be processed inattentionally. Although the maximum presentation time is not fixed by this definition, Moore et al. used short ones. In this study, however, we show that some processes are inattentive and nevertheless require a long presentation time. In Experiments 1 and 2, we examined whether line length judgments were affected by a background of differently oriented Gabor patches. These patches could sometimes be oriented in such a way that they formed an upright or an inverted V (i.e., the two tracks in the Ponzo illusion) based on texture segregation and were otherwise randomly oriented. In a critical trial the participant was asked whether he or she had seen the background pattern, and to guess whether it showed an upright or an inverted V, along with a confidence rating of it. Results showed that the illusion could be observed inattentionally with a 500 ms but not with a 200 ms presentation time. In Experiment 3, we used a letter discrimination task and a background of horizontal Gabor patches. One patch, however, was vertical and appeared either to the left or the right of the letter, either compatible or incompatible with the required response to the letter. Even with a 500 ms presentation time, this task could not be performed inattentionally, demonstrating the validity of our procedure in Experiments 1 and 2. We conclude that, using Moore et al.'s definition, attention is independent of processing time.

159 Sequential Effects and Stimulus-Response Dependencies In an Orientation Identification Task: Characterization of the Class 2 Oblique Effect

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The Class 2 oblique effect (C2OE) refers to poorer performance for obliquely oriented stimuli compared to horizontal or vertical ('cardinal') stimuli on memory-related tasks (Essock, Perception, 1980). This effect is thought to stem from a greater confusability of obliques and is distinct from the poorer visibility of oblique stimuli (i.e., the Class 1 oblique effect). In the present study several aspects of the C2OE obtained on a timed orientation identification task were examined. Subjects reported the orientation of a brief (200 msec) presentation of an oriented pattern (0°, 45°, 90°, or 135°) via the four fingers of the right hand (one mapped to each orientation). Results indicated that the C2OE arises from trials for which the preceding trial was a stimulus of the other category (oblique/cardinal). The increase in RT associated with the presented stimulus having changed category was much greater for oblique stimuli than cardinal stimuli. Other findings suggest that for a large (5°) central patch of broadband noise, this effect was large for finger/orientation pairings where oblique and cardinal stimuli were assigned to laterally grouped fingers (e.g. 45-135-0-90), and was not significant for alternating finger/orientation pairings (e.g. 45-0-135-90). When smaller (.5°) line or patch stimuli were presented randomly at one of eight locations (2° outer boundary), a C2OE was found for both types of finger/orientation pairings. Finally, when the smaller line stimuli were presented randomly at locations arranged vertically or horizontally, a C2OE was found only in the horizontal displacement condition.

Together these findings suggest that the greater confusion of obliques observed when identification of stimulus orientation is required occurs when the category of the stimulus (oblique/cardinal) is switched on sequential trials, and, secondly, that this effect is altered by factors such as spatial configuration of the stimuli and stimulus/response pairings.

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160 Feature Specificity of Global-Feature-Based-Attention

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Purpose: Previous studies have shown evidence of a global feature-based attentional mechanism in which attention to a particular stimulus feature, such as direction of motion or color, enhances neural responses to unattended stimuli sharing that feature (Saenz, Buracas, and Boynton 2002). We used the motion aftereffect (MAE) to measure this effect psychophysically, and to determine whether this effect is specific to only the attended feature or whether it spreads to other features of the attended stimulus.

Methods: Subjects performed a two-interval-forced-choice (2IFC) speed or luminance discrimination task on a field of moving dots presented either to the left or right of fixation. The attended hemifield also contained a field of overlapping dots moving in the opposite direction. Simultaneously, on the opposing visual hemifield, a field of dots moved either in the direction of the attended dots, in the opposite direction, or had uncorrelated motion. Immediately following each 2IFC trial, subjects were presented with a unidirectional field of slowly moving dots on the previously unattended side and indicated whether the dots appeared to move either upward or downward. The strength of the MAE was measured as the speed in which the slowly moving dots appeared to move upward or downward with equal probability.

Results: We found that for both the speed and luminance discrimination task, there was a systematic influence of the direction of the attended dots on the strength of the MAE. For example, when subjects attended to either the speed or luminance of the upward moving dots on the left side, an unattended field of uncorrelated moving dots on the right side induced a MAE in the downward direction. These results suggest that attention to a stimulus enhances the response to all unattended stimuli that share any feature in common with the attended stimulus.

161 Both accuracy and response times vary depending on target location in a sustained attention task

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Purpose. In a transient attention task, Carrasco et al. (2004; Vision Research) found differences in response time (RT) and cue benefit depending on the position of the target. In a sustained attention task, Mackeben (1999; Spatial Vision) found differences in accuracy depending on position. The current study combines features of these two studies to determine if RTs also show this pattern in a sustained attention task.

Methods. Three subjects identified the orientation of an E in a field of figure-8s presented in a circular array 7.5 deg from fixation. Subjects fixated a central dot for 1000 msec. Following this fixation period, a valid cue or no cue was presented for 1000 msec, followed by a delay of 100 or 1000 msec, then the target for 66 to 200 msec. Eye position was monitored with an Arrington Viewpoint/E eyetracker. Trials on which the eyes moved more than ± 1 deg were recycled. Cue and no cue conditions were blocked. In each block stimuli were presented 16 times at each position.

Results. RTs were slower on the vertical meridian relative to the horizontal meridian (623 \pm 162 msec vs. 525 \pm 118 msec), and accuracy was reduced (67 \pm 15% vs. 93 \pm 9%). The data also show a greater cue benefit on

the vertical meridian. The cue benefit for RT was 210 \pm 112 msec on the vertical meridian and 122 \pm 98 msec on the horizontal meridian. The cue benefit for accuracy was 21 \pm 16% on the vertical meridian and 6 \pm 12% on the horizontal meridian. **Conclusions.** The data show faster RTs and greater accuracy on the horizontal meridian in both cued and non-cued conditions. However, the effect of the cue was greater on the vertical meridian. These results replicate the differential performance fields found by Mackeben, and extend the RT asymmetries and cue benefits found by Carrasco et al. to a sustained attention task.

162 Acquiring visual information from central and peripheral fields

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Visual functions vary with retinal eccentricity. Spatial resolution declines with eccentricity, while motion discrimination is often better in the periphery than in the center. Visual attention usually involves the central field, but this might result from demands for spatial resolution. The present study investigated discriminations of both static and moving patterns under varied attentional demands, with multiple patterns in both central and peripheral fields.

Vision was evaluated simultaneously in central and peripheral fields, using three adjacent monitors, each perpendicular to the visual direction - one central and two peripheral displays, at ± 30 deg eccentricity. Stimuli were Gabor patches. Static form perception was measured by orientation discrimination thresholds; and motion perception was measured by temporal thresholds for direction discrimination. Attentional demands were manipulated by varying the number and spacing of simultaneous Gabor patches; and visual performance was studied with three different tasks - using spatial cuing, discrimination of a target among distracters, and odd-ball detection. Thresholds in multi-stimulus conditions were compared with those in single-stimulus baseline conditions.

Multiple static forms were visually competitive - in both central and peripheral fields, and especially in the periphery. Moreover, the central and peripheral fields were competitive, with peripheral form discriminations hindered by central attention. With moving patterns, however, competitive visual interactions were reduced or eliminated, both within and between central and peripheral fields. In the central field, interactions among moving patterns were sometimes even cooperative, mutually facilitative. In general, the visual field is organized by qualitatively different spatial mechanisms for perceiving static forms and motion in the central and peripheral regions.

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163 Relative Motion in the Periphery of the Visual Field is a Powerful Cue for Visuo-spatial Attention.

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By moving through the environment, an observer generates flow field patterns from which information about the movement's speed and trajectory can be extracted. Onset of peripheral object motion or a change of object motion direction disturbs this observer-generated flow field by producing a relative motion stimulus. Can relative motion in the near and far periphery of the visual field act as a cue to attract visuo-spatial attention? How powerful is such a relative motion cue (RMC) in comparison with conventional cueing with a ring-shaped frame?

At 20, 30, 40, and 60 degrees eccentricity, we tested the performance of 10 subjects in a near-threshold, 4-afc Gabor orientation discrimination task without vs. with a briefly appearing ring-shaped cue attracting attention to the target location. In the second part of the study, the Gabor gratings were embedded in a random-dot flow field, and subjects performed the same task as above after presentation of a RMC (a group of random dots moving in the direction opposite from that of the flow-field) compared to a baseline without the RMC.

Both types of cues induced a significant improvement of discrimination performance at all test locations. The RMC effect was stronger at more eccentric positions while the ring-shaped cue had a more pronounced effect closer to the center. Thus RMC is at least as powerful attracting attention as conventional spatial cueing.

Our data point to the special role of peripheral vision in motion processing. The results have high practical relevance for tasks involving navigation and mobility.

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164 Can Transient Attention Offset the Effects of Sustained Attention?

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The subjective boundary effect (SBE) describes a performance impairment at the boundaries of subjectively defined regions (Carrasco & Chang, 1995). We investigated whether the SBE, resulting from sustained attention, can be eliminated or reduced by transient attention. In Exp 1, observers reported whether a tilted target among vertical distracters in a 9 x 9 display appeared in the leftmost, middle, or rightmost 3 columns, the boundaries of which were maintained by sustained attention. The display was preceded by a transient cue; 50% neutral cues at fixation & 50% peripheral cues directly above the possible target location. With neutral cues, the SBE was evident. Peripheral cues improved overall performance, but the SBE remained. To investigate whether the failure to affect the SBE was robust, in Exps 2 & 3 observers performed a detection task while attending to multiple disjoint regions and ignoring the regions in between, thereby engaging sustained attention in the maintenance of boundaries (Gobell, Tseng, & Sperling, 2004). In Exp 2, a transient cue preceded the search array, 50% neutral & 50% peripheral. The neutral cue appeared at fixation, whereas the peripheral cue was a line extending the length/width of the display, drawing attention to the entire row or column in which the target might appear. The peripheral cue increased accuracy, but the SBE remained. In Exp 3, to see if a transient cue which indicated only the location of the target rather than an entire row/column would eliminate the SBE, the cue was a small bar appearing directly above the potential target location. The cue increased accuracy and eliminated the SBE. Whereas the SBE was not eliminated in Exps 1 & 2, Exp 3 demonstrated that transient attention can eliminate the SBE. Reasons for the different results in Exps 1 & 3 are discussed, and a strength-map account of the data, in which both sustained & transient attention increase the strength of elements in the display, is presented.

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165 On the Flexibility of Covert Attention and Its Effects on a Texture Segmentation Task

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We investigated the flexibility and adaptability of spatial covert attention in a texture segmentation task that is constrained by spatial resolution. In a study of transient attention and texture segmentation, Yeshurun & Carrasco (1998) found that precueing the target location improved performance in the periphery, where spatial resolution was too low for the task, but impaired performance at central locations, where spatial resolution was already too high. This counterintuitive central attentional impairment can only be explained by transient attention increasing spatial resolution, even when it is detrimental to performance. Such unidirectionality of the effect supports the automaticity of transient attention and suggests that it is not flexible. Here we investigated whether the voluntary and more controlled component of covert attention-sustained attention-can also affect spatial resolution and be more flexible, i.e., both increase and decrease spatial resolution to optimize performance at all eccentricities.

As previously found, in neutral trials performance peaked at mid-peripheral locations and dropped at farther peripheral and more central locations. Sustained attention aided performance at both central and peripheral locations; thus, in contrast to transient attention, it did not impair performance at central locations. This is consistent with the hypothesis that sustained attention can affect spatial resolution. The attentional effect varied as a function of both target eccentricity and texture scale. The benefit of sustained attention at all eccentricities suggests that it increased spatial resolution where it was too low (periphery), but decreased spatial resolution where it was too high (central locations). These results indicate that sustained attention is more flexible than transient attention, and are consistent with the idea that it can optimize performance by either enhancing or decreasing spatial resolution at the attended location.

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166 Transient Attention Reduces the Effect of Adaption

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Background: Transient attention enhances contrast sensitivity by increasing the gain of the neurons processing a stimulus. Conversely, adaptation reduces contrast sensitivity by reducing neuronal gain. Given that both attention and adaptation act on the gain of the neurons processing the relevant stimuli, their effect may interact. We hypothesize that transient attention would reduce the effect of adaptation on contrast sensitivity.

Method: We presented two 4 cpd Gabor patches for 100 ms at 5 deg of eccentricity to the left and right of a central fixation point. On each trial one Gabor was slightly tilted (target) and the other was vertical, and contrast was manipulated to obtain psychometric functions. Observers performed a left/right orientation-discrimination task on the target. There were two attentional conditions: neutral and peripheral. The cue was a small bar presented for 40 ms before (60 ms ISI) the stimulus display either at fixation (neutral) or above the target (peripheral). There were two adaptation conditions: adapt-same and adapt-different orientation. Before each 20-trial block, observers adapted for 60 s to two 4-cpd counter-phase flickering (7.5 Hz) Gabor patches (5 deg eccentricity). Top-up stimuli were presented for 2.5s before each test trial. The adapting stimuli were vertical in the adapt-same condition and horizontal in the adapt-different condition.

Results: Performance in neutral trials was better in the adapt-different than in the adapt-same condition (adaptation effect). Performance in peripheral trial was better than in neutral trials (attention effect). Moreover, these effects interacted: performance in peripheral trials was comparable for the adapt-different and adapt-same conditions. These results indicate that transient attention diminishes the effect of adaptation.

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167 Covert transient attention affects motor response trajectories

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Background: Spatial attention modifies both visually guided manual and ocular motor responses and motor responses can be used to quantify covert attention. Given that transient covert attention accelerates the rate of visual information processing (Carrasco & McElree, 2001), here we compare the spatial trajectories of hand movements toward peripherally cued stimuli with those toward neutrally cued stimuli to investigate the effects of accelerated processing on motor control. We use a visually guided motor response task that previously has been shown to replicate keyboard response results (Faludi, Maloney, Carrasco, VSS 2004), allowing us to focus on the response trajectories.

Methods: Observers performed a 2AFC task in which they were asked to judge whether the target (2 deg, 4 cpd tilted Gabor) was present or absent. The target stimulus appeared on 50% of trials at one of eight 9 deg iso-eccentric locations, with distracters occupying the non-target locations. To direct attention, a cue appeared either adjacent to the potential target location or at the neutral fixation location (67 ms). Following an ISI (54 ms) the stimulus was presented (54 ms). These timings maximize the effects of transient attention and precluded eye movements. Observers touched the target location on the monitor or the fixation point if no target was perceived. Response trajectories were measured using an Optotrak 3020 motion capture device.

Results: As in previous experiments, we found a horizontal-vertical anisotropy (HVA) and a vertical meridian asymmetry (VMA). Pointing response trajectories revealed a difference between peripherally and neutrally cued trials. In peripherally cued trials, trajectories deviated toward the target location sooner, and arrived at a greater eccentricity than neutrally cued trials. We suggest this is the effect of temporally enhanced information accrual influencing motor response.

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168 Action Affordance Effects: Location and Grasp

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There is now compelling evidence that vision exists to serve action, such that when objects are observed, corresponding motor actions are prepared for interaction with these objects irrespective of the intentions of the observer. Two properties of an object have been shown to affect automatic motor encoding. The first is the spatial location of the object relative to the responding hand. For example, Simon (1969) has shown that a key-press response to identify a stimulus is faster if it is on the same side of space as the responding hand. The second aspect of an object that appears to automatically drive action is the grasping action it affords. For example, if a graspable object such as a frying pan is observed in an orientation that is congruent with the responding hand, then facilitation of reaction time to this object is observed (e.g. Tucker & Ellis, 1988). However, it is still not clear what the relationship is between these spatial and grasp affordances: it is possible that grasp effects are actually determined by the spatial properties of the object. Therefore we report a series of experiments that investigate whether grasp affordance effects can be observed independent of the spatial properties of an object.

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169 Orthogonal Simon effect: A new interference effect with vertically arrayed stimuli and horizontally arrayed responses

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According to the salient-features coding hypothesis, S-R translation is more efficient when an S-R mapping maintains a structural correspondence of the salient features between the stimulus and response sets (Weeks & Proctor, 1990). As "above" and "right" are the salient features in vertical and horizontal axes respectively, an above-to-right/below-to-left mapping has an advantage over the opposite mapping when vertically arrayed stimuli are mapped to horizontally arrayed responses (orthogonal stimulus-response compatibility effect). However, the above-right/below-left advantage may not be restricted to the intentional S-R translation. With parallel S-R arrangements, response selection is faster and more accurate when the stimulus and response positions correspond even if the stimulus location is task-irrelevant (Simon effect). We investigated whether a stimulus automatically activates a response corresponding in the saliency dimension. In Experiment 1, participants responded with right or left key-press to the color of the stimulus presented above or below the fixation. Although the stimulus location was task-irrelevant, the above-right/below-left advantage was observed (orthogonal Simon effect). In Experiment 2, we manipulated the salient feature in the horizontal response dimension by varying the position of the response set horizontally because the side on which a response set is positioned becomes the salient feature (Proctor & Cho, 2003). An orthogonal Simon effect emerged with response set on the right side. In contrast, a reversed orthogonal Simon effect (i.e., above-left/below-right advantage) emerged with the response set on the left side. It was confirmed that the orthogonal Simon effect is based on the S-R correspondence of the salient features. We conclude that the salient and non-salient stimulus features automatically activate the corresponding salient and non-salient response features.

170 Attentional modulation of orientation adaptation to resolvable and unresolvable patterns using brief orientation adaptation paradigm

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Several psychophysical studies have shown that adaptation to different attributes of visual stimuli is modulated by attention. There is also evidence demonstrating that brief adaptation to an oriented grating impairs identification of nearby orientations by broadening orientation selectivity and changing the preferred orientation of individual V1 neurons (Dragoi et al, 2002). In this study, we investigated the effect of visual attention on brief orientation adaptation using resolvable and unresolvable patterns. In the first experiment, observers performed a delayed match-to-sample task in the peripheral visual field (at 10 deg of eccentricity) in attended versus non-attended condition. In the attended condition they were asked to report whether two briefly flashed Gabors, sample and test stimuli, differ in orientation or not. The test Gabor patch was preceded by a 400 ms resolvable adapting stimulus. In the non-attended condition, observers performed the same task concurrent with a secondary task (even/odd judgment) at the fixation point during the adaptation period. The second experiment was identical in all respects to the first experiment, except that unresolvable Gabor patches were used in the adaptation phase. Results in both experiments showed orientation-selective adaptation in the attended condition but no adaptation in the non-attended condition. We suggest that unresolvable oriented patterns could activate the primary visual cortex and that this activation (as revealed by brief orientation adaptation paradigm) is modulated by attention.

171 Can attention to auditory signals affect processing of simultaneous visual stimuli?

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Objectives. Previous studies found that auditory aftereffects were affected by accompanying visual stimuli (near the fovea), but not vice versa [Kitagawa & Ichihara, 2002]. We tested whether attending to an auditory signal affects the processing of a simultaneous peripheral visual stimulus. We also studied differences in performance with congruent and incongruent intermodal stimuli, and the effect of space-based attention.

Methods and Results. To quantify the visual processing, we tested the motion aftereffect (MAE) of an expanding disk. We used a double-staircase procedure to find the speed of expansion that annulled the MAE. In Experiment 1, during adaptation, we used co-located sounds that were either congruent (increasing intensity) or incongruent (decreasing intensity). Subjects had to perform an easy luminance-change discrimination task on the fixation mark, as well as an attentional task on the congruent and incongruent auditory stimuli. In a control condition, subjects had no auditory attentional task for the incongruent case. We found no effect of attention on MAE, and no differences between the congruent and incongruent conditions. In Experiment 2, during adaptation, we used short sound beeps that were not co-located with the visual stimulus, and subjects attended to the sound. In a control condition, there was no accompanying sound. The MAE was significantly reduced after attending to the sound, as compared to the no-sound control condition.

Conclusions. The results of Experiment 1 indicate that attending to co-located auditory stimuli cannot affect the processing of simultaneous visual stimuli. These results complement earlier findings by Duncan, Martens & Ward [1997] and Rees, Frith & Lavie [2001] for separate attentional resources for audition and vision. The results of Experiment 2 confirm that auditory-based spatial attention can affect the processing of simultaneously presented visual stimuli [e.g., Hikosaka, Miyauchi & Shimojo, 1996].

172 Visual-Auditory spatial attention in human visual cortex

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Purpose: To examine how auditory spatial attention influences responses in early visual areas.

Methods: Subjects were presented four stimuli simultaneously: two drifting gratings, one to the left and one to the right of central fixation, and two auditory tones, one to the left and one to the right ear. Auditory stimuli presented to the left ear was perceived as being on the left side of space, and vice versa. All four stimuli were presented in two successive intervals, with the speed of the visual gratings and the frequency of the auditory tones independently increased or decreased between the first and second interval. On any given trial, subjects were cued to attend the auditory stimulus in either the left or right ear and had to judge whether the attended stimulus contained the higher frequency tone in the first or second interval. Auditory frequency increment thresholds were determined prior to scanning, so as to maintain constant task difficulty throughout the scan. Subjects alternated between performing the task on the auditory stimulus in the left versus the right ear every 20-sec (6 blocks per scan, 8 trials per block). We measured fMRI responses to an unattended visual stimulus when attention was directed to an auditory stimulus on the same or the opposite side of space.

Results: In early visual areas we found a larger fMRI response to an unattended visual stimulus when auditory attention was directed to the same side of space, compared to when auditory attention was directed to the opposite side of space. These results are consistent with a cross-modal mechanism of spatial attention in which attention to a stimulus in one region of space leads to an enhancement of the response to any other stimulus in the same spatial region, regardless of modality. Thus, when visual and auditory stimuli share a common spatial region, even an

unattended visual stimulus can gain a processing advantage, yielding a larger fMRI response.

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173 Distorting Visual Space with Sound

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The attentional repulsion effect refers to the perceived displacement of a Vernier stimulus in a direction that is opposite to a brief peripheral visual cue (Suzuki & Cavanagh, 1997, JEP:HPP, 23, 433-63). The present study assessed whether a spatial auditory cue would also elicit the repulsion effect. Broadband noisebursts located -18, 0, or +18 degrees along the azimuth and at an elevation equal to that of the uppermost line of the Vernier stimulus were presented 100 or 150 ms prior to the presentation of the Vernier display. In a forced-choice procedure, observers were more likely to judge vertically aligned Vernier displays as being displaced in a direction that was opposite to the lateralized sounds. Interestingly, this repulsion effect was strongest when the preceding sound came from the left rather than the right hemifield, suggesting that brief auditory events in left hemisphere have a more deleterious effect on difficult visual spatial judgments.

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Spatial Vision 1

174 Comparing Estimated and Actual Visual Acuity at High and Low Luminance

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How well do we know our own visual limitations? To evaluate whether observers appreciate the extent to which low luminance and low contrast affect their own visual acuity, we compared observers' estimates of their own visual acuity with their actual visual acuity. Estimates of acuity were measured using newly refined methodologies. Twenty observers (M = 69 years) were given systematic training in reporting their size estimates using both a magnitude estimation (verbal) technique and a manual matching technique using calipers (manual). The stimuli used during training were Es ranging in size from the observers' threshold to logMAR 1.4 (21.9 cm high) viewed at high luminance (85 cd/m²) at 6 m. Following training, observers dark adapted and then made acuity estimates while wearing goggles containing ND filters (ND 4, 3, 2, 1, or 0) while sitting 6 m from a blank white wall. At each luminance level, they indicated the height of stimuli that they imagined they would be "just able to see as an E" on the wall. Because there was no reliable difference between the verbal and manual acuity estimates for either high or low contrast stimuli, these measures were averaged and then compared with measures of actual acuity. At the higher luminances, the observers' mean high contrast acuity estimates were quite accurate. At lower luminances, however, observers dramatically overestimated their high contrast acuity. At the lowest luminance, the mean estimated high contrast acuity (20/55) was 0.75 log units better than the actual mean acuity (20/300). This trend to overestimate acuity at low luminances was even stronger for low contrast stimuli, where the mean estimated acuity (20/90) was 0.95 log unit better than the actual mean acuity (20/800). We conclude that observers fail to appreciate the extent to which their own acuity is degraded as luminance decreases. This may help explain why drivers are comfortable overdriving their headlights at night.

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175 The dependence of texture density judgments on texture element contrast

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PURPOSE: Much evidence (due mainly to Durgin & colleagues) shows that human vision is sensitive to the density of elements in sparse displays. Here we investigate the dependence of density judgments on element intensity. **METHOD:** In Expt. 1, S's viewed a brief display comprising two sparse fields of dots, separated by a central vertical line and judged (with feedback) which had more dots. Dots varied in grayscale over 9 levels from black to white, with grayscale 5 equal to the background (making dots of grayscale 5 invisible). There were 30 experimental conditions, each stipulating a particular pair of grayscale histograms to be pitted against each other. Each trial in a given condition randomly displayed elements conforming to the prescribed histograms across the left and right portions of the viewing window. The data yield a function giving the impact (in multiples of d') exerted on density judgments by different grayscales. In Expts. 2 and 3, S's judged which side had more black (grayscale 1) dots, and more white (grayscale 9) dots, respectively. **RESULTS:** In Expt. 1, impacts exerted by grayscales 1, 2, 3, 7, 8 and 9 were approximately equal, and approximately double the impacts exerted by grayscales 4 and 6 (Weber contrasts -0.25 and 0.25), showing that the statistic S's use to sense overall density is largely invariant to dot contrast. When S's focused on just the black dots (Expt. 2), impact decreased linearly from grayscale 1 to 5, and was 0 for all positive polarities. When S's focused on white dots (Expt. 3), performance was worse than for black dots, with grayscales of opposite polarity exerting substantial influence. **CONCLUSIONS:** Observers can use any of several statistics with differential tuning to graylevel for making judgments about texture density. One such statistic is symmetrically sensitive to positive and negative polarity (Expt. 1); another is sensitive exclusively to dots of negative polarity (Expt. 2).

176 Dynamics of collinear facilitation assessed using classification images

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Contrast sensitivity for detecting a Gabor pattern is facilitated by the presence of collinear flanking Gabor elements (Polat and Sagi, Vision Research, 33, 993-999, 1993). We examined the spatial and temporal properties of such facilitation using a psychophysical reverse correlation paradigm. This involved subjects performing a 2AFC task- the detection of a target (2 c/deg Gabor) embedded in two dimensional noise. A staircase procedure varied target contrast and attempted to converge on a level that maintained detection performance at a constant (75% correct) level. Subjects performed the detection task in the presence and absence of 30% contrast flanking Gabors, spatially arranged to optimize facilitation (Woods et al., Vision Research, 42, 733-745, 2002). The orientation and phase of the flankers relative to the target were varied independently. In order to probe the dynamic properties of facilitation, the noise was either static (duration = 250ms) or dynamic (520 ms). True 14 bit grey scale resolution was obtained using a Bits++ system (Cambridge Research Systems). Classification images (CI) were obtained by conventional means and were then fit with two dimensional Gabor functions to determine the parameters of the perceptive field supporting detection of the target. We report that in both the static and dynamic conditions, the presence of flankers led to facilitation only when they were of the same orientation and phase as the target. The CIs from static noise conditions demonstrate that observers' perceptive fields were well-matched to the target stimulus. The CIs from the dynamic noise condition reveal that subjects rely mainly on the initial frames of the sequence to perform the task, suggesting that the facilitation effects are both rapid and are temporally lowpass tuned.

177 Perceptual inhomogeneities in the Upper Visual Field

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Performance on visual tasks is poor for stimuli presented on the vertical rather than the horizontal meridian, and gets poorer as spatial frequency and eccentricity increase (Carrasco, Talgar & Cameron, 2001). Performance is particularly poor for stimuli presented directly above fixation - the *north effect*. In many of the experiments that have demonstrated such results, targets were presented at one of 8 locations across the visual field, at a fixed eccentricity. Thus, the nearest location to the vertical meridian tested was 45 deg away. The first goal of the present study was to examine the extent of the north effect by examining performance at many locations in the upper visual field. The question was: does performance increase gradually or abruptly as stimuli are presented further from the vertical meridian? Covert visual spatial attention (manipulated with peripheral precues) is known to improve performance equally across the visual field (typically measured at 8 locations). A secondary goal of this study was to assess the effect of attention at a wider range of locations. Three observers (2 naive) performed an orientation identification task with 8 cpd Gabor patches that were tilted either 15 deg clockwise or counter clockwise. Stimuli were presented briefly (mean 35 ms) at 4.5 deg eccentricity, at one of 17 locations across the upper visual field. Half of the trials contained a neutral precue (indicating when a target would appear) and half of the trials contained a peripheral precue (indicating when and where a target would appear). We found that, as previously reported, performance was best for stimuli presented on the horizontal meridian, and worst for stimuli presented on the vertical meridian. Performance *gradually* improved as stimuli were presented further from the vertical meridian, suggesting that the extent of the north effect may be larger than previously thought. The peripheral precue significantly improved performance across the upper visual field.

178 More ups and downs of visual processing

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Several investigations have shown enhanced sensitivity for stimuli presented in the lower visual field (LVF) as compared to identical stimuli presented in the upper visual field (UVF). However, conflicting reports have emerged regarding differences in UVF/LVF sensitivity, as enhanced sensitivity for some stimuli has been reported in the UVF. At VSS 2004, we showed that stimuli that differed in color produced better performance in the LVF than in the UVF, while stimuli differing in apparent depth due to interocular disparity were better discriminated in the UVF. We now extend these results to a more explicit investigation of the spatial frequency characteristics contributing to these differences. Our stimuli were suprathreshold Gabor patches (sinusoidal gratings multiplied by circular Gaussian windows). The subject was asked to determine which of three simultaneously presented patches had an orientation that differed from 45°. The trio of patches appeared at random either above or below fixation for 280 ms. By manipulating the spatial spread of the Gaussian and the spatial frequency of the grating (which could be in either cosine or sine phase relative to the center of the Gaussian), we found that performance is generally better in the LVF unless the spatial frequency spectrum includes significant low frequency and DC components. LVF performance improves with narrower bandwidth, while UVF performance is relatively insensitive to these parameters. This is consistent with our previous tentative conclusion that magnocellular processing is more influential in the UVF, while parvocellular processing is more influential in the LVF.

179 Effect of phase on the detection of spatial patterns

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Ideal detectability of visual patterns should be determined by the contrast energy of the pattern. In general, experimental data are consistent with this idea. However, several authors have argued that there are special

mechanisms sensitive to ecologically important spatial patterns, e.g. edges and lines.

In this study, I measured detection thresholds for phase-congruent (edges, lines) and phase-incongruent patterns with the same spatial frequency content and spatial extent.

The patterns consisted of 32 equal-amplitude spatial-frequency components.

Phase-incongruent patterns were generated from patterns with random phases by adjusting them for a minimal phase congruency. Four phase-incongruent patterns were compared with four phase-congruent ones.

The contrast thresholds were measured with 1-up 3-down staircase and 2-interval forced choice method. Presentation duration was 250 ms and stimulus extent (sigma of Gaussian window) was 1.5 deg. Location (absolute phase) was randomized.

The results for two observers show an elevation of thresholds for phase-incongruent patterns as compared with phase-congruent ones by factor 1.2 to 1.5. The results may indicate a presence of special edge-line detecting mechanisms. However, a simple non-linearity of contrast response function can probably also explain these results

180 Accessibility of spatial channels

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Purpose. It is now well accepted that the early stages of visual processing comprise mechanisms that are relatively narrowband for spatial frequency (1 octave) and orientation (308). It is less clear whether the outputs of these narrowband mechanisms can be individually accessed by later stages of perception. We address this question using elementary, local motion and stereo tasks. **Methods** Our stimulus comprised a disc containing fractal noise embedded in a field of fractal noise. The fractal noise in the disc was spatially displaced between eyes/frames resulting in either a near/far disparity task or a left/right motion task. The noise was stochastically filtered (amplitudes unaltered, just phases scrambled outside passband) using idealized filters of variable bandwidth and peak spatial frequency. In this way a band of correlated information was preserved with uncorrelated information at higher and lower spatial frequencies (a notched filter of signal correlation). Phase scrambling involved either spatial frequencies or orientations of noise components. We used a simple Gaussian signal/noise model to derive the minimum spectral region that subserved our tasks. **Results** Similar results were found for the stereo and motion tasks. In either case the minimum bandwidth necessary to accomplish these tasks was many times previous estimates of the bandwidth of early visual mechanisms. In fact it closely corresponded to the spatial frequency and orientation spectrum of the stimulus, suggesting that all stimulus information was necessary. **Conclusion** For both local motion and stereo, there is no individual access to information from narrowband channels tuned to either spatial frequency or orientation.

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181 Contextual effects on orientation identification and contrast discrimination in the fovea

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We wanted to know whether contextual effects on orientation identification and contrast discrimination were consistent with contemporary models of orientation-selective lateral interaction. To measure contextual effects, we used phase-locked and phase-randomized Gabor patterns for target and flanks. Wavelength and spread were $\lambda=0.25^\circ$ and $\sigma=0.18^\circ$. When present, eight flanks surrounded the central target. Center-to-center separation between the target and each flank was 1.06° . Contrast

discrimination was assessed using an adaptive, 2IFC procedure. Orientation identification was assessed by having observers decide whether the target was clockwise or counter-clockwise of some reference orientation. Implicit and explicit references were used. The former was horizontal; the latter was formed by the junction of black and white semi-annuli (inner radius: 2.4° ; outer radius: 2.5°), which appeared in a different orientation prior to each trial. Flanks had little effect on contrast discrimination (or detection). Orientation judgments can be described by the standard normal distribution $\Phi[(t-\theta)/\sigma]$, where t is target tilt and the parameters reflect two different aspects of performance: tilt bias θ and tilt sensitivity $1/\sigma$. Tilted flanks produced biases of opposite sign. This is the tilt illusion. Largest biases were obtained when flank tilts were $\theta \pm 22.5^\circ$, where θ is the reference orientation. The tilt illusion is usually attributed to lateral inhibition between neurons with similar orientation preferences. However, despite a sizeable reduction of tilt sensitivity induced by grossly oblique flanks ($\theta \pm 22.5^\circ$ and $\theta \pm 45^\circ$), flanks aligned with the reference orientation induced no such reduction. This latter result seems to be incompatible with an iso-orientation preference for divisive inhibition. Model fits were only slightly improved when a) other features of the contrast-response function or b) the strength of excitatory interactions were allowed to vary monotonically with target/flank orientation difference.

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182 Detection of Gabor Patterns

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We measured contrast thresholds of vertical Gabor patterns as a function of their eccentricity, size (standard deviation, SD), shape (ratio of collinear to orthogonal SD's), and phase using a 2AFC method with threshold corresponding to 82% correct. The patterns were 4 c/deg and they were presented for 90 or 240 msec. Log thresholds increase linearly with eccentricity at a mean rate of 0.47 dB/wavelength. Thresholds decrease as the SD of the pattern increases (TvS function). The TvS functions are concave up on log-log coordinates. Thresholds continue to decrease with SD over the entire range of 0.07 to 12 wavelengths. The threshold decrease is less than proportional to the area increase over the entire size range. For small patterns only, threshold depends on shape, and there is an interaction between shape and phase such that, for patterns with the same area, patterns in cosine phase have the lowest thresholds when they are narrow; patterns in sine phase have the lowest thresholds when they are short. Threshold energy is a U-shaped function of SD with a minimum in the vicinity of 0.4 wavelength indicating detection by small receptive fields (RF). A supplementary experiment showed that observers can discriminate among patterns of different sizes when the patterns are at threshold indicating that more than one mechanism is involved. For small patterns, TvS functions for all sizes and shapes are well fitted by a one Gabor linear receptive field model. The best RF is either circular or slightly longer in the collinear direction. Larger patterns require at least several additional RF's. Thresholds for all sizes and shapes are described by a model in which peripheral RF's are in phase with the center mechanism and falloff in sensitivity at 0.47 dB/wavelength. Their excitations are combined nonlinearly according to Quick's rule to determine the threshold.

183 Lateral spatial interactions for the detection of luminance-defined and contrast-defined blobs, at the fovea and in the periphery

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Considerable evidence supports the notion that the detection of luminance-defined and contrast-defined stimuli undergoes separate early stages in vision. In this study, we investigated lateral spatial interactions for detection, using such stimuli in the fovea and in the periphery.

Lateral spatial interaction stimuli consisted of a test blob placed between two horizontally separated flanking blobs. Blobs were either luminance-modulated (LM) or contrast-modulated (CM), constructed either by adding or multiplying random dot noise to a Gaussian profile. Modulation depth thresholds for detecting the test blob alone and in the presence of flanking blobs with 50% modulation depth, were calculated from psychometric functions generated using a self-paced, temporal 2AFC paradigm. Flanking blobs did not overlap the test blob and separations were increased up to ~20 times the blob spread. Because larger summation areas have been found for detecting CM than LM blobs (VSS 2003), lateral interactions for different sized blobs were assessed.

At the fovea, a suppressive effect (30-80% increase in threshold) was found for both LM and CM blobs, at the closest separations between the test and the flanks. A milder facilitatory effect (15-35% decrease in threshold) was evident for greater separations.

At 5 deg in the periphery, detectability was also suppressed (25-100% increase in threshold) for both LM and CM blobs. This suppression extended over much greater spatial distances than were found at the fovea. There was no clear evidence for facilitation for larger separations in the periphery. Increasing blob size in the periphery increased the magnitude and the spatial extent of the suppression, particularly for CM stimuli.

These findings suggest that providing the stimulus size is made equivalent for both LM and CM detection systems, the nature of the underlying mechanisms for lateral spatial suppression and facilitation of detection thresholds appears similar.

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184 Noise masking reveals channels for second-order letters

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We used critical-band masking to characterize channels mediating 2nd-order letter identification.

METHODS: Stimuli were noisy 2nd-order letters (Sloan font: D, N, R, S or Z). Stimulus contrast was $(M_v)^{0.5}S_v + (M_h)^{0.5}S_h$, where S_v and S_h are carrier patterns (4 c/deg horizontal and vertical sine wave gratings, random phase). Modulator $M_v = 0.5 + kL + N$, where L is a letter, k is 2nd-order contrast, and N is a low- or high-pass noise mask. M_v is clipped at 0 and 1. $M_h = 1 - M_v$. Thus, letters are regions with increased vertical energy on a plaid background. The 2nd-order noise adds patches of increased horizontal or vertical energy that mask the letter. The square root in the definition of stimulus contrast ensures that expected contrast energy is constant across the stimulus. Interleaved staircases controlled 2nd-order contrast k . This results in a plot of identification threshold elevation (relative to no noise) as a function of noise cut-off frequency. The derivative of this curve provides an estimate of channel tuning.

RESULTS: Observers used an approx. 1-1.5-octave-wide channel for this task. The preferred spatial frequency of this channel (in cycles/letter) was fixed across noise conditions (indicating the inability of observers to switch channels to improve signal-to-noise ratio) and across different letter sizes (indicating scale invariance), for a fixed carrier frequency (again in cycles/letter). The channel's preferred spatial frequency was proportional to stimulus carrier frequency (when both are given as cycles/letter). We define a *stroke frequency* for 2nd-order letters (identical to the carrier frequency in c/deg) and use a previous definition of stroke frequency for 1st-order letters (Majaj et al., *Vis. Res.*, 42, 1165-1184, 2002). With these definitions, the preferred spatial frequency of the letter identification channel is proportional to stroke frequency for 2nd-order letters, and is lower in frequency than the channels used for 1st-order letter identification.

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185 Perceptual Size Distortion: Expansion of Left Hemisphere

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Errors of perceptual judgement are systematically made by normal observers during visual line bisection tasks. In this pattern of response, termed pseudoneglect, participants tend to bisect lines slightly to the left of their true centre. One explanation of this effect is that attentional differences between left and right hemispheres cause the leftward extent of a line to be misrepresented and appear longer than it actually is. Recent findings have also shown that patients with hemispatial neglect perceive objects in right hemisphere as larger than physically identical objects in left hemisphere. Presuming that this type of size estimation task involves the same attentional resources as line bisection, it is predicted that observable differences should be obtained in measurement of perceived size of objects presented in left and right hemisphere in normal observers. Sensitivity in detection of object size was measured by presenting a circle simultaneously with an ellipse varying in horizontal or vertical dimension only. In one experimental manipulation participants were asked to indicate which of the two objects was wider in horizontal direction, and in another to report which object was taller in the vertical direction. A psychometric function for discrimination of a circle versus an oval was obtained for each condition for comparisons across hemifields. These revealed a consistent bias of size judgements of horizontal extent but not of vertical extent. For horizontal orientation judgements, the point of subjective equality for objects presented in the left hemisphere decreased. This finding suggests that in much the same way as normal observers misperceive true centre in line bisection tasks, perception of space is distorted; left hemisphere is enlarged relative to right hemisphere and therefore the left stimulus is overestimated when left and right stimuli are identical. The findings are discussed in relation to attentional and perceptual accounts of visual bias.

186 Labelled lines for phase?

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Purpose. There is psychophysical support for a phase model of visual processing involving four channels, each optimally sensitive to one of the following four phase relations; + cosine, - cosine, +sine and - sine. Neurophysiology suggests either an even distribution of neuronal phase responses or else a sine/cosine phase dichotomy that is dependent on spatial bandwidth. We investigated whether there were labelled lines for phase; this can be thought of as testing a strong version of the four channel phase model in which each of the above phases can be discriminated at threshold. **Methods.** Our stimulus comprised Gaussian weighted (space and time) patches of either Gabor or edge/bar stimuli for which we measure simultaneously detection and phase identification to determine if phase identification can be accomplished at detection threshold (hence labelled lines). We used two bandwidths of Gabor and varied both absolute and relative phase. **Results.** Subjects could not reliably discriminate at threshold Gabors of even symmetry from Gabors of odd symmetry nor could they discriminate bar from edge stimuli. **Conclusion.** While there may be labelled lines for polarity there are not labelled lines for bars vs edges. The smallest discriminable step we can reliably make across the phase spectrum at threshold is 180°.

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187 Characterizing visual performance fields in children

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INTRODUCTION. For adults, we know that contrast sensitivity and spatial resolution are better along the horizontal than vertical meridian-a.k.a. horizontal vertical anisotropy (HVA)-and better in the lower than upper vertical meridian-a.k.a. vertical meridian asymmetry (VMA). Speed of information accrual in adults follows this same pattern, i.e. it is faster along the horizontal meridian and slowest at the upper locations (Carrasco et al., 2001, 2004). To assess whether ecological factors modulate these performance fields, we investigated whether the discriminability asymmetries are present with grammar school children.

METHODS. Observers performed a 2AFC orientation discrimination task on Gabor patches tilted +/- 308 from vertical. Each trial consisted of a central fixation point (.28), which was soon replaced by a smiley face (18) to maintain participants' fixation and to signal the onset of the trial. A 28 Gabor (4-cpd) was presented for 100 ms at one of 8 equally probable iso-eccentric (68) locations. The brief display duration precluded eye movements, allowing us to equate field and retinal eccentricities.

RESULTS. The HVA was present for all adult and child observers. Surprisingly, the children exhibited an inverse VMA to that of adults; whereas adults' performance was superior at the lower regions of the vertical meridian, children's performance was better at the upper regions. This finding suggests that ecological factors may help modulate the visual constraints underlying the VMA. Studying the developmental course of visual field asymmetries helps elucidate the role that the environment plays in perceptual performance, and may have implications for human factors.

188 Sensitivity to tilt in first-order and second-order gratings is immature in 5-year-olds

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We measured orientation discrimination in 24 5-year-olds (\pm 3 months) and 24 adults (18 - 25 years of age) for first-order (luminance-modulated) and second-order (contrast-modulated) gratings. To achieve equal visibility, contrast for each age and condition was set at a fixed multiple of threshold contrast for discriminating horizontal from vertical gratings. For the test of sensitivity to orientation, the subject's task on each trial was to indicate whether the stripes were tilted to the left or right of vertical. Tilt was varied over trials according to a ML-TEST staircase procedure (Harvey, 1986) to measure the minimum tilt that could be discriminated from vertical 82% of the time. An ANOVA showed that tilt discrimination was immature in 5-year-olds (main effect of age, $p < 0.0001$). Unlike some aspects of motion perception (Ellemberg et al., 2003, 2004), tilt discrimination was equally immature for first-order and second-order stimuli (nonsignificant interaction, $p > 0.20$). Specifically, the minimum discriminable tilt was 4 - 5 times worse in 5-year-olds than adults for both first-order patterns (adult mean = 0.98; 5-year-old mean = 4.48) and for second-order patterns (adult mean = 1.48; 5-year-old mean = 5.58). These immaturities are unlikely to be caused by motivational or attentional factors because 5-year-olds have nearly adult-like values for other thresholds measured with similar methods (Ellemberg et al., 2003). Thus, the neural mechanisms mediating orientation discrimination appear not to become adult-like until some time after 5 years of age. Moreover, thresholds at both ages were significantly worse (1.2 - 1.5 times worse) for second-order modulation than for first-order modulation (main effect of stimulus type, $p < 0.01$). This difference provides further support for the hypothesis (e.g., Chubb & Sperling, 1988) that the processing of first- and second-order information is mediated, at least in part, by separate mechanisms.

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<http://cbcl.mit.edu>

189 Scotopic Contrast Sensitivity: Cat versus Human

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Here we estimate the contributions of optical and neural factors to scotopic sensitivity differences between cats and humans. A central laser spot was fixated at trial start (for cats, a prerequisite for trial progression). Targets were upward drifting (temporal frequency = 4 Hz) Gabor functions of fixed width (SD = 1.5 deg) and various spatial frequencies (0, 1/8, 1/4, 1/2, 1, 2 or 4 cyc/deg) presented 8 deg left or right of center, with onset and offset occurring smoothly over 500 msec. A correct response was defined as an eye movement toward the target for cats, or a correct button press for humans. Humans were instructed to fixate the laser spot throughout the trial, and to always respond. Cats had 5 sec to respond, and the target stayed on until the response was made. For humans, targets appeared for 1.25 sec, an interval encompassing most cat response latencies. Stimulus contrast was adjusted following a modified staircase procedure, and thresholds estimated from psychometric functions. Pupils were measured by digital photography at each adaptation level. As expected, cats had better dim-light vision than humans for low spatial frequencies over a wide range of contrast: in terms of ambient light levels, cats were approximately 0.80 log units (a factor of 6.2) more sensitive for 0 and 1/8 cyc/deg. For spatial frequencies above 1/2 cyc/deg, humans were more sensitive. However, most, if not all, of the cats' advantage in dim light was optical: their larger exposed pupil areas, reflective tapeta, and shorter focal lengths would improve sensitivity by about 0.32, 0.16 and 0.26 log units, respectively. When these optical elements are factored out of the data, the cat's advantage for low spatial frequencies in the scotopic range shrinks to 0.06 log units (a factor of 1.15), which is well within the range of cumulative errors in our measurements. We conclude that at 8 deg eccentricity, the retinas of the two species have similar intrinsic sensitivity. Supported by NIH EY02695.

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190 Concentric and parallel textures differentially activate human visual cortex

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Introduction

Mid level visual processes integrating local orientation information to detect global structure can be investigated using global form stimuli of varying complexity. Several lines of evidence suggest that the identification of concentric and parallel organisations have different underlying neural substrates. The current study compared brain activation by concentric and parallel arrays of line segments.

Methods

Four subjects were scanned in a blocked design fMRI experiment. In 'parallel' blocks short line elements within a circular central region had parallel orientations; in 'concentric' blocks they were aligned tangential to concentric circles. In 'random' blocks the elements were randomly oriented. The early retinotopic regions - V1, V2, V3, V3A and V4 - were previously localised in each subject. We compared the percentage BOLD signal change (against the random blocks as baseline) for the parallel and concentric conditions within these regions of interest.

Results

In general, there was more significant and more widespread activation of posterior brain regions by the parallel than by the concentric stimulus. In particular, for the retinotopic regions, the percentage BOLD signal change was greater for the parallel stimulus compared to concentric by ratios

varying from 3.2:1 in V3 to 2.2:1 in V1. Areas that were better activated by concentric compared to parallel were found in only one of the subjects, in the right postcentral gyrus and left cingulate gyrus.

Conclusions

This unexpected result, of greater and more widespread activation produced by the parallel stimulus, is compatible with it being a less 'specific' stimulus than the concentric, and activating neurons across many cortical regions. Psychophysical studies (including our current work) suggest that there are specialized detectors involved in the global processing of concentric structure. The lower activation by the concentric stimulus suggests that these detectors are not very numerous or widespread.

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191 Measuring the activity of spatial frequency channels using fMRI-adaptation

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Psychophysical research has established that there are channels selective for the spatial frequency (SF) components of visual stimuli (e.g. Blakemore & Campbell, 1969, *J. Physiol.*, 203, 237-260). Building on our previous work (Sowden, Myers & Payne, 2004, *Perception*, 33, 173), we sought to link such psychophysically defined SF channels to the underlying neural substrate using the fMRI-adaptation method (Grill-Spector & Malach, 2001, *Acta Psychologica*, 107, 293-321). We first identified area V1 using retinotopic mapping (Sereno et al., 1995, *Science*, 268, 889-893). Then observers viewed runs of 6 blocks of counter-phasing sinusoidal gratings (8Hz temporal frequency) interspersed with fixation blocks, each block lasting for 60 seconds. Of these blocks, one contained grating patterns of the same SF (1.27 c/deg) while the other blocks were composed of this SF and two others symmetrically chosen to be (+/-) 0.25, 0.5, 1, 2 or 3 octaves different. Given that typical V1 SF channel bandwidths are a little over 1 octave, we would expect that multiple SF selective populations of neurons would be stimulated in the blocks spanning the greatest SF ranges. Further, previous work shows that a 25msec exposure to a grating - a fifth of the duration here - is enough time for adaptation to occur (Georgeson & Georgeson, 1987, *Vis. Res.*, 27, 369-379) and that recovery from adaptation is unlikely to have occurred during the 250 msec gap between each repetition of the same SF (Greenlee et al, 1991, *Vis. Res.*, 31, 223-236). Thus, at the present repetition frequency, we should predict greater adaptation in the blocks spanning the wider range of SF's and therefore adapting multiple cell populations. In line with this, the BOLD response in V1 showed a greater drop for the blocks with wider ranges of stimulus SF's; the +/- 3 octave block showed the biggest drop in signal, hence greatest adaptation. Our findings indicate that fMRI can be used to isolate the activity of individual SF channels.

192 Normal variability of reversal- and onset-VEPs and their amplitude measurement

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Question: The ISCEV VEP-standard suggests quantifying amplitude of pattern reversal-VEPs as the N75-P100 excursion; some laboratories use the P100-N170 deflection. We asked which of the two, or their average, is more suitable; we used intraindividual and interindividual variability as quality measures. **Methods:** We recorded pattern-reversal and pattern-onset VEPs from 22 normal eyes of 11 subjects. Check size was 0.258 and 1.08, luminance 45 cd/m², contrast 97% for reversal and 80% for on-off. Binocular runs, later discarded, initiated a block design balancing eyes, stimuli, and repetitions. One channel, Oz vs. Fpz, was recorded using the EP2000 'Freiburg Evoked Potentials' system. **Results:** Automatic algorithms evaluated all traces. Traces to onset-offset stimulation varied

significantly in amplitude and shape between individuals. In some individuals the C1-C2-C3 complex was not well defined. Traces show that onset-offset stimulation produces poor consistency of response between subjects. Traces to reversal stimulation were markedly more similar between subjects. The N75-P100-N170 complex was always well defined. There was sizable variation between subjects with respect to amplitude, and the relation of the N75-P100 vs. P100-N170 amplitude; in some subjects a large N75-P100 compensated a small P100-N170 and vice-versa. CV of repeated runs was 7.25±0.82 for N75-P100, 8.50±1.26 for P100-N170, and 6.07±0.94 for the N75-P100-N170 average; mean amplitude across subjects was 14.34±2.07. Inter-ocular CV was very low, always in the range of the test-retest CV. **Interpretation:** It is important to recognize norm-variants. The higher variability of on-off is well known, as is the high interocular similarity. The results suggest that for reversal, the average of N75-P100 and P100-N170 amplitudes reduces population variability. Assuming on average similar pathologic effects on the two components, the N75-P100-N170 average may be a more sensitive and specific measure of VEP magnitude.

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<http://or.mcmaster.ca/lab/>

3D Space Perception

193 Perception of the Horizontal During Roll Rotation of Self or Scene

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We examined the separate and combined effects of scene rotation and body rotation on the ability of subjects to set a visual rod to horizontal. Subjects sat in a cockpit in a sphere, 2.6 m in diameter, lined with dots. They set a rod to horizontal before, during, and after roll motion of the sphere, the self, or both scene and self. Subjects fell into three groups. Those in one group, whom we call 'visual subjects', experienced full self rotation (vection) when sitting upright in the rotating sphere. However, these subjects set the test-rod to horizontal with reasonable accuracy when they themselves were rotated in the stationary sphere. They therefore used both visual and non-visual inputs. Those in the second group, whom we call 'non-visual, disoriented subjects', maintained the test-rod reasonably horizontal when stationary in the rotating sphere but became severely disoriented when they were rotated in the stationary sphere. They therefore did not use either visual or non-visual inputs effectively. Those in the third group, whom we call 'non-visual, oriented' subjects, were non-visual because they did not experience full vection when sitting in the rotating sphere but they did not become disoriented when rotated in the stationary sphere. Thus, they did not rely heavily on vision but had reliable inputs from the non-visual sense organs. The tests we have developed could be used to probe the extent to which people use visual and non-visual information for orientation during roll.

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194 Cues that determine the perceptual upright: visual influences are dominated by high spatial frequencies

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INTRO: The perceived direction of upright - the preferred orientation for polarized objects to be recognized - depends on the relative orientations of the visual background, the body and gravity. The perceptual upright (PU) is distinct from the subjective visual vertical (SVV) which is dominated by

the direction of gravity and which predicts the perceived effects of gravity on objects and the observer. The PU is highly sensitive to the orientation of the visual background: that is the preferred orientation for object recognition is critically influenced by the ambient visual environment. Which spatial frequency range carries the information that most influences the PU?

METHOD: The PU is measured from the perceived identity of the character p/d. The orientations where one interpretation (p) changes to the other (d), are bisected to indicate the PU. Subjects were tested upright and supine whilst viewing the character against a highly polarized photograph of a natural scene displayed on a laptop computer whose screen was masked to a 42° circle viewed at 25 cms through a tube that obscured all peripheral vision. The influence of a tilted background picture was examined as a series of circular Gaussian blurs were applied to it at 2, 4, 8, 16 and 250 pixel widths.

RESULTS: The influence of the visual background on the PU was initially about equal to that of gravity and about half that of the body. When we blurred the background image, the influence of the visual background on the PU systematically decreased at a rate independent of body posture, though the magnitude of effect remained reliably higher for supine observers.

DISCUSSION: The systematic decrease of the influence of the visual environment as it is blurred suggests an important role for higher spatial frequencies and the detail they convey rather than the overall structure of the scene in providing cues that determine the perceptual upright.

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195 Skating Down a Steeper Slope: The Effect of Fear on Geographical Slant Perception

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Previous research in our lab has shown that conscious awareness of the slant of a hill is overestimated, but visually guided actions directed at the hill are relatively accurate (Proffitt et al., 1995). In addition, steep hills were consciously estimated to be steeper from the top as opposed to the bottom, apparently because these hills were too steep to walk down and were viewed as dangerous. Furthermore, when an observer's physiological potential was manipulated by having him go on a long run or wear a heavy backpack, hills appeared even steeper with the conscious measures of slant, but the visually guided action was unaffected (Bhalla & Proffitt, 1999). In the present studies, we extend this research to show that viewing the hill in a fearful way also increases conscious estimates of slant, but not visually guided actions. Participants were situated at the top of a hill and stood either on a skateboard or on a wooden box of the same height. They gave three estimates of the slant of the hill: verbal report of the angle of the hill in degrees, a visually matched estimate of the slant, and a visually guided action (a haptic palmboard). After participants gave the three estimates of slant, their fear of descending the hill was assessed with a continuous rating scale. Experience on skateboards was also assessed, however almost no participants had substantial experience with skateboarding. Those participants that stood on the skateboard and reported feeling scared verbally judged the hill to be steeper and overestimated with the visual matching measure relative to those participants who stood on the box. However, the visually guided action measure was accurate across conditions. These results suggest that our explicit awareness of slant is influenced by the fear associated with a potentially dangerous action. As was found in our previous work, the visually guided action was unaffected by this experimental manipulation.

196 Seeing Beyond the Target: An Effect of Environmental Context on Distance Perception

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Previous research on egocentric distance perception has shown that contextual factors can influence our perception of distance. For instance, an obstacle placed between an observer and a target causes an underestimation in distance to the target (Sinai, Ooi, He, 1998; He et al., 2004). In these studies, however, the relevant cues are nearly always between the observer and the object. However, Shelton et al. (2002) recently reported that environmental context surrounding a target affected perceived midpoints of egocentric distances to that target. Perceived distance was overestimated when participants viewed targets in a hallway or a lobby, whereas perceived distance was accurate when viewing distances in an open field. In two experiments, we present further evidence indicating that information beyond the target can also affect egocentric distance perception to that target. Participants stood closer to one end of a long hallway and viewed targets while facing either the foreshortened end of the hallway or the extended end of the hallway. We measured perceived distance using a visual matching task (Exp. 1) and a blindwalking task (Exp. 2). The angular elevation of the targets in all conditions was the same. When the participants viewed a target near the closer end of the hallway, they overestimated the distance with both measures relative to targets viewed in the extended end of the hallway and vice versa. Our findings suggest that contextual effects on distance perception are not limited to obstacles between the observer and target, but also include the environment beyond the target.

197 Perceiving distances to targets on the floor and ceiling: A comparison of walking and matching measures

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It has been proposed that a continuous ground surface is important for perception of distance (Gibson, 1950; Sinai, Ooi, and He, 1998). Most studies of absolute egocentric distance perception have only investigated targets placed on the ground. We asked whether distance perception as indicated through blind walking or matching would differ when targets were placed on the ceiling versus the floor. The position of objects on the ceiling is not consistent with our everyday experiences and creates less ground-surface information for depth, potentially leading to increased error or variability. In three experiments, targets were placed 5, 10, 15, and 20 feet from the observer and each subject performed two tasks. In Experiment 1, targets were placed on the ceiling. In one condition, subjects blind walked so that their bodies were aligned underneath the target. In the second condition, they completed a location matching task in which they adjusted a visual marker in depth on the floor so that it was aligned underneath the target. We found accurate blind walking but a significant 10% overestimation in the marker position relative to the target position. Experiment 2 also placed targets on the ceiling and compared blind walking with a frontal matching task in which two poles were moved to set an exocentric width extent to match the egocentric depth extent from the observer to the target. Both measures showed accurate performance. Experiment 3 was the same as Experiment 2 but placed targets on the floor, again showing accurate performance for both measures. The results indicate two novel findings in need of further investigation: 1) blind walking remains accurate even when targets are not on the ground plane and 2) matching a location in depth leads to an overestimation of distance to targets on the ceiling that is not seen in the frontal matching-extent task.

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198 The Representation of Visual Space in an Expanding Room.

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We have found that when a virtual room expands around an observer as they walk, observers fail to notice any change despite veridical binocular and motion parallax cues (VSS 2003). This leads to gross errors in size constancy, particularly at far viewing distances. Here, we investigate whether this pattern of results imply a distorted representation of viewing distance in the expanding room.

Wearing a head mounted display in an immersive virtual reality system, subjects carried out the following forced-choice tasks in both an expanding and a static room. Each task was carried out with the subject on the left of the room (when the expanding room was small) and on the right (when it was 4 times larger). Subjects (i) compared the size of an object visible on the left side of the room with one visible on the right; (ii) judged the depth of a triangular prism relative to its half-width; and (iii) judged the distance of a rod as greater or less than half (or twice) the distance to a comparison rod. Only task (i) required the observer to compare two objects viewed when the room was a different size.

Estimates of viewing distance derived from the size comparison task were close to veridical in a static room but in the expanding room were consistent with either a compression or an expansion of visual space depending on whether the comparison object was shown when the room was small or large. For the depth-to-width judgement, subjects' biases were consistent with a compression of visual space in both static and expanding rooms. For the half- and double-distance task, judgements were close to veridical in both the static and expanding rooms. Conclusion: Performance in these tasks does not rely on a single internal 3D representation (e.g. Gogel, W.C., 1990). Instead, task-specific strategies are used.

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199 Invasion of Personal Space Influences Perception of Spatial Layout

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Perception can be influenced by physical properties of the perceiver, such as whether the perceiver is encumbered, or is feeling fatigued (Proffitt, Bhalla, Gossweiler, & Midgett, 1995). However, it is unclear to what extent social properties of a situation influence perception. People use space in specific ways as a function of social relationships (e.g., Argyle & Dean, 1965). For example, people maintain an area of personal space around them, and are very sensitive to violations of this personal space (Hall, 1968). This study investigated whether an invasion of personal space influences distance estimates to an object. In the invasion condition, participants' space was invaded by an experimenter who casually placed a can of Coke from which she had been drinking immediately in front of them (at a distance of about 10-45 cm). In the control condition, the experimenter retrieved a fresh can of Coke from her briefcase, and placed it in front of the participant, with the words, 'This is for you for participating.' Thus, the only difference between the two conditions was whether the experimenter had established ownership of the can (as indicated by drinking from it), and thus invaded the participant's personal space, or the participant had ownership of the can (as indicated by the experimenter's comment). Then participants gave a matching estimate of the distance between the Coke can and the edge of the table where they were sitting. Participants whose space had been invaded estimated the experimenter's can to be significantly closer than participants who had their own can within their personal space. Thus, when personal space was invaded another person's object was experienced as 'too close.' These data support the notion that not only physical, but also social properties of the context can influence the perception of spatial layout.

200 The Idiosyncrasies Of Foreshortening And What They Reveal About Space Vision

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The depth interval of a test target line in the sagittal plane is underestimated compared to a matching target line in the frontal plane. To reveal how such foreshortening depends on the representation of the ground surface, Exp 1 placed the matching target on the ground at (i) 2.5m; between the observer and the test target (near condition), (ii) 9.5m; beyond the test target (far condition); thus biasing the ground surface range to be sampled. We found that with monocular viewing the foreshortening is less in the near condition. This is attributable to an increased ability to sample the near ground surface for constructing an accurate global ground surface representation that is vital for space vision. In contrast, the far condition emphasizes the sampling of the distant ground. Exp 2 tested how varying viewing criteria, which presumably adjust how various processing levels weigh visual information, affect foreshortening. Using an L-shaped target on the ground with a 44cm frontal limb and an adjustable sagittal limb, observers judged the Ratio of Aspect Ratio (RAR) of the L-shaped target in the light with (i) a physical dimension criterion, (ii) an angular size/retinal image criterion. It is predicted that the latter criterion leads to a larger foreshortening since it is ideally impervious to size constancy. Our results support this prediction, but only to a point, as the measured-RAR from the retinal image criterion is larger than the predicted-RAR based solely on the retinal image of the L-shaped target. Further, when we compared our data from the retinal image criterion to the measured-RAR data in the dark (with a physical dimension criterion), where performance is based on the visual system's intrinsic bias (an implicit slant plane), we found that the foreshortening is similar. Thus, it is likely that the intrinsic bias determines the upper limit of foreshortening when the extrinsic visual information on the ground is either ignored or unavailable.

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201 Spatial updating of locations after posture changes in the vertical dimension

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A large body of research has focused on spatial updating after rotational and/or translational motions on the ground. Here we extend the research into the third dimension: How good is updating of spatial representation after body movements in the vertical dimension, such as posture changes (e.g., sitting to standing)? Underlying this work is the assumption that when people update spatial location after shifts in posture, they center their spatial coordinate system on some self-referred location. The body and head are candidates for such ego-centers and indeed, both may be present and interact in spatial updating. The first experiment tested the hypothesis that people use shift in perceived eye level to update their vertical position after a postural change. It examined the perception of eye level in different postures and also directly measured judgments of relative shift in eye level across postural changes. To assess the relative effectiveness of visual cues and vestibular/proprioceptive cues, subjects were tested in both dark and lit environments. The experiment found that eye level was perceived with reasonable accuracy in the light, but underestimated by a similar amount across all postures in the dark. Thus judging eye-level shift from the difference in perceived eye levels would have led to accurate responses. In contrast, the relative shift was over-perceived in both lit and dark conditions. An ongoing experiment is testing whether updating of body position leads to commensurate change in head posture, so as to maintain gaze. Subjects in light or dark are asked to maintain eye fixation on a previously viewed target as accurately as possible while sitting down or standing up. Their head orientation is continuously tracked to determine whether there is slippage between body and head change. Errors will be related to the corresponding errors from Experiment 1, to test whether slippage in gaze and misperception of eye-level shift stem from a common origin.

Target Mislocalization

202 Distorting visual space without motion signal

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Studies have shown that the perceived position of flashed objects is distorted in the presence of stimulus or eye motion: e.g., flash-lag effects (Nijhawan 1994; Schlag et al. 2000), presaccadic mislocalization and compression (Cai et al. 1997; Burr et al. 1997), and position capture (Whitney & Cavanagh 2000). Here we demonstrate that, even in the absence of such motions, the perceived position of flashed objects can be systematically distorted depending on the timing of their presentation with respect to other objects in visual field. When a target object is flashed at the offset of another object (here called 'inducer'), the perceived position of the target object shifts toward the center of gaze, regardless of the number of inducers and their location.

Observers judged the relative alignment of two vertical lines separated by a short gap. One line was continuously present at 8 deg right to the central fixation point, the other was briefly flashed at least 1s after the onset and 1s before the offset of the continuous line. At various times around the line flash, four small disks grouped around the lines were presented: either 1) continuously, 2) from the trial onset to line flash, 3) from the line flash to the end of the trial, or 4) flashed simultaneously with the line.

We found that when the line was flashed at the extinction of the disks (i.e., conditions 2 & 4), the perceived position of the line shifted toward the center of gaze. The perceived shift was several times larger than the baseline tendency of compression (Mateeff & Gourevich 1983) obtained in control trials with no disk. In other experiments, the stimulus offset asynchrony (SOA) between the flashed line and disks, the number of disks and their location relative to the line were varied. The perceived shift was strongest at SOA = 0ms and disappeared with SOA > 100ms. Although the perceived shift was affected to some extent by the spatial configuration of the disks, its direction was always toward the center of gaze.

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203 Sub-threshold motion influences apparent position

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Until recently, it was assumed that motion and position coding were independent. However, now it is apparent that these attributes interact. For instance, stationary stimuli that contain internal movement can appear shifted in the same direction as the internal motion. Recently, it has been suggested that this sort of illusory position shift is caused by changes in apparent contrast at the edges of moving objects. This suggestion is consistent with psychophysical observations that the apparent height of static gratings can be influenced by internal motion patterns. Here we show that motion-induced changes in apparent height and position both increase linearly with stimulus presentation time (up to ~100ms). We also show that apparent position shifts can occur when stimulus presentations are too brief for the direction of internal motion to be identified. This implies that illusory motion-induced position shifts can be a more sensitive direction cue than behavioural responses that are presumably based upon analysis of the motion signal itself.

204 If we saw it, it must have been where we were looking!

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When there is a high degree of uncertainty about a target's position, for instance because the target is moving fast or because it is only visible near the time that the observer makes a saccade, judgments of the target's position are not only unreliable, but they often also contain systematic

errors. It is often evident that the systematic errors mainly have a temporal origin. However, there may also be spatial biases. We examined one particular kind of spatial bias: a bias towards the fovea. There is a higher probability of seeing something if it is centred on the fovea than if it is more eccentric. Thus there is also an increased probability that things that one sees are where one is looking. To examine whether uncertainty incites people to localise things closer to the fovea than they really are, we asked subjects to fixate the centre of a screen. A green dot jumped to a new position on this screen every 250 ms (retinal eccentricities between 0.8 and 3.8 deg). At some moment there was a short (one frame) red flash at the screen centre. The subjects' task was to indicate where the green dot had been at the moment of the flash. We analysed subjects' responses in relation to when the flash appeared relative to the sequence of dots. There appeared to be a 'delay' (relative to the flash) in selecting a target of about 58ms, with a standard deviation of about 160ms. The temporal bias and temporal uncertainty were independent of the target's eccentricity, but there was a clear tendency to select targets that were close to the fovea. Once a target had been selected, there was a tendency to underestimate its eccentricity if the eccentricity was large, but to overestimate the eccentricity if it was small. This bias can be related to the range of eccentricities encountered during the experiment, but the bias to select less eccentric targets cannot, so the latter is presumably caused by the differences in the probability of seeing things at different eccentricities.

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205 The Flash-Pulfrich Effect

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The classical Pulfrich effect describes a perceived depth elicited by a moving object that is viewed with unequal illuminance in the two eyes. The image in the dimmer eye is thought to have a latency-induced spatio-temporal offset that results in a binocular disparity between the dim and bright images. The Pulfrich effect has a monocular correlate, the Hess effect, that describes the relative mislocalization of two moving objects of different brightness in the same eye. As would be expected, the dimmer object is seen to move with a positional lag.

We present a novel version of the Pulfrich effect based on another monocular mislocalization, the Flash Lag effect (FLE). The FLE describes the relative misalignment of two moving objects when they are presented for different temporal durations. The position of a flashed object appears to lag behind a continuously presented object. We developed a binocular correlate of this stimulus to produce a Pulfrich like motion-depth illusion.

We compared the Hess and FLE under monoptic and dichoptic conditions while varying luminance and flash duration. Both dichoptic conditions produced Pulfrich depth effects with pendular motion. The dichoptic Hess condition produced the classic Pulfrich effect. When we combined the Hess and FLE in the dichoptic condition, we could reverse the depth direction of the classic Pulfrich effect if the brighter image was flashed. Thus the dichoptic FLE produced disparities that were independent of those produced by luminance difference between the two eyes.

*Note that the flash-Pulfrich effect is not to be confused with the stroboscopic-Pulfrich effect (Lee 1970) that attempts to cancel binocular disparities by strobing both bright and dim images. The flashed-Pulfrich effect is generated by strobing only one of the images.

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206 Internal and External Prediction in The Flash-Lag Effect

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If an object is flashed in alignment with a moving object, we perceived the former as lagging behind the latter. There is some agreement that this

misalignment (FLE) implies a temporal error: the visual system would ascertain the location of both objects at different times. Consequently, the moving object is perceived leading the flashed one. It is also known that sensory consequences of voluntary actions are perceived earlier than they actually did (Haggard et al. 2002 Nat. Neurosci.). If the FLE implies a temporal error, this would be reduced if the flash were perceived as a sensory consequence of our action. Here we explore this hypothesis. We combined different velocities of the moving object with different spatial offsets between the flash and the object in three different conditions: (1) subjects triggered the flash by pressing a key; (2) the flash was presented after a predictive beep and (3) the flash was unpredictable. We fitted cumulative Gaussians as a function of spatial offset and time. Results can be summarized as follows. First, the time differences predicted the percentage of response-type (p.e. flash lagging behind) much better than the spatial offset. Relative to the unpredictable condition (3), the FLE was reduced about 30% when the flash was internally predicted (1) and 8% when it was predicted externally (2). Furthermore, predictability not only shifted the fitted curves but also decreased the variability. These results are consistent with a spatio-temporal interpretation of the FLE.

207 Distortion of Positional Representation of Visual Objects by Motion Signals

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Many studies have shown that relative visual localizations of briefly flashed stimuli are systematically modified in the presence of motion signals. These studies imply that perceived visual space may be distorted due to motion signals. To explicitly test this space-distortion hypothesis, the detailed 2-dimensional spatial mapping of mislocalization was performed.

A moving black disk was presented while observers fixating a stationary cross. A white disk was briefly presented ahead of or behind the moving disk with a vertical offset. The observer adjusted the position of the flash to indicate where the flash had been perceived relative to the moving stimulus. A flash ahead of a moving disk was perceived to lag more than a flash behind the moving disk. Moreover, the pattern of positional shifts indicated that perceived positions were distorted toward a point behind a moving stimulus. The convergent point was not influenced by the variation in the velocity of a moving stimulus. These results support the space-distortion hypothesis.

To clarify the process of the asymmetric mislocalization, the shape perception of a flash stimulus was evaluated by presenting two disks simultaneously and connecting them with a line. It was found that mislocalization was similar to that with single flash. However, the shape of connected flashes was not changed, except for space around the moving stimulus. These results suggest that the asymmetric mislocalization originates from the shift of the positional information of represented visual object, not from the distortion of space itself (i.e., medium of positional representation.)

208 The coding of combined pointing movements and saccades in the Brentano illusion

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For movements to a visual target either visual judgments of direction and distance (or length) of the required displacement can be used (vector coding), or the final position (position coding), or a combination of both. Earlier studies using the Brentano illusion (de Grave et al., VSS 2002) showed that pointing movements and saccades both use vector coding, however not to the same extent. The saccades relied more strongly on vector coding than the hand (pointing), leading to the conclusion that the eyes (saccades) and the hand (pointing) use different information for their movement. However, these studies do not rule out the possibility that eye

and hand use the same information. In the pointing study correction saccades could have been made by the time the pointing movement was finished. This could explain the smaller effect on pointing if eye position information is used in pointing. In this study we tested whether combined saccades and pointing movements are influenced by the Brentano illusion to the same extent when the stimulus is only presented for 200 ms, so subjects could not make a corrective saccade. Subjects started with their index finger in the middle of a touchscreen and made saccades and pointing movements in four directions. Movements were always from an outer vertex of the Brentano illusion toward the middle vertex. We found an illusion effect of about 25% in pointing as well as in saccades when both movements are performed in the same task. This favours the interpretation that the same information is used in eye and hand movements.

Contours/Form Perception

209 Evaluating curvature aftereffects with radial frequency contours

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Psychophysical and physiological evidence demonstrates that global shape coding depends on mechanisms located at intermediate levels of visual processing. Evidence also suggests that these mechanisms are vulnerable to adaptation techniques historically used to probe mechanisms underlying performance in lower-level visual tasks. We explored the nature of these global shape aftereffects using radial frequency (RF) patterns, where stimuli are defined in terms of deformations from a circular pattern. On each trial, subjects adapted to a RF pattern with a high ($\times 15$ threshold) amplitude for 5 seconds, followed by a brief (53 ms) test RF that was either in-phase or anti-phase to the adapted RF. Subjects identified the phase of the test RF pattern using a 2AFC paradigm. Performance was evaluated by determining the RF amplitude at which subjects equally classified the test stimulus as the in-phase or anti-phase pattern (Point of Subjective Equality (PSE)). With no adaptation, subjects were exquisitely accurate when classifying RF patterns (PSE=1.0arcsec). After adaptation, the PSE shifted towards the pattern that was in-phase with the adapted RF (P_{eq}=52.3arcsec), demonstrating that subjects were more likely to classify the test RF as the anti-phase pattern. This perceived shift is equivalent to a stimulus that is modulated 2-3x above threshold under these conditions. When subjects adapted to a RF pattern with a larger number of cycles, on the other hand, the PSE did not change. Preliminary results suggest that the strength of the shape-specific aftereffect is similar when adapting to either a high (90%) or low (10%) contrast RF pattern. Together, these results suggest that the mechanisms adapted by RF patterns code information that is specific to the geometry of the stimulus, and are located beyond those responsible for contrast gain control.

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210 Properties of Shape Interaction in Temporal Masking

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The perceived shape of a pattern (target) can be masked by that of a subsequent pattern (mask). The purpose of the present work is to elucidate the nature of this shape masking. Perceived deformation of a target radial frequency (RF) pattern (radius 1.1deg) was measured when followed by an RF mask (radius 1.6 deg) of high amplitude (16 x detection threshold). The effect reaches a maximum at a stimulus onset asynchrony (SOA) of 80-100 ms, where thresholds are elevated by a factor of 16. Various configurations in which target and mask are separated by this SOA were tested (the mask is termed primary here). Conditions in which a second mask is interleaved

in time between the target and primary mask, lead to smaller threshold elevations and reveal that the onset of the mask that appears first in time determines the magnitude of masking. Configurations in which apparent motion is possible between the target and both masks lead to large threshold elevations (factors of 16-20) and demonstrate that both masks contribute to the effect. The magnitude of these effects is much larger than that predicted by a combination of spatial lateral interactions and apparent motion between target and mask. Results suggest that shape, apparent motion, and stimulus onset play an interactive role in masking, and that target shape is not determined at initial onset, but rather, is extrapolated (postdictively) after a window of 80-100ms.

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211 The role of spatial phase in the detection of position-defined and orientation-defined linear and circular contour deformation

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Purpose: Previous studies on the role of spatial phase in perceptual grouping may be complicated by the co-varying of various local features. Here we investigated effects of phase coherence on the detection of contour deformation defined by the changes of local position or orientation features. **Methods:** Stimuli were linear and circular contours composed of Gabor patches with carrier frequency of 3 cpd. Contour deformation was introduced by sinusoidally modulating a vertical line or the radius of a circle. Position-defined deformation (P-Pattern) was created by placing patches at peaks and troughs of the modulation, so that changing modulation only changed their positions but not orientations. Orientation-defined deformation (O-Pattern) was created by placing patches at zero-crossings. Circular contours had 1.5 deg mean radius and 4 cycles of modulation; Compatible stimulus parameters were used for linear contours. Deformation thresholds were measured for 3 carrier phase manipulations: in-phase, phase reversal of alternating patches, and random phase. **Results:** Subjects showed higher sensitivity for detecting O-Patterns than P-Patterns. The mean thresholds of 3 normal subjects were $0.45 \pm 0.07\%$ and $0.62 \pm 0.29\%$, respectively, for detecting in-phase linear and circular O-Patterns, and $0.77 \pm 0.36(\text{SD})\%$ and $0.97 \pm 0.54\%$, respectively, for detecting in-phase linear and circular P-Patterns. Phase reversal significantly elevated the threshold for detecting linear P-Patterns by 40% ($p < 0.02$). Randomizing the phase further disrupted the detection of linear p-Patterns, with threshold increased by 60% ($p < 0.011$). In comparison, thresholds for detecting both linear and circular O-Patterns were not affected by either phase reversal or random phase. **Conclusion:** While local spatial phase change may affect the grouping of local position features, orientation linking can occur between cells with different phase sensitivities and may take place at a more global level of processing.

212 Aftereffect of Adaptation to Glass Patterns

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We observed that adaptation to a series of similar Glass patterns causes an unstructured test stimulus to appear to take on illusory structure locally perpendicular to that of the adaptor. We measured the magnitude of this aftereffect using a method analogous to that devised by Blake & Hiris (1993) to assess the strength of the motion aftereffect. After adaptation to a particular global form, subjects reported the perceived structure of Glass patterns varying in their coherence. A test pattern coherence of around 30% was required to null the aftereffect. Three lines of evidence indicate that this effect is mediated predominantly at the level of local oriented filtering of the image. 1. The objectively measured magnitude of the

aftereffect appears essentially independent of the global structure of the adaptor, even though humans are reportedly more sensitive to concentric and radial Glass patterns than to translational ones. 2. The aftereffect transfers only partially between the two eyes, implicating monocular V1 neurons. 3. The aftereffect transfers almost completely across contrast polarities, a characteristic shared with the direct tilt aftereffect, a supposedly low-level phenomenon. However, the aftereffect of adaptation to Glass patterns does show weak position invariance such that small 'phantom' aftereffects are observed in unadapted regions of the visual field. These phantom aftereffects indicate that adaptation is also occurring at a more global level of form analysis. Thus, it appears that the aftereffect of adaptation to Glass patterns is mediated at multiple levels of the cortical visual processing hierarchy. We argue that this effect is distinct from those reported by McKay (1957ab) and discuss its implications for our understanding of the coding of spatial image structure in the human visual system.

Blake, R. & Hiris, E. (1993) *Vision Res.*, 33, 1589-1592.

McKay, D. M. (1957a) *Nature* 180, 849-851.

McKay, D. M. (1957b) *Nature* 180, 1145-1146.

213 Second-order Contour Discontinuities in Segmentation and Shape Representation

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Previously, we reported efforts to better define good continuation as the principle governing perception of unity, separateness, and parts in continuous contours. That work showed that the presence of first-order (tangent) discontinuities primarily governed segmentation (Kellman, Garrigan, Kalar & Shipley, 2003). Here we report subsequent efforts to determine whether second-order discontinuities (locations at which the contour's second-derivative is undefined) play a role in segmentation and grouping. Using our earlier paradigm, in which subjects searched in noise for a contour segment with varying levels of continuity to other segments, we found no reliable sensitivity to second-order discontinuities as a basis for segmentation.

Other research has suggested that second-order discontinuities are features, and can lead to "pop-out" in a search paradigm (Kristjansson & Tse, 2001). These and other results have been interpreted as implicating second-order discontinuities in contour shape representation and segmentation. We replicated the visual search findings of Kristjansson & Tse (2001), and then showed with additional manipulations that second-order discontinuities alone do not account for their previous findings. Displays containing even more second-order discontinuities but with a less-noticeable difference in symmetry from ellipses showed serial, not parallel search patterns. We explore alternative hypotheses that may explain both sets of data.

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214 Effect of dichoptically presented reference on systematic shape distortion during pursuit eye movement

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Li, Brenner, Cornelissen and Kim (2002) have recently reported that the perceived shape of spatiotemporally defined 2D object was systematically distorted during pursuit eye movement and that the perceived shape just reflected the retinal image. Does this imply that the perceptual shape distortion during pursuit eye movement is determined in the early level of visual information processing? Although the perceived shape just reflected the retinal image ignoring extra retinal information, it is still possible that the perceived shape is determined at a late stage, e.g., later than binocular information is processed. To examine this possibility, I measured the effect of reference on the perceptual shape distortion during pursuit eye movement in three separate conditions; no-reference, dichoptic (i.e., target and reference were presented to separate eyes), and

binocular conditions. If perceptual shape distortion is determined before binocular information is processed, then perceptual distortion should not be affected by the dichoptically presented reference. The size of the spatiotemporally defined object was 1.6 deg X 1.6 deg. The luminance-defined rectangular reference surrounding the target object had one of three sizes; 2.1 deg X 2.1 deg, 2.6 deg X 2.6 deg, and 3.1 deg X 3.1 deg. Subjects reported the perceived shape by the method of adjustment. As found in Li et al, the perceived shape of the target object was systematically distorted during pursuit eye movement, but the amount of perceptual distortion decreased as the reference became closer to the target. More interestingly, the dichoptically presented reference affected the perceptual shape distortion as the binocularly presented reference did. No significant difference in the amount of perceptual distortion was found between these two conditions. These results imply that the perceptual shape distortion observed by Li et al is determined later than binocular information is processed.

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215 Perceived orientation of complex shapes reflects graded part decomposition.

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Although orientation of line segments and simple shapes is a well-studied area of vision, little is known about the factors that influence perceived orientation of complex shapes. Study of these factors is of great interest because it allows for a better understanding of how local shape attributes are integrated into a global shape description. We studied the perceived global orientation of two-part shapes using an adjustment method and a 2AFC task. In particular, we investigated the influence of (i) the perceptual distinctiveness of a part -- as defined by the turning angles at the negative minima of curvature defining its boundaries, and (ii) its area relative to the main 'base' part. Results exhibited systematic deviations of perceived orientation from the axis of greatest elongation of the shape (i.e., the principal axis with the greatest eigenvalue). For sharp part boundaries, perceived global orientation deviated maximally from the principal axis, and was approximated instead by the axis of the main 'base' part of the shape (i.e., observers largely ignored the attached part in estimating overall orientation). However, with weakening part boundaries, the perceived orientation gradually approached the principal axis of the entire shape (albeit with weaker precision) -- reflecting that both parts were taken into account in estimating orientation. The results allow us to quantify a largely ignored characteristic of complex shape representation: part independence. Previously we showed that increase in part-boundary strength leads to systematically better performance in a 4AFC part-identification task (Cohen & Singh, VSS 2003). The current results show that geometric factors such as turning angles at part boundaries determine not only the strength of a part's representation, but also the extent to which it is represented as an independent unit, i.e., the extent to which its influence is separable from the rest of the shape.

Acknowledgment: Supported by NSF BCS-0216944

216 Systems Factorial Technology Analysis of Pomerantz's Configural Figures

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People are faster and more accurate at detecting a certain feature, say, a left parenthesis, when presented within a context, '()', than when presented alone, '(' (Pomerantz et al, 1977; 2003). Similarly, people seem better at identifying a given facial feature, say a nose, within the context of a face, than when the nose is presented alone. According to theories of configural processing, highly symmetrical ('good figures') or highly learned (faces) figures are processed as a Gestalt, and that holistic experience aids in the resolution of comprising parts. We applied System Factorial Technology,

developed by Townsend and Nozawa (1995), to examine whether the influence of configuration can be measured in terms of architecture, capacity, stopping rule and (in)dependence. The participants performed in a redundant target search task, in which a single stimulus was presented on each trial, comprised of a diagonal line (either left, '/', or right, '\') and the shape 'L' (presented normally, or as a horizontal mirror image). Participants had to detect the target items '/', rotated 'L', or both. In experiment 1, the two items were combined together such that they formed a Gestalt. The results showed no redundancy gains. In fact, Participants were faster on single target trials (449.8 ms) than they were on redundant target trials (634.1 ms). Capacity, calculated as the ratio between the integrated hazard functions of redundant target and the sum of single target conditions, was severely limited, suggesting that configural processing was actually stronger for the single target displays than for the redundant target displays. In addition, topological similarity may also play an important role in RT tasks. In further experiments, we constructed the stimuli such that the comprising parts did not necessarily formed 'good' configurations. Results were different both in terms of mean RTs and in terms of the properties of the underlying cognitive system (i.e., its architecture, capacity etc.).

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217 Rapid successive presentation improves symmetry perception

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To study temporal characteristics of symmetry perception symmetric dot patterns were successively presented. Each pattern differed from others but all patterns in a stream were symmetric about identical axis. Task was to judge orientation of axis of symmetry (right or left diagonal). The total duration of the stream was fixed to 853ms, and presentation frequency was varied among 1.2 - 75Hz. Higher frequency meant larger number of patterns in the duration. Although such stimuli prevented the observers from scrutinizing each pattern, resulted performance was better compared to static presentation in same duration (experiment 1). Following experiments probed what enhanced symmetry perception of the successive stimuli. Experiment 2 contrasted (a) unique patterns condition in which all unique patterns were presented in a stream same as experiment 1, and (b) 4 patterns condition in which only 4 patterns were repeatedly presented in a stream. The latter yielded worse performance, suggesting that larger number of unique patterns, not flickering of patterns, improved the performance. In experiment 3 each trial presented 4 streams, and they all comprised of same set of 16 patterns (16 patterns condition) or they were repetitive presentation (same as experiment 2) of unique set of 4 patterns (4 patterns condition). 16 patterns appeared 4 times in one trial of both conditions, whereas one stream contained more patterns in 16 patterns condition. In result 4 patterns condition showed worse performance. This result suggested that larger number of patterns in limited temporal window improved the performance. Further experiment suggested that noise reduction underlay the improvement. In conclusion successive presentation of dot patterns in brief duration improved symmetry perception. Such improvement implies that temporal summation of visual information may occur in the mechanism of symmetry perception.

218 Intermediate Level, Medium-Span, Configurations Can Trigger Past Experience Effects On Figure Assignment

Mary A. Peterson (mapeters@u.arizona.edu), Emily Skow¹; University of Arizona

Behavioral, computational, and physiological theorists have suggested that intermediate-level medium-span configurations play a role in shape perception. Which behavioral tasks probe medium-span configurations

rather than local configurations or global shapes? Figure-ground tasks show effects of experience with previously seen shapes only when representations are accessed quickly, consistent with intermediate-level representations. Here we show that the relevant representations are medium-span configurations by altering a paradigm used previously to assess past experience effects implicitly. We measured the time needed for figure assignment when past experience competes with, but does not dominate, other cues. Novel shapes with three straight and one (vertical) stepped edge were shown on prime trials. On probe trials subjects judged whether two vertically aligned shapes were the same as or different from each other. On experimental probe trials, the stepped edge of the prime was repeated but other cues (closure, small area) specified that the figure lay on the opposite side of the edge. Consequently, the perceived shape of the probe differed from that of the prime. On control probe trials the probe shapes were completely novel. Competition from past experience led to longer RTs on experimental than control probes. Thus, repeating just the stepped edge of the prime activated the memory of where the figure was the first time the edge was encountered; repeating the whole prime was unnecessary. Here, we ask whether repeating a smaller span (only the top or the bottom half) of the continuous stepped edge was sufficient to trigger the effects of past experience. Again, we found that RTs were longer on experimental than control probe trials, $p < .05$. Surprise recognition trials showed that subjects were unaware that the experimental probes were related to the primes. The results are consistent with a distributed shape representation system with medium-span configurations lying at intermediate levels.

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219 Shape recognition with propagation fields

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A shape recognition system is presented that learns novel shapes (like letters) in one shot and recognizes them even if they are distorted, changed in size, shifted in position, fragmented or disrupted by 'noisy' contours. A shape is represented as a field of local orientations, which is analogous to an optical flow field. This orientation field is obtained by looking at the contour propagation flow of a shape through a set of orientation columns and it is thus called the 'propagation field'. Recognition occurs firstly by determining the local orientations of the input shape, followed by matching them against the propagation field of each shape. A neural architecture is presented that performs this template matching process. It consists of three separate components: 1) a 'propagation map' that propagates contours, which is employed for learning and partly for recognition; 2) a set of orientation columns that determine local orientations in the propagation map; 3) a stack of 'shape maps', in which each map encodes a separate propagation field: a shape map consists of a 2D field of neurons with each neuron having the same number of synapses as there are distinguishable orientations. Each synapse (in each shape map) receives input from its spatially corresponding orientation cell. To learn a novel shape, a new shape map is employed and only those synaptic weights are turned on, whose corresponding orientations are stimulated during contour propagation in the propagation map. During recognition, the shape map with the most similar propagation field is activated the highest and its population activity signals the presence of a shape. Due to the wide-spread representation of a shape, recognition is enormously robust and occurs without error. The recognition system has already been presented in book form (Rasche 2005, *The Making of a Neuromorphic Visual System*, Springer, New York) but is here publicly presented the first time.

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220 Character recognition and Ricco's law

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The contrast threshold for the detection of patches of light depends upon stimulus size as described by Ricco's classical law of areal summation. The critical diameter within which Ricco's law holds increases with retinal eccentricity. Here we present an analogon of Ricco's law for the recognition of characters at low contrast, and describe its variation with retinal eccentricity. Stimulus size has a more pronounced effect on character recognition than it has on stimulus detection, such that the maximum slope of the (log-log) areal-summation function is much steeper than Ricco's (-2) slope. It ranges from -3 in the fovea to -7.5 at 308 eccentricity. At larger stimulus sizes there is a range at which Weber contrast threshold C_W is proportional to stimulus area S^2 (i.e. slope is -2); we denote this as the Ricco size range. The latter increases with retinal eccentricity at the same rate as receptive field size. Furthermore, the effect size $C_W \times S^2$ is a constant multiple of Spillmann's perceptive field size. The law will be formally related to that presented by Fischer & May (1970) for the cat.

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<http://rocky.psych.ucla.edu/>

221 Different Aspects of Form Perception Develop at Different Rates

Yasmine El-Shamayleh (yasmine@cns.nyu.edu), Lynne Kiorpes¹, J. Anthony Movshon¹; Center for Neural Science, NYU

Newborn macaques can detect the presence of luminance gratings. However, they are unable to process more complex cues, such as dots pairs that define a global form percept in Glass patterns, until about 11 wks. This difference may be due to the late development of ventral extrastriate areas, known to be important for mature form vision, or may be attributed to differences in the extent of spatial integration required to extract the form cues present in simpler and more complex stimuli. To address this question, we compared the performance of macaques on a texture-defined form task, which did not require extensive integration over space, to detection of Glass patterns. The texture cue was defined by differences in the orientation of carrier patterns whose spatial form was determined by a separate modulator pattern (Landy & Oruc, 2002).

We trained young monkeys to discriminate orientation. We presented two modulators; one vertical, the other horizontal. The animal's task was to indicate the vertical target. We varied texture modulation depth and modulator spatial frequency, and used either horizontal/vertical or oblique carrier patterns whose orientation differed by 90 deg. For comparison, we tested the same animals on a Glass pattern detection task using concentric or linear form cues.

Infant monkeys can detect texture-defined boundaries as early as 4 wks and are able to use this cue for orientation discrimination as early as 6 wks. Sensitivity is higher for textures defined by horizontal/vertical carriers than for those based on oblique carriers. All animals performed the texture discrimination at earlier ages than Glass pattern detection. Our results suggest that different aspects of form perception develop over different time courses, reflecting a developmental cascade of visual functions. Thus, mechanisms underlying the integration of form cues on a local spatial scale mature earlier than those implicated in global spatial integration.

Talk Sessions

May 7, 2005 – Saturday PM

Conscious Perception (222-226), Spatial Vision (227-232), Attentional Mechanisms (233-239), Lightness and Surfaces (240-246)

Conscious Perception

1:30 - 2:45 pm

Hyatt North Hall

Moderator: Peter Tse

222 Predicting the Orientation of Invisible Stimuli from Activity in Human Primary Visual Cortex

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It has been proposed that activity in human primary visual cortex (V1) is necessary but not sufficient for conscious awareness, but direct physiological evidence for the activation of human V1 in the absence of awareness has been elusive. Here, we used functional MRI to measure activity in V1 while participants viewed masked and invisible orientated gratings. Remarkably, when participants were unable to report the orientation of a masked grating they were viewing, we could nevertheless predict its orientation significantly better than chance, based only on a single brief measurement of activity from their primary visual cortex. This was achieved by using multivariate pattern-recognition to substantially improve the ability to detect orientation signals in V1 (see also Kamitani & Tong, VSS 2004). Thus, activity in primary visual cortex conveys orientation-specific information that is inaccessible to conscious report. Orientation can therefore be represented unconsciously in V1, suggesting that information must be relayed to another region of the brain to be represented in conscious experience.

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223 Brain Correlates of Conscious Perceptions

Philippe G Schyngs (p.schyngs@psy.gla.ac.uk)¹, Marie L Smith¹, Frederic Gosselin²; ¹University of Glasgow, Scotland., ²University of Montreal, Canada.

A fundamental problem in vision is to understand which visual information correlates with the perception of a stimulus and how the brain extracts and aggregates this information to arrive at a conscious perception. We examined this problem in a case study involving the perceptual reversal of an ambiguous image (here, Dali's painting the Slave Market with the Disappearing Bust of Voltaire). We applied Bubbles in 3D space (2D image space x 5 spatial scales) to five observers disambiguated the image. We determined the visual information correlated with each perception from the observers' responses ('nuns' vs. 'Voltaire' vs. 'don't know'). Simultaneously, we recorded the observers' EEG at 1024 Hz with a 64 electro-cap and determined the visual information correlated with modulations of amplitude in the theta, alpha, beta and gamma bandwidths of oscillatory

EEG activity.

Brain correlates of conscious perceptions are likely to integrate the scale information that determines the 'the nuns' vs. 'Voltaire' behavioral responses. To find the time points of highest scale integration, we first derived the sensitivity of oscillatory brain activity to the scale information associated with behavioral responses, independently for each EEG band. We computed these sensitivity curves from -200 to +800 ms around stimulus onset, in 2 ms independent time steps. The sensitivity curves (one for each spatial scale considered) effectively project EEG activity into the space of the scale information associated with perception. To find the time points of highest information integration, we computed phase-locking factors between all possible pairs of sensitivity curves and averaged them.

With this new approach, we were able to isolate the time points at which brain signals are mostly correlated with an integration of the spatial scale information underlying the perception of each observer. This suggests a new approach to find the brain correlates of conscious subjective perceptions.

224 Learning to ignore: Practice can increase disappearance in motion induced blindness

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In Motion-induced-blindness (MIB; Bonneh et. al., Nature 2001), a salient static or slowly moving pattern (target) may disappear and reappear spontaneously in the presence of a global moving pattern (mask). The effect which varies in magnitude across the visual field, involves, at least in part, high level processing as disappearance depends on Gestalt properties of the target, on the 3D relations of target and mask, and on some residual processing of the invisible patterns (adaptation, grouping). Here we report that practice across several weeks may show gradual increase of the amount of disappearance. Six naïve observers reported the disappearance of a single target in an optimal position at 2.5 deg. of eccentricity, which was embedded in a dynamic mask of two types: the standard rotating dot sphere and a new mask constructed from an inner small sphere and a larger rotating dot ring around fixation that surrounded the target from the outside. During the course of 12 sessions along 3 weeks, four of the observers reported progressively more disappearance, reaching a two-fold increase in the accumulated duration of invisibility (up to 80% invisibility). The increase of disappearance was mainly expressed as lengthening of the invisibility periods and shortening of the visibility periods rather than changing the rate of disappearance events. The effect was partially specific to the position of the target (quadrant, eccentricity) as well as to the type of mask. We interpret the results in terms of "learning to ignore" in which the system learns to adapt and ignore more rapidly and for longer durations a trained stimulus in a trained context as part of a novelty-seeking process. The lengthening of the invisibility periods indicates altered processing of the invisible target, and/or enhanced processing of the visible mask, possi-

bly by learning to better objectify it in a competitive process that occurs in the absence of a coherent stimulus interpretation.

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225 Neural correlates of conscious visibility found in ipsilateral retinotopic cortex

Po-Jang Hsieh (*peter.u.tse@dartmouth.edu*), Gideon P Caplovitz, Peter U Tse; Dartmouth College

Perceptual fading occurs when an object, though present in the world and casting light upon the retina, vanishes from visual consciousness. Perceptual fading may be caused by bottom-up local adaptation mechanisms that attenuate the edge signal sent to cortex by retinal ganglion cells under conditions of visual fixation. In addition, there may be a cortical component underlying perceptual fading because a "filling in" mechanism replaces the missing object information with that of the background. The event-related functional magnetic resonance imaging (fMRI; $n=15$) data reported here reveal that the BOLD signal in ventral retinotopic areas (V1, V2V, VP, and V4V, but not LGN, V2D, V3, V3A, or MT) decreases when an object subjectively disappears, and increases when the object reappears. Surprisingly, this effect occurs whether the stimulus is presented contralaterally or ipsilaterally. This modulation occurs on top of a negative BOLD response in V1/V2, suggesting modulation of an inhibitory signal that suppresses neural activity in ipsilateral and contralateral retinotopic areas. We conclude that there must be cortical signals involved in perceptual fading for three reasons: (1) Negative BOLD responses observed in the ipsilateral LGN must be due to a feedback signaling mechanism sent from the cortex; (2) Though there is a general decrease in BOLD signal response in the LGN, it does not modulate with perceptual state. Therefore, the neural correlates of perceptual fading presumably occur after the LGN, whether in V1 or elsewhere in cortex; (3) Since the object that fades does not project signal directly from the retina to ipsilateral V1, the ipsilateral effect implies that ipsilateral V1 is receiving feedback from either contralateral V1 or other cortical areas.

226 Visual Motion Shifts Perceived Position Without Awareness of the Motion

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A number of striking illusions show that visual motion influences perceived position. While most of these demonstrations have used luminance defined motion, presumably detected by passive motion processing units, more recent demonstrations have shown that it may not be the physical or retinal motion that matters: the perception or awareness of motion may actually determine perceived position (Shim & Cavanagh, 2004; Watanabe, et al., 2002, 2003). In fact, all motion-induced position shifts may be a product of higher level mechanisms like inferred motion or attentive tracking processes that require an awareness of motion. To test whether an awareness of motion is necessary to shift the perceived positions of stationary objects, subjects adapted to a moving pattern in a crowded scene filled with other moving patterns; because of the crowding, subjects could not identify the direction of motion in the adaptation pattern. Following adaptation, when a single static test stimulus was presented within the adapted location, subjects perceived the test stimulus to be shifted in position. Even when the test stimulus did not display a motion aftereffect, it still appeared shifted in position due to the previous motion that subjects were not aware of. The results suggest that awareness of motion is not necessary to shift the positions of stationary objects, and that there must be a contribution of passive, bottom-up motion detection mechanisms to perceived position.

Spatial Vision

1:30 - 3:00 pm

Hyatt South Hall

Moderator: Lynn Olzak

227 Surround Masking Comes After Cross-orientation Masking, and is Only Found in the Periphery

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Physiological measurements show two types of V1 suppression: cross-orientation and surround. Oddly, few psychophysical studies of contrast masking show any evidence of surround suppression. We measured how contrast thresholds for a Gabor target were modulated by the two types of suppression. Our results show that both types of suppression strongly elevate the detection thresholds, but have very distinct properties. For masks superimposed and coextensive with the target (overlay masking) suppression is largely independent of mask orientation and spatial frequency. But, for annular surrounds (surround masking) the suppression is sharply tuned for the same orientation (20 deg. bandwidth) and spatial frequency (1.5 octave bandwidth) as the test. We also show that, while overlay masking originates from within the target area, surround suppression originates from the extended annulus around it. For stimulus configurations that mimic the physiological arrangements, our contrast sensitivity measurements are completely consistent with the known physiology. By making use of the distinct tuning properties of the two types of suppression we showed that cross-orientation masking precedes surround masking. Our most surprising result is that while overlay masking is essentially the same at foveal and peripheral loci, surround masking is very strong in the periphery but nearly absent in the fovea. This explains the contradiction between physiology and psychophysics: the majority of psychophysical studies positioned their stimuli in the center of the visual field, while physiological recordings were mostly done for stimuli shown in the periphery. Our results indicate that surround suppression may have a different functionality than cross-orientation suppression, which is thought to be a contrast-normalization mechanism. Perhaps the iso-orientation suppression masks homogeneous peripheral regions, thereby selecting salient regions for further foveal scrutiny.

228 The spatial interaction zone of a shapeless noise flanker

Bosco S Tjan (*btjan@usc.edu*), Sabin Dang¹; University of Southern California

Crowding, in which flankers impede the identification of an adjacent target, represents a significant deficit in form vision in the periphery. Crowding persists even after having compensated for the lower spatial acuity in the periphery. Little consensus exists among the theories of crowding. Palomares et al. (ARVO99) showed that while white noise was an effective masker when superimposed on a letter target, it was ineffective as a spatially separated flanker, challenging any contrast-masking theory for crowding. We (He & Tjan, VSS04) found evidence that "pink" noise, obtained by phase-scrambling a letter, was an effective flanker, which defies theories that rely on similarities between high-level features and imprecision in spatial attention. The purpose of the current study is to determine if pink letter noise are as effective as letter flankers by measuring the threshold contrast vs. spatial separation (TvS) function. Threshold contrast for identifying a letter target at 5-deg inferior visual field, of size 2.5 times the S_s' acuity, was measured as a function of spatial separation between the target and flankers. The flankers (at 20% rms contrast) were white noise, pink noise, or letters. The TvS functions for letter flankers and pink noise were virtually identical, both showed a threshold elevation of 0.6 log units (factor of 4) at a separation of 0.8 x-height which declined rapidly with a log-log slope of -1.4 to 0.05 log units at a separation of 2 x-height. In contrast, white noise elevated threshold by only 0.3 log units at a

separation of 0.8 x-height, and its TvS function declined gradually with a log-log slope of -0.63. In a separate experiment, we showed that when white noise or pink noise was superimposed on a letter target, they led to the same threshold elevation. Our results show that a minimum requirement for an effective flanker is that it has a similar spatial-frequency distribution as the target but need not share any high-level features.

229 Modeling Neural Tuning to Border Ownership of Figures through Intracortical Interactions in V2

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A border between two image regions is normally owned by only one of the regions; determining which one is essential for surface perception and figure-ground segmentation. Border ownership (BOWN) is signalled by some V2 neurons, even though its value depends on information coming from well outside their classical receptive fields (Zhou, Friedman, von der Heydt, J. Neurosci. 20(17):6594-411, 2000). Tuning to BOWN is significantly weaker or even absent in V1, so the tuning in V2 cannot be relayed from V1. Thus the key question arises whether the context-dependent neural tuning to BOWN in V2 is generated by mechanisms within this area, by top-down feedback from higher visual areas, or by a combination of both top-down and local mechanisms. I use a model of V2 to show that this visual area can plausibly generate the ownership signal by itself, without requiring top-down mechanisms or external explicit labels for figures, T junctions or corners. In the model, neurons have spatially local classical receptive fields, are tuned to orientation, and only receive information (from V1) about the location and orientation of borders. Tuning to BOWN arises in the model through finite-range, intra-cortical interactions. The model can account for the physiological observations in Zhou et al 2000 and Qiu and von der Heydt, VSS abstract 115, 2003, including the effect of occlusion, transparency and figures of different sizes, shapes and neighborhood relationships. The model also makes testable predictions, the matches to which can be used to constrain the model parameters further. The model can be extended to include the effects of additional image cues, such as surface luminance and depth, or top down attention, whose influence on BOWN have been observed psychophysically.

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230 Classification Images For Second-Order Patterns Velitchko Manahilov (oma@gcal.ac.uk)¹, William A Simpson², Julie Calvert¹; ¹Department of Vision Sciences, Glasgow Caledonian University, Cowcaddens Road, Glasgow G4 0BA, UK, ²Simulation & Modelling Section, DRDC Toronto, 1133 Sheppard Avenue West, Toronto, Ontario, Canada M3M 3B9

Vision is sensitive to first-order luminance patterns and second-order modulations of carrier contrast. The response classification technique has shown that the observers' template for detecting first-order patterns resembles the waveform of the luminance modulations. We sought to determine the relevant stimulus features used by human observers to detect contrast modulations. Two types of carrier were used: a 10-c/deg sinusoidal grating and one-dimensional static binary noise. The carrier contrast was modulated by a sinusoidal signal of 2 c/deg. The stimuli were embedded in one dimensional Gaussian static noise. The observers detected the second-order patterns in 2 alternative forced choice experiments.

We found that the classification images for contrast modulations of a sinusoidal carrier resembled the side-band component of the contrast modulations (the product of the carrier and the modulation signal). The classification images for contrast modulations of binary noise contained a component at the modulation frequency. These findings correspond to two models for detecting contrast modulations. The first one consists of a matching device whose template is a copy of the difference between the stimuli presented in both stimulation fields, which is the side-band component of the contrast modulations. The second model is based on the idea that second-order patterns are detected by a distinct second-order path-

way consisting of a non-linearity followed by a matching device which extracts the modulation signal.

The results suggest that the observers may use different strategies to detect second-order patterns depending on the nature of the carrier. When the carrier is a sinusoidal grating, the template is the side-band component of the contrast modulations which could be implemented by a combination of luminance channels. When the carrier is binary noise, observers seem to use a non-linear second-order pathway whose template is a copy of the modulation signal.

231 Maximum differentiation competition: A methodology for comparing quantitative models of perceptual discriminability

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Given two quantitative models for the perceptual discriminability of stimuli that differ in some attribute, how can we determine which model is better? A direct method is to compare the model predictions with subjective evaluations over a large number of pre-selected examples from the stimulus space, choosing the model that best accounts for the subjective data. Not only is this a time-consuming and expensive endeavor, but for stimulus spaces of very high dimensionality (e.g., the pixels of visual images), it is impossible to make enough measurements to adequately cover the space (a problem commonly known as the "curse of dimensionality").

Here we describe a methodology, Maximum Differentiation Competition, for efficient comparison of two such models. Instead of being pre-selected, the stimuli are synthesized to optimally distinguish the models. We first synthesize a pair of stimuli that maximize/minimize one model while holding the other fixed. We then repeat this procedure, but with the roles of the two models reversed. Subjective testing on pairs of such synthesized stimuli provides a strong indication of the relative strengths and weaknesses of the two models. Specifically, if a pair of stimuli with one model fixed but the other maximized/minimized are very different in terms of subjective discriminability, then the first (fixed) model must be failing to capture some important aspect of discriminability that is captured by the second model. Careful study of the stimuli may, in turn, suggest potential ways to improve a model or to combine aspects of multiple models.

To demonstrate the idea, we apply the methodology to several perceptual image quality measures. A constrained gradient ascent/descent algorithm is used to search for the optimal stimuli in the space of all images. We also demonstrate how these synthesized stimuli lead us to improve an existing model: the structural similarity index [Wang, Bovik, Sheikh, Simoncelli, IEEE Trans Im Proc 13(4), 2004].

232 Dynamics of centre-surround interactions in orientation perception

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Contextual effects abound in vision. For example, a vertical grating appears rotated away from a surrounding grating that is oriented at 15° to the vertical: the tilt illusion (TI). The orientation-selective nature of the TI is consistent with mediation by interactions within visual cortex. Here, we investigate the dynamics of these interactions by presenting centre and surround asynchronously. The test stimulus is a 1cpd sinusoidal grating presented in a 3° diameter circular aperture. The surround is a grating of the same spatial frequency oriented at ±15° to the vertical and presented in an annulus with an external diameter of 15°. Centre and surround are each presented in Gaussian temporal windows of 20ms full-width at half-height. Subjects report whether the central grating appears tilted clockwise or anti-clockwise from vertical. Subjective vertical is measured for ±15° surrounds using interleaved adaptive staircases. The magnitude of the TI is taken as half the difference between subjective vertical for the two surround orientations. We vary the contrast of these gratings, the size of the

spatial gap between them, and their relative timing. At equal contrast with no spatial gap, the largest effect typically occurs when centre and surround are presented simultaneously. Varying stimulus contrast affects the asynchrony at which the maximum TI occurs, so that in general presenting the surround earlier produces the largest effect. Introducing a spatial gap between centre and surround tends to reduce the TI magnitude without a clear modulation in temporal properties. These results demonstrate that manipulating the spatial properties of the stimulus can change not only the size of the TI but also its temporal tuning. We argue that manipulations of this kind may prove valuable in disambiguating the role of lateral interactions and intra-cortical feedback in contextual modulation.

Attentional Mechanisms

3:15 - 5:00 pm

Hyatt North Hall

Moderator: John Palmer

233 Temporal dynamics of covert attention

Marisa Carrasco (amg223@nyu.edu)^{1,2}, Anna Marie Giordano¹, Brian McElree¹; ¹New York University - Department of Psychology, ²New York University - Center for Neural Science

Background: Covert attention increases discriminability and accelerates the rate of visual information processing (Carrasco & McElree, 2001). In addition, covert attention eliminates the temporal processing asymmetries that exist along the meridians of the visual field (i.e., temporal performance fields: information accrues faster in the horizontal than vertical meridian and in the North than South locations; Carrasco et al., 2004). Here we examined whether the effect of attention on information accrual varies with eccentricity (48 vs. 98) and with search type (feature vs. conjunction). Methods: We collected time-course functions for orientation discrimination with the response-signal speed-accuracy trade-off (SAT) procedure. Each trial began with a cue (67 ms), peripheral (a circle adjacent to target location) or neutral (a circle at fixation). After a 53 ms ISI, a 2-cpd target Gabor patch (tilted either to the right or left) and 0 or 7 distracters appeared for 40 ms at 8 equidistant locations from fixation at 48 or 98 eccentricity. In the feature task, all distracters were vertical 2-cpd gratings. In the conjunction task, some distracters shared the orientation of the target and others shared its spatial frequency: the 2-cpd distracters were vertical patches; half the 8-cpd distracters were tilted to the left, and half to the right. To measure discriminability and information accrual conjointly from chance to asymptote, a tone sounded at 1 of 7 SOAs, ranging from 40 to 2000 ms, prompting observers to respond.

Results: For all observers, information processing was faster at 98 than 48, consistent with our previous findings. Covert attention increased discriminability and accelerated information accrual similarly for near and far eccentricities and for both feature and conjunction searches. In contrast to the compensatory effect of covert attention on temporal performance fields, covert attention did not eliminate speed differences across eccentricity.

234 The neural hemodynamics of a speed-accuracy tradeoff in decision making

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Under conditions in which response speed is stressed, response accuracy often suffers. Using a motion coherence task and functional magnetic resonance imaging (fMRI) chronometry, we sought to identify neural regions that are differentially sensitive to the mental set for speed versus accuracy. Regions of interest (ROIs) involved in the detection of motion coherence were first identified in a localizer run by comparing high coherence dis-

plays with static displays. The other fMRI runs stressed either speed (SPD) or accuracy (ACC) of the task in separate blocks of event-related trials ('mixed-trial' design). We used an experimental manipulation that allowed reaction time differences between ACC and SPD conditions to be resolved with fMRI: for each 20s-long trial, the proportion of dots with coherent motion was either nil (0% coherence) throughout the trial, started at 0% and increased 3% every 2s, or remained constant at a low coherence (< 10%). The behavioral data revealed the expected speed-accuracy tradeoff: the ability to detect and identify the direction of motion coherence (leftward vs rightward) was better under ACC instructions and, conversely, reaction times were shorter under SPD conditions. Time course analyses revealed that the temporal dynamics of the peak BOLD signal corresponded with reaction time differences between SPD and ACC conditions in a large network of sensory, motor and premotor regions. Furthermore, the mental set for speed versus accuracy had a more dramatic impact on frontal/prefrontal cortex activity than in sensory/perceptual cortex (MT+ and extra-striate cortex). These results suggest that the establishment of a mental set for speed versus accuracy is not equally implemented across the neural network mediating the detection and identification of motion coherence.

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235 Attention-based long-lasting sensitization and suppression of colors

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In contrast to the short-duration and quick reversibility of attention, a long-term sensitization to color based on attention in a visual search task was reported by Tseng et al. (Nature, 2004). When subjects are trained for a few days to search for a red object among colored distracters, sensitivity to red is altered for weeks. This sensitization is quantified using ambiguous motion displays containing isoluminant red-green and texture-contrast gratings, in which the perceived motion direction depends both on the attended color and on the relative red-green saturation. Thus, sensitization can be measured by the additional color saturation required to balance the motion sequence.

Such long-term effects could result from either sensitization of the attended color, or suppression of unattended colors, or a combination of the two. Here we tried to unconfound these effects by eliminating one of the paired colors of the motion display from the search task. The other paired color in the motion display can then be either a target or distracter in the search task. Thereby, we can separately measure the effect of attention on sensitizing the target color or suppressing distracter colors.

The results in the motion test indicated both effects, sensitization of the target color in the search task and suppression of the distracter colors: i) When red was the attended color and blue was the distracter color, salience to red increased at the expense of green for 4/5 subjects. ii) When blue was the target color and red was the distracter color, suppression of red in favor of green occurred in 3/4 observers. The magnitudes of sensitization and suppression were positively correlated with search performance. Conclusion: Selective attention to a color in visual search causes long-term sensitization to the attended color and long-term suppression of the unattended color. Our findings imply that the facilitatory and inhibitory effects of attention might be mediated separately.

236 Effect of prior probability on choice and response time in a motion discrimination task

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A decision is a commitment to a proposition or action based on a combination of evidence, prior knowledge and the anticipated costs and benefits. Even simple psychophysical tasks draw on these elements when an observer chooses between two alternatives. Here, we address how sensory evidence is combined with prior knowledge of the probability of the alternatives. Human and nonhuman primates discriminated the direction of dynamic random dot motion. We manipulated both stimulus strength and prior probability that the motion was to the left or right. Observers viewed displays consisting of a pair of peripheral choice targets and a central patch of dynamic random dots. A fraction of the dots chosen at random moved coherently to the left or right. The task was to indicate the net direction of motion by making an eye movement to the left or right target. Motion strength was manipulated by varying the motion coherence and bias was manipulated by varying the probability of a particular direction of motion within a block of trials. We found that the effect of prior probability is equivalent to the effect of motion strength: changing the odds of rightward motion from 1:1 to 4:1 induced a change in both choice and response time equivalent to adding about 5% coherence to the right. This result is inconsistent with the traditional view that prior probability affects decisions by altering the decision criterion. In the framework of sequential sampling (e.g., random walk) models, a change in criterion predicts a pattern of choice and response time that was not seen in our experiments. Our findings are consistent with sequential sampling, but instead of affecting the decision criterion, prior probability affects the representation of the sensory information. This sensory effect resembles feature-based attention. Although the result seems to contradict a tenet of Bayesian decision making, we show that it may be a sensible strategy under some conditions.

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237 Temporal kernels of motion perception are sharpened by training and attention

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The perceptual and physiological consequences of visual attention and training have primarily been studied using tasks which are spatially, but not temporally, demanding. To investigate the effects of attention and training on temporal integration, we used a temporally demanding motion detection task. Two monkeys were trained to detect a brief pulse of motion (67-117 ms) inserted into one of two peripherally located arrays of randomly moving Gabors. Attention was investigated by shifting the probability of pulse occurrence over the course of a trial between the two arrays and had clear behavioral effects: performance and reaction times improved when the motion pulse occurred at a likely time and place. To investigate the mechanisms underlying this effect, perceptual spatiotemporal kernels were constructed by averaging the random motion preceding false alarms. By comparing kernels constructed according to a global motion metric with those constructed according to a local motion metric, we determined that the animals were spatially integrating over the entire array. Consistent with this conclusion, reaction times closely corresponded to the latency of the global motion kernel. To evaluate the effect of attention, we then compared temporal kernels associated with false alarms made during a high probability epoch with kernels constructed from low probability epochs. As expected, attention increased the sensitivity of motion perception. However, the effect of attention was not a simple gain change: attention sharpened the temporal kernel so that it was better matched to the duration of the motion pulse. Furthermore, we found that

this attentional effect increased with training as the subjects were able to detect briefer motion pulses. These results contrast with a classification image study showing attention increasing spatial sensitivity but not selectivity (Eckstein et al, 2002) and suggest that attention can have distinct effects on spatial and temporal integration.

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238 Attention-dependent discrete sampling of motion perception.

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Temporal subsampling of the perceptual stream can cause illusory reversals of the perceived motion direction. This 'Wagon Wheel Illusion', most apparent in movies or on television, can also be observed under continuous illumination, suggesting that our visual systems too might sample motion in a sequence of discrete epochs (Purves et al, Proc. Nat. Acad. Sci. USA, 1996). This phenomenon is bistable by nature, with the actual motion direction generally dominating perception (Kline et al. Vis. Res, 2004). Previously we reported that a motion energy model subsampling visual inputs at a rate between 10 and 20 Hz can quantitatively predict the relative durations of real and illusory percepts during continuous viewing of the illusion (VanRullen et al, Society for Neuroscience, 2004). Here we used pairs of gratings drifting in opposite directions to investigate this effect. By way of these 'counterphase' gratings of slightly different contrasts, one can directly manipulate the ambiguity of motion direction, and enhance the relative strength of the illusory percept. We found that motion direction judgments for these stimuli were selectively impaired around 10 Hz, as predicted by the temporally subsampled motion energy model. Interestingly, this impairment vanished when focal attention was directed away from the motion stimulus. We used a dual-task paradigm to draw spatial attention to a stream of rapidly presented randomly rotated letters at the center of the grating. Under these conditions, simultaneous motion direction judgments were in fact better at 10 Hz than when attention was directed to the motion itself. This is one of very few known instances where focal attention is found to impair performance. These results support the idea that, at least in some circumstances, the visual system represents motion in discrete epochs, and that this effect is mediated by focal attention.

239 Single neuron correlates of change blindness in the human medial temporal lobe

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Observers are often unaware of changes made to the visual environment when attention is not focused at the location of the change. This phenomenon, known as change blindness, has been extensively studied using psychophysics and fMRI. Yet its correlates at the single cell level remain unclear. We recorded from the medial temporal lobe (MTL) of patients with pharmacologically intractable epilepsy, implanted with depth electrodes and microwires, to localize the focus of seizure onsets. Subjects were shown one set of 4 simultaneously presented images twice, each time for 1s, with a brief blank interval of 1.5s between the 2 presentations. On half the trials, a change occurred at one of the four locations, and subjects had to report whether they detected the change or not. In separate "screening" sessions, specific images that cells were visually responsive to ("preferred stimuli") were determined. We investigated neuronal responses when the set of preferred stimuli were used as changing elements. We have currently recorded from 29 visually responsive cells in 10 patients using this paradigm. Over these cells, the preferred stimuli elicited significantly higher firing rates on correct trials (e.g. change detection) compared

to incorrect (e.g. change blindness) trials. For each cell, we were able to predict on a trial-by-trial basis (using an ROC analysis) whether or not a change occurred 65% of the time on average. Thus, the firing rates of certain MTL cells constitute a neural correlate of change detection and change blindness.

Lightness and Surfaces

3:15 - 5:00 pm

Hyatt South Hall

Moderator: Branka Spehar

240 Lightness computation in the simplest images

Alan L Gilchrist (alan@psychology.rutgers.edu), Ana Radonjic; Rutgers University - Newark

The simplest image consists of two different gray surfaces that fill the entire visual field. Perceived lightness is determined by both photometric and geometric factors. As for photometric relations, Li and Gilchrist (1999) found that the region with the highest luminance appears white. As for the geometric factor, the larger a region, the whiter it appears. We mapped the exact function of this effect. Nine opaque acrylic hemispheres (diam = 74 cm) were created. Each was divided into two radial sectors of dark and light gray (dark sector: 11°, 22.5°, 45°, 90°, 180°, 270°, 305°, 327°, 355°; reflectances: light: 36%, dark: 7.7%, luminance ratio 4.7:1). Each hemisphere was viewed by a separate group of 20 observers. Results: the lighter region always appeared white, while the lightness of the darker region moved from middle gray to very light gray as its area moved from 11 degrees to 355 degrees, but most of this change occurred when the darker region was more than half the total area. These results can be understood in terms of the photometric/geometric conflict. When the darker area is less than half, the lighter region has both the highest luminance and the largest area. Thus it makes a stable anchor and area plays little role. But as the darker region grows larger a conflict emerges. Each region now has a claim on white; one as the highest luminance and the other as the largest area. In addition to this area-lightness effect, three other phenomena occur in this zone that, while unusual, are also consistent with the conflict: range compression, brightness indentation and perceived luminosity. The area function that we found is the same as that reported in 9 other studies using complex images, except for a weaker in the latter case, consistent with the Kardos principle of co-determination.

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241 Does Target Lightness Depend on Background Luminance or Background Lightness?

Ana Radonjic (ana@psychology.rutgers.edu)¹, Alan L Gilchrist¹, Vilayanur S Ramachandran²; ¹Rutgers University - Newark, ²University of California - San Diego

When two targets of equal luminance are seen against adjacent dark and light backgrounds, as in simultaneous contrast displays, does their lightness depend on the physical luminance of the two backgrounds, or on background lightness? We tested this question using the well-known Mach folded-card illusion. A folded gray card was placed in the convex (roof) position on a large sheet of glass and illuminated from one side, producing luminances of 3.2 and 0.5 ftL. For one group of observers who saw the card in the roof (convex) position, the two sides appeared differently illuminated but roughly the same in lightness. By the use of an artificial shadow cast onto a white surface located below the glass sheet and illusory linear perspective cut into the card, we caused a second group of observers to see the card in the book (concave) position and the two sides appeared as black and white. Equi-luminant target squares were added to each face of the folded card by cutting an aperture in the center of each face. Although from the observer viewpoint the apertures actually

revealed sections of a common distant surface, they appeared as opaque chips lying on the two faces. These were matched for lightness using a Munsell chart. If background lightness were crucial, we would expect a larger contrast effect in the book condition. If background luminance were crucial then we would expect no difference between our conditions. In fact neither of these outcomes occurred. In the convex condition the targets appeared as Munsell 2.7 and 6.7, while in the concave condition they appeared as Munsell 5.7 and 5.9. In a separate study, observers voluntarily reversed the Mach card, matching the targets in each perceived orientation. The results were qualitatively the same, but with a reduced difference between conditions. Thus, target lightness depends, not on background lightness or background luminance, but on background illumination level.

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242 Assimilation and Contrast in Complex Configurations

Branka Spehar (b.spehar@unsw.edu.au)¹, Monica Iglesias¹, Colin WG Clifford²; ¹School of Psychology, The University of New South Wales, Sydney, Australia, ²School of Psychology, The University of Sydney, Sydney, Australia

Lightness induction is the shift in surface appearance caused by adjacent or nearby surfaces. The spatial arrangement of the surround can make the appearance of the surface more different from (contrast) or more similar to (assimilation) the surround. Although most research on lightness induction has focused on contrast effects, it is effects of assimilation that have generally proven more challenging for theories of lightness perception. Although assimilation effects tend to occur with more complex contexts, often containing repetitive patterns, we are still generally unable to ascertain the particular conditions that determine whether assimilation or contrast effects will occur. The present study is motivated by our earlier findings with White's effect, where assimilation seems to be restricted to specific luminance conditions (Spehar, Gilchrist & Arend, 1995; Spehar, Clifford, & Agostini, 2002). A matching procedure and a forced-choice judgment procedure were used to investigate the influence that the luminance relationships between target and inducing surfaces had in four different configurations: checkerboard, bullseye, White's effect and Todorovic's effect. The results demonstrate that under classical luminance conditions, when target luminance is intermediate in luminance to the different inducing regions, all four configurations produce assimilative effects. However, when target luminance is either higher than or lower than that of all the inducing regions, the direction of the illusion reverses and all four configurations show contrast effects. These results provide strong evidence for the importance of qualitative luminance relations in the emergence of assimilation and contrast effects in lightness induction.

Spehar B, Clifford CWG, & Agostini T (2002). *Perception*, 31, 189-196.

Spehar B, Gilchrist A, & Arend L (1995). *Vision Research*, 35, 2603-2614.

243 Temporal properties of brightness induction

Mark E. McCourt (mark.mccourt@ndsu.nodak.edu), Barbara Blakeslee, Wren Pasiaka; Center for Visual Neuroscience, North Dakota State University, Fargo, ND

The brightness of a target depends on its surround, which exerts influence through lateral interactions mediated by interneurons: A time lag is introduced between the registration of the surround and its effect on target brightness. DeValois et al. (1986, *Vision Research*, 26, 887-897) used a matching technique and found that induced brightness modulations existed only at temporal frequencies below 2.5 Hz. Paradiso & Nakayama (1991, *Vision Research*, 31, 1221-1236) and Rossi & Paradiso (1996, *Vision Research*, 36, 1391-1398) suggested that brightness percepts are determined by a 'fill-in' process whose signals propagate at 110-150°/sec (6.7-9.2 ms/degree). We sinusoidally counterphased the inducing grating of a grating induction display (McCourt, 1982, *Vision Research*, 22, 119-134) to create a counterphasing induced grating within the test field. Adding a second (luminance) counterphasing grating in temporal and spatial quadrature phase to the induced grating transforms the brightness modu-

lation into a traveling wave (motion). Varying the temporal phase of the added luminance grating permits a precise estimate of the temporal phase lag of induction. Results indicate that induction lag is remarkably short, on the order of a few milliseconds, and does not vary with inducing field height in a manner that suggests the operation of a fill-in process.

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244 Deformation of perceived shape with multiple illumination sources

Michael J Tarr (*Michael_Tarr@brown.edu*), Massimiliano Di Luca¹, Wendy D Zosh¹; *Department of Cognitive and Linguistic Sciences, Brown University*

The human visual system can easily interpret patterns of shading and attribute them to 3D surfaces. However, perceived shape is rarely veridical. Here we introduce a new effect in which extreme deformations of shape are perceived relative to ground truth. Specifically, convex, specular surfaces illuminated by multiple point-light sources are interpreted in a manner more consistent with one light source illuminating a quite different shape. We hypothesize that the visual system is not able to correctly derive the shape of objects under multiple illuminations due to an overriding single light-source assumption. However, this assumption can be disregarded if there is sufficient evidence against it. For example, other cues to shape such as shadows or stereo disparity may provide information sufficient to support more accurate shape perception, regardless of inferences based on this assumption (although this does not mean that observers now interpret the image as arising from multiple light sources). On the other hand, even the presence of boundary contours may not be sufficient for a 'correct' interpretation of the image. Along with psychophysical evidence that observers interpret multiple light-source images as the product of a single source, we developed an image-matching method that produces an image of a shape plus single illuminant that is nearly indistinguishable from the original image with multiple light sources. This method is based on local adjustments of slant in order to minimize the difference between the new image and the target. This method effectively predicts the perceived shape of multiply illuminated convex surfaces. In summary, observers appear to apply relatively simple assumptions in how they derive shape percepts from shading. Moreover, it is possible to capture these assumptions in an image-matching model that accurately predicts observer performance. Thus, our ability to derive accurate models of lighting in a scene may be severely restricted.

245 Voluntary attention modulates the brightness of overlapping transparent surfaces

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A striking new class of brightness illusions (Tse, VR, 2004) is introduced that cannot be entirely accounted for by bottom-up models. In these illusions, brightness can be modulated by voluntary attention in the absence of eye movements. For example, imagine three partially overlapping gray transparent disks on a white background. Fixating any point and attending to just one disk causes it to darken. These effects may arise from top-down or mid-level mechanisms that determine how 3D surfaces and transparent layers are constructed, which in turn influence perceived brightness.

Attention is not the only factor that influences perceived brightness here; Grouping procedures favor the minimal number of transparent layers necessary to account for the geometry of the stimulus, causing surfaces on a common layer to change brightness together. Attentional modulation of brightness places constraints on possible future models of filling-in, transparent surface formation, brightness perception, and attentional processing.

In addition to behavioral data characterizing the effect, fMRI was used to locate areas of the brain that modulate with perceived brightness change. In an event-related design, 15 subjects viewed just two disks, overlapping

at fixation. They pressed a button whenever the righthand disk darkened, and carried out a color detection task at fixation to guarantee fixation, wakefulness, and attentiveness. The BOLD signal was measured using a 1.5T GE scanner. Voxel volume was 3.75x3.75x5mm in 16 horizontal slices collected using single-shot T2* weighted gradient-recalled EPI sequences. Retinotopy was carried out in a separate session.

Neither retinotopic areas (V1, V2d/v, V3/VP, V4v, V3A) nor MT or LGN were found to modulate with perceived darkening. However, a whole brain GLM random effects analysis revealed temporal and parietal areas that modulated with perceived brightness changes. These areas could trigger the percept or serve as the neuronal correlate of this percept.

246 An fMRI Investigation of the Perception of Form, Texture, and Colour in Human Occipito-Temporal Cortical Pathways

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In a previous neuroimaging study (Cant et al., VSS 04), we showed that the processing of object form selectively engages the lateral occipital area (LO), whereas the processing of surface properties selectively engages the inferior occipital gyrus (IOG) and the collateral sulcus (CoS). It was not clear, however, whether the pattern of activation associated with attending to the surface properties of objects was related to the processing of colour, the processing of visual texture, or a weighted combination of the two. To explore this question, we carried out an additional neuroimaging study in which participants performed same/different judgements in separate blocks of trials on pairs of unfamiliar 'nonsense' objects that shared the same form, colour, or texture. Again we showed that attention to object form was associated with specific activation in area LO, whereas attention to surface properties was associated with specific activation in areas IOG and CoS. Additional surface-property selective regions were also identified, including the inferior temporal sulcus, the lingual sulcus, and the fusiform gyrus. In all the surface-property selective regions, however, the activation associated with surface texture was significantly higher than the activation associated with either colour or form. In fact, the only regions where the activation associated with colour was higher than the activation associated with texture were primary visual cortex and neighbouring regions in the cuneus. Taken together, the results show that the processing of object form and the processing of surface properties engage anatomically distinct regions in the occipito-temporal cortex. With respect to surface properties, it appears that the visual system can extract the colour of objects relatively early in visual processing whereas information about texture, perhaps because it is more complex, requires the participation of higher-order visual areas.

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Poster Session C

May 7, 2005 – Saturday PM

Adaptation (247-251), Binocular Stereopsis (252-264), Color Vision 1 (265-283, Visual Disorders and Blindsight (284-303), Locomotion, Steering and Posture (304-324), Motion in Depth 1 (325-339), Perceptual Organization 1 (340-354), Hand Movements 2 (355-365)

2:00 - 7:00 pm (Authors present 5:30 - 7:00 pm)

Municipal Auditorium

SATURDAY PM

Adaptation

247 Adaptation to blur: normalization or repulsion?

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Adapting to a blurred or sharpened image alters the perceived blur of a focused image, shifting the subjective best-focus toward the level of the adaptation (Webster et al. *Nature Neuro.* 2002). This aftereffect could reflect repulsion in the appearance of stimuli away from the adapt level (similar to spatial frequency adaptation) or normalization in the appearance of the adapt stimulus so that it appears better focused (similar to chromatic adaptation). The two alternatives differ in whether or not the response to focused stimuli is special, and thus in the functional implications of blur adaptation. We used matching between pairs of images to examine the form of the perceptual change. Stimuli were 4-deg noise images with amplitude spectra filtered over log-log slopes from -2 (strongly blurred) to 0 (white noise). Subjects adapted for 120 s to a sequence of blurred or sharpened images to the left of fixation, along with 'focused' noise (slope = -1) on the right, and then used a 2AFC task to match the slope of intermittent test images. Normalization in the perceived focus of the adapting images was confirmed with a blur-difference task, in which an adapt pair (shown above fixation) was compared to the same unadapted image pair shown below. The 1/f images remained similar while the lower blurred (or sharpened) image had to be sharpened (or blurred) to match the adapted pair. Changes across different test blur levels were probed for images with slopes ranging from -1.75 to -.25. Adapting to a blurred (-1.5) or sharpened (-0.5) sequence produced similar shifts at test levels near the adaptation, but these diminished and in some cases changed sign for tests far removed from the adapt. These effects are inconsistent with a simple normalization and could reflect repulsions relative to each adapt level. Thus both forms of perceptual change may occur. The partial renormalization suggests that under some conditions the focus point does have a special status in the encoding of blur.

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248 The influence of different surface segregation cues on temporary blindness

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Motion-induced blindness (MIB) and Perceptual Filling-in (PFI) are two instances of temporary blindness in which, after prolonged viewing, perceptually salient targets repeatedly disappear and reappear, amidst a field of distractors. Hsu and Yeh (VSS2004) provided an integrated model in which the establishment of surfaces is assumed to cause both these phenomena. In this model, a target is assumed to fade when its surface is

perceived to lose its boundary due to either adaptation, or due to the presence of other surfaces that are defined by distractors. A surface representation can be established with the help of various segregation cues, and here we test whether, as the model predicts, any kind of cue can give rise to the same effect. Four different cues were used that were based on (1) motion, (2) binocular disparity, (3) perceptual grouping, or (4) occlusion. The results support our hypotheses that all kinds of surfaces produced the temporary blindness phenomenon.

249 Vision works by concatenating factors of change

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Light adaptation is regionally restricted, rapid and (at least approximately) reciprocal. We demonstrate the reciprocity by allowing two Gaussian adapting blobs of different luminance, I and J, to fade completely under several seconds of steady fixation. If the two blob intensities are then suddenly changed, by unequal increments, to kI and kJ, the blobs reappear but remain matched. The brightnesses remain the same if the factors of intensity change are the same, as expected if retinal signals specify factors of change rather than absolute intensity. Hence the brightness gains in the two regions are quite unequal, and are reciprocally related to the initial intensities I and J.

But, if the new intensities are introduced early during the fading of the blob pair, the two brightness gains turn out to be nearly equal, even though threshold sensitivities have already approached their steady-state reciprocal values.

The very different behavior in the 'faded' and 'unfaded' conditions is understandable if the subjectively perceived 'baseline' of local brightness, perceptually present before the sudden change of intensity, combines multiplicatively, not additively, with the reciprocally scaled retinal signal in the revision of our perception.

This enables perception to be nearly veridical despite reciprocal adjustments of retinal sensitivity. The brain can make appropriate use of retinal signals that specify factors of change only if it considers what the factor of change is applied to.

250 High Intensity Flash-Probe Measurements of Visual Adaptation

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Previous studies of the dynamics of light adaptation have used a probe-sine wave paradigm, where the threshold for detecting a probe flash is measured at various phases with respect to a sinusoidally modulated background. Our interest is in the temporal changes in visual adaptation that occur during exposure to a train of brief, high intensity flashes. To investigate this we have used a flash-probe paradigm, where the sinusoidally modulated background is replaced with a flashing

background. By varying the parameters (frequency, onset time, intensity, duration) of both the flash and the probe stimulus the adaptive state of the visual system has been explored. This technique has the potential for extremely elegant determination of the adaptive state of the visual system, including the investigation of temporal adaptation mechanisms to flashed stimuli.

In contrast to most other studies, the intensity of the flashing background we used was very high - up to seven log-trolands. For our initial investigations, although we have used temporal frequencies up to the threshold for fusion (around 50 Hz), most of our measurements have been at 3 Hz and 10 Hz. We have demonstrated forward and backward masking, and have observed very rapid adaptation within 50 ms of the flickering background. At these intensities and frequencies there is a shift in adaptation and the probe threshold is elevated at all phases relative to that on a steady background (of the same mean luminance). The detailed shape of the probe-threshold-versus-phase curve is being investigated, and will be used as test data for computational models of light adaptation dynamics.

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251 Simple Stimulus Metrics vs. Gestalt in High-Level Aftereffects

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High-level visual aftereffects (AEs) arise when adaptation to stimuli such as shapes, faces, or spatial configurations affect the subsequent perception of comparable figures. Like classical AEs, high-level AEs are characterized by a percept that is distorted in feature space in the opposite direction of the vector between adaptation and test stimulus. Shape-contrast AEs have been reported for aspect ratio, convexity and taper, but the combined effect of such parameters remained unexplored. In the present experiment the adapting stimulus consisted of two arcs. While keeping the flexion of the arcs constant we varied the distance between them in a range of ± 8.28 , allowing us to examine the effects of (1) aspect ratio and (2) convexity/concavity. The test stimulus was a closed ellipsoid of about 7.88 in diameter. Perceptual distortions were assessed with repetitive adaptation and testing in the context of a staircase procedure converging to the point of subjective circularity. We found significant main effects for both factors and the interaction, i.e. smaller aspect ratios lead to stronger effects and convex stimuli result in larger effects than concave ones. The direct spatial correspondence between the location of the adapting and test stimulus was not critical for inducing an AE. We repeated the experiment with a set of smaller stimuli of roughly 18 and the distance between the curves scaled down proportionately. Results in both experiments were comparable, although the interaction was not significant in experiment 2. The results suggest that simple stimulus metrics, such as the absolute size of the curves and distance between them, are less important in creating this AE than the overall shape created by the pair of arcs together.

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Binocular Stereopsis

252 Scene layout and binocular distance perception: effects of angular separation

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The ability to judge distance is critical for interacting with objects in our environment. In impoverished environments, distance perception can be radically altered by the pattern of relative binocular disparities between

objects in the scene. For example, when two points are presented simultaneously, the farther point can appear at a constant distance, and the near point as nearer than when it is alone (far anchor effect). Effects like this have been modelled in terms of the visual system estimating a 'reference distance' and the distances of all other points being calculated using that distance and the disparity between the point and the reference. The reference distance is thought to be a weighted combination of the distances of scene points. Here we explore how the reference distance varies with the angular separation between points in a scene.

Observers viewed a simple scene containing two points presented in depth. In one condition, distance to the nearer point was varied (between around 12cm and 40cm) whilst the relative disparity between points was held constant (2.25 deg). In another, one point was held at a fixed distance (25cm) whilst the other's distance was varied. We compared distance estimates using both verbal and manual (pointing) responses for different angular vertical separations.

Our observers provided a wide range of responses, some exhibiting the far anchor effect, some producing a linear relationship between verbal and manual responses. For most observers and conditions, performance was similar across vertical separations. Some observers saw distances as slightly further away when points were more separated. This suggests that the reference point weighting does not differ dramatically across a range of angular separations.

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253 Drastic differences in binocular disparity tuning of V4 cells for random dots and solid figures: quantitative analysis and mechanisms

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A random-dot stereogram (RDS) contains many identical dots that give rise to numerous false matches for binocular correspondence. Thus, the determination of stereo matching is much more difficult when viewing an RDS than when viewing a solid-figure stereogram (SFS). Psychophysically, adaptation to left-right reversing spectacles differentially affects stereoscopic depth perception for figural stereograms than RDSs (Shimojo and Nakajima, 1981). In order to characterize the cortical processing required for stereoscopic depth perception when viewing RDSs and SFSs, we studied the responses of single neurons in area V4 to dynamic RDSs and SFSs (bars) in an alert, fixating monkey. Consistent with a previous study (Hegde and Van Essen, 2004), the binocular disparity tuning obtained with RDSs and SFSs differed markedly. Quantitative analysis revealed that the modulation amplitude, the tuning sharpness, and the preferred disparity of tuning curves tested with RDSs did not correlate with those of the SFSs, and the disparity tuning was sharper for RDSs than for SFSs. A possible cause of these differences may be the positional shift of monocular images that inevitably occurs with disparity changes in SFSs, but not in RDSs. We examined whether neuronal sensitivity for the positional shift of monocular images of SFSs could explain the differences in disparity tuning. In order to compensate for the response modulation caused by the monocular features of SFSs, we subtracted the linear sum of responses to the left and right monocular images from the binocular responses at each corresponding disparity. Despite this compensation, however, the differences between tuning curves obtained with the RDSs and SFSs remained essentially unaffected. A single read-out mechanism for V4 responses to the two types of stereograms would produce significantly different stereoscopic depth judgments. Our results suggest that stereo processing for RDSs and SFSs is not based on a single mechanism.

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254 Explaining Depth Perception in Dynamic Noise with an Interocular Delay

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When dynamic visual noise is viewed with an interocular delay, it appears in depth. Near depth planes appear to stream horizontally from the undelayed to the delayed eye, while far depth planes stream in the opposite direction. This illusion is often cited as psychophysical evidence for the joint encoding of disparity and motion. In this view, the percept is supported by neurons which are sensitive to the direction of horizontal motion as well as to binocular disparity. This explanation was strengthened by the observation of neurons with the appropriate properties in cat area 17/18. However, recent studies have found that they are rather rare in monkey V1. Motivated by this, we examined whether the percept can also be explained even if disparity and motion are initially encoded separately rather than jointly. It has been argued that a similar explanation, proposed by Tyler, cannot explain several experimental phenomena. However, these failures have never been demonstrated in a fully implemented model. We constructed a population of model neurons, which were either pure motion sensors (sensitive to direction of motion but not to disparity) or pure disparity sensors (sensitive to disparity but not to direction of motion), and simulated its response to dynamic visual noise with an interocular delay. We found that the activity of motion sensors tuned to horizontal motion in the direction of the delayed eye was correlated with the activity of near disparity sensors, while the activity of sensors tuned to the opposite direction of motion was correlated with the activity of far disparity sensors. We suggest that this correlation is sufficient in itself to explain the depth percept in all the tested configurations. We conclude that the depth illusion reflects spatial disparities present in the stimulus, and so is consistent with any reasonable neuronal mechanism of stereo depth perception. It therefore does not provide specific evidence for joint motion/disparity encoding.

255 Time course of local adaptation in the Pulfrich phenomenon

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Introduction

The Pulfrich stereophenomenon is a perception of depth in moving targets resulting from time delays in one eye. We have shown previously that Pulfrich effects can result from localized changes in retinal adaptation caused by objects in the immediate surround of a target. In this study we will attempt to characterize the time course of local retinal adaptation by leading the target in one eye with a small bright spot of light.

Methods

Two counter-phased, computer generated luminous discs (50cd/m² - 10' arc) on a black background were presented to each eye in a haploscope. The discs moved in a saw tooth wave at 300' per second with a 2-degree excursion. A smaller (50cd/m² - 2' arc) luminous flank either led or followed the disc in its trajectory. By adjusting the interocular phase delay of the two discs the subject nulled any perceived depth. This difference in phase, quantified in milliseconds, corresponds to the interocular difference in signal timings. To determine the time course of adaptation we measured the Pulfrich caused by flanks at several temporal gaps relative to the bob.

Results

A leading flank in one eye produced a Pulfrich effect of 12 to 15 msec for targets that were otherwise equal in luminance. The effect occurred when the flank led the disc by 0 to 100 msec and was maximum at about 35 msec. A lagging flank had little or no effect for any time lag.

Discussion

In this experiment we were able to exploit this timing-critical judgment to characterize the time course of local retinal adaptation. As a flank traverses

the retina, it leaves a wake of local adaptation in its path. As the disc passes through this region of adaptation its transmission time is shortened, causing depth with motion. When the position of a disc corresponds to the peak of the adaptation wave the relative disparity between the two retinal signals is at its maximum.

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256 The Absolute Phase Effect in Energy Model

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The energy model for motion and binocular vision has been considered to be invariant with respect to the absolute phases of the input stimuli^{1, 2}. This has not been disputed since the introduction of the energy model (pointed out by an anonymous reviewer). However, Zhao and Farell³ reported that the binocular energy model may depend on the absolute phases. Yet, many consider the result by Zhao and Farell³ is due a bug in the simulation. Here we present an analytic proof showing that the energy model does depend on the absolute phases of the input stimuli.

For a sinusoidal stimulus oriented parallel to the major axis of the receptive field of complex cells, the model yields a response for these cells that is the sum of three parts: (1) $\cos^2 \{[(p_r^1 - p_s^1) + (p_r^2 - p_s^2)]/2\}$ and a constant. Here p_r^1 and p_r^2 are the absolute phases of the receptive fields, p_s^1 and p_s^2 are the absolute phases of the input stimuli. (2) $\cos^2 \{[(p_r^1 - p_r^2) + (p_s^1 - p_s^2)]/2\}$ and a constant; (3) $\cos \{[(p_r^1 - p_r^2) + (p_s^1 - p_s^2)]\}$ and a constant. Clearly, the first and the second terms do not depend on the absolute phases of the input stimuli since $(p_s^1 - p_s^2)$ is the relative phase of the input stimuli. However, because of $\cos \{[(p_r^1 - p_r^2) + (p_s^1 - p_s^2)]\}$, the third term depends on the absolute phases.

This theoretical result is analytical without any approximation--This is fundamentally different from former research on the analysis of the energy model. Therefore the analytical result should give every detail of the information of the model. Furthermore, the proof can be easily generalized to related stimuli, such as gabor patches.

The proof also holds for the motion energy model, since it is a special case of the binocular energy model.

References:

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257 The visual system does not compensate for different image sizes in the two eyes that result from eccentric gaze

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When the eyes are in eccentric gaze, the image is larger in one eye than the other. Previous research has shown, with the eyes in forward gaze, that images of different sizes are difficult to fuse and do not allow fine stereopsis. We asked whether the deleterious effects of differential magnification in the two eyes affect stereopsis in eccentric gaze. Ogle suggested that the visual system compensates for differential magnification in eccentric gaze. He proposed that a neural mechanism, triggered by eccentric gaze, adjusts the relative sizes of the two images so that fusion and fine stereopsis remain possible. We tested Ogle's hypothesis. Specifically, we measured disparity thresholds (the lowest discernible amplitude in a sinusoidal depth corrugation) as a function of relative image magnification in the two eyes and as a function of eccentric gaze. We found, as others have, that threshold is lowest in forward gaze when the image sizes are similar. We also found no effect of gaze eccentricity; in other words, disparity thresholds remained lowest in

eccentric gaze when the size difference in the retinal images was minimal. These results show quite clearly that retinal-image magnification is not adjusted neurally with changes in gaze eccentricity. We will describe the implications of this finding for everyday vision.

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258 Adaptation to Interpolated Disparity

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Three-dimensional interpolation occurs when observers perceive surfaces that vary smoothly in depth despite sparse or absent image disparity. The neural mechanism(s) responsible for 3D interpolation are unknown. One possibility is that local disparity or depth information is propagated into blank image regions (Mitchinson & McKee, 1985). An alternate possibility is that surface-based 3D shape detectors mediate interpolation (Domini et al., 2001; Wilcox & Duke, 2003). Can a stereoscopic after-effect be obtained from the interpolated region of a 3D surface? Stereoscopic after-effects are explained by fatigue among neural mechanisms tuned to different disparities. The interpolated region of a 3D surface, however, contains no disparity. A stereoscopic after-effect obtained by adapting to an interpolated region would suggest that surface-based mechanisms mediate 3D interpolation. Observers first adapted to either random dot (density = 25%) or contour stereograms (which contain disparity only at the vertical edges). Adaptation stimuli were 6 sq. deg 3D surfaces curved about a horizontal axis and containing a maximum of either 10 min or 20 min of disparity. Observers then judged whether a 3 sq. deg random dot or contour test stereogram in the fixation plane was convex or concave. Thus, observers were making a direction of 3D curvature judgment for a test stimulus that appeared well within the interpolated region of the adaptation stimulus. The means (PSEs for a flat surface) of the resulting psychometric functions were different from baseline (un-adapted), indicating a stereoscopic shape after-effect. The magnitude of the after-effect was not consistently related to the adapt-test surface types nor to the maximum disparity of the adapting stimulus. Both outcomes are consistent with depth interpolation that is mediated by a surface-based mechanism responding to the spatial derivatives of disparity rather than a mechanism which propagates local disparity signals.

259 Depth and size perception in stereo displays

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Stereo displays using LCD shutterglasses are used for a variety of tasks, including Computer Aided Design of industrial products. Graphics for these displays use Emmert's Law to covary retinal angle and stereo disparity of an object displayed at different depths. Anecdotal reports from designers suggest that depth judgments made in these environments show systematic errors, and that the same object displayed at different depth is often seen as different in size. If the range of perceived depths were compressed relative to the stereo disparity, distortions such as those reported would result.

Our experiment asked subjects to judge the size and distance of physical and computer-generated graphical spheres in low context conditions (a single sphere positioned on a dark background). Subjects consistently underestimated the distance of spheres that were further away than the projection screen and overestimated the distance of spheres that were closer to them, resulting in a compression of distance around the plane of the screen. Size judgments in the virtual condition were highly inaccurate relative to the physical control, however the high variance in virtual condition size judgments did not permit any clear explanation of information processing in that task.

Since extraretinal inflow is a potential cue for depth of a fixated object, we also evaluated a technique for manipulating the extraretinal signal by placing the display well above eye level (eccentric gaze). Our results showed a similar but smaller effect for eccentric gaze in the physical

control condition compared to the stereo display. This suggests that extraretinal inflow alone is not sufficient to explain the biases in depth and size judgments in these environments, although it may be a contributing factor. Further work is being conducted on comparisons between physical and virtual as well as comparisons of virtual to virtual stimuli.

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260 Vertical Size Disparity and Perceived Position Measured by Perceptual and Action Tasks

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Vertical size disparity of a vertical line varies as a function of eccentricity and distance, but it has not been reported that the vertical size disparity of such the small stimulus contributes to the perceived eccentricity and distance. For large stimulus, some studies have shown that vertical disparity affects the perception of straight-ahead (Berends et al. 2002) and distance (Rogers & Bradshaw 1995). In this study, we investigated the perceived eccentricity and distance for the small stimulus with manipulated vertical size disparity using perceptual and action tasks. The stimulus was a vertical single-line composed of dots. The head-centric eccentricity and the magnitude of vertical size disparity of the stimulus were manipulated. Subjects responded the two-dimensional position of the line on a horizontal plane by perceptual and action tasks. The perceptual task was a relative judgment of the positions for successively presented two stimuli. The action task was pointing the perceived position by unseen finger. The results were the same for both of the tasks. Perceived distance to the stimulus at large eccentricity depended on the magnitude of vertical size disparity, but that near the median plane did not affected by vertical size disparity. These results for perceived distance are consistent quantitatively with the predicted distance from vertical size disparity along the presented eccentricity. Perceived eccentricity to the stimulus was kept stable in all of the eccentricity condition tested. This result for perceived eccentricity is consistent with the result of perceived eccentricity to large size stimulus (Banks et al. 2002). These results indicate that the perceived eccentricity of an object is determined by the position of the eyes and the image position on the retina, and that the perceived distance of the object is affected by the vertical size disparity along the given eccentricity.

261 Stereoscopic slant seen against monocular surrounds

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Slanted surfaces are often seen against backgrounds or through apertures. In addition to providing a binocular context, such conditions result in the presence of monocular regions (sidebands) at the side of the binocularly slanted surface whose locations and/or relative widths could provide information about slant independent of azimuth, distance to the slanted surface, distance between surface and background/aperture or width of the slanted surface. Sidebands can be either temporal on each eye (background condition), nasal on each eye (aperture condition), or temporal and nasal on the same eye (equivalent to a surface intersecting an aperture). Using random dot stereograms Gillam & Blackburn (Perception, 1998) showed that vertical axis slant is considerably enhanced when appropriate monocular sidebands of uncorrelated texture are added to the nasal and temporal sides of the same eye with no binocular background. Here we expand these findings and also explore for the first time the pure background and aperture cases where information is given by the angular ratio of the monocular sidebands. Further investigation of the same eye case showed that for absolute slant the information provided by sidebands interacted with the disparity gradient rather than summing with it. The slant advantage with same eye sidebands also increased with the width of the binocular surface, although their absolute enhancing effect declined. It

was found that background sidebands had little enhancing effect on perceived slant whereas aperture sidebands had a strong effect. Only aperture sidebands give unambiguous information about relative depth at the sides of the slanted surface. A phantom aperture is seen that 'accounts for' the monocular sidebands. It was also found that under aperture conditions the slant of the surface could normalise so the aperture appeared slanted. The perceptual effects of sidebands are considered in relation to geometric constraints and to Panum's Limiting Case.

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262 Non-horizontal disparities enhance sensitivity of the human stereovision system

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Purpose>> Several studies have shown that disparity information provided by the non-vertical spatial frequency (SF) components in a stimulus exert a substantial influence on the perception of stereoscopic depth. Here, we tested how non-horizontal disparity information contributes to the sensitivity of the human stereovision system by comparing stereothresholds for orientationally broad- and narrow-band stimuli with equal contrast in their vertical SF components. **Methods**>> Stereothresholds were measured in 2 subjects for SF band-pass (2-4 cpd) and orientation low-pass filtered random-dot stimuli (mean luminance = 3 cd/sq. m), using the method of constant-stimuli. Broad-band stimuli included SF components at all orientations from vertical (0 odeg) to the cut-off orientation of 89 odeg. Narrow-band stimuli with a cut-off orientation of 15 odeg were tested for comparison. All SF components that did not belong to the selected spatio-orientation band were removed. To maintain orientation balance, a corresponding band of negative orientations was present in each stimulus. The RMS contrast was 0.21 cd/sq. m for broad-band stimuli and 0.15 cd/sq. for narrow-band comparison stimuli. These values produce equal contrast of the broad-band and narrow-band stimuli within the 15 odeg orientation band. **Results**>> Stereothresholds for the broad-band stimuli are lower by a factor of approximately 2.5, compared to those obtained with the near-vertical narrow-band stimuli. Similar results were obtained when the RMS contrast of the broad-band stimuli was 0.31 cd/sq. m. **Conclusions**>> The results provide clear evidence that optimal stereo-sensitivity depends on disparities in SF components outside the ± 15 odeg band. We conclude that disparity signals from vertically and non-vertically tuned neural mechanisms are pooled prior to computation of horizontal image disparity and that this pooling substantially enhances the signal to noise ratio of the stereovision system.

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263 Incomplete integration of local and global information in stereopsis

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Previously (VSS 2004) we reported experiments in which we investigated the bias and sensitivity in the apparent equidistance settings of two laterally separated stereoscopic probes. When each probe was presented in front of a square frontal platform, the variability of the adjustments was substantially reduced, compared with when the probes were presented in empty space, thus demonstrating that the perceived relative depth of the probes was mediated by the discontinuous platforms behind them. This result was found even when the two platforms were at different distances from the observer, but this situation also produced a substantial bias in the equidistance settings, with the probe in front of the farther surface being set farther away. This constant error could have arisen because of an incomplete integration of the local information specifying the depth of each probe relative to its platform with the more global information

specifying the relative depth of the two platforms; or the error could have arisen from an underestimation of the depth separation of the two platforms. Here we report a new experiment that replicated the previous experiments but also contained conditions in which the probe in front of the more distant platform was adjusted to equal the perceived distance of the other platform, thus measuring the perceived relative depth between the two platforms. We again found that the probes appeared equidistant when the probe in front of the farther platform was farther away. When the probe was adjusted to match the distance of the other platform, however, the bias was much smaller and in the opposite direction. These results suggest that the bias in the equidistance settings of the two probes is primarily due to incomplete integration of local and global stereoscopic information. This result is compared with an analogous result previously found using monocular pictorial information (Meng & Sedgwick, 2002).

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264 Partial occlusion influences the binocular matching solution

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Constraints of the binocular matching solution are described by several rules, one of which is the minimum-relative-disparity (MRD) rule (smoothness constraint), which minimizes the relative depth between nearby features. Occlusion has been shown to affect surface interpolation (especially 3-D) of nearby partially occluded features in 2-D images. Does partial occlusion of nearby surfaces facilitate their MRD matching solution?

Our stimulus configuration was two vertically separated 1-D Gabors, with a 1.2 cpd carrier, presented with a fixed relative disparity (3608 phase disparity) over a range of absolute pedestal disparities (708- 1508). The envelope disparity matched the carrier disparity. The Gabors were presented with a 28 high blank gap between them (blank gap), or with a RDS presented inside the gap (partial gap), or with a RDS that covered the gap (no gap). The RDS had zero disparity. We measured the probability of MRD solutions as a function of the absolute disparity of the pedestal. The results were compared for the three conditions in order to investigate the influence of partial occlusion on the matching solution.

The matching solution could be influenced by several factors, including MRD of the Gabor carrier, and the absolute disparity of the Gabor envelope (second order information). We put these two factors into conflict for the matching solution and we tested if the RDS occlusion cue could change the balance between the two solutions. We found that the likelihood of an MRD matching solution was highest in the no-gap (partial occlusion) condition and lowest in the blank gap condition. These results indicated that high-level processing such as depth ordering, cued by partial occlusion of nearby surfaces, could influence the binocular matching solution.

Color Vision 1

265 Spatial organization of L- and M-cone inputs to neurons in the macaque lateral geniculate nucleus

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In chromatically opponent retinal ganglion cells and LGN neurons in macaque it has been hard to establish how the different types of cones contribute to centers and surrounds of receptive fields. To pursue this we recorded in anaesthetized macaque monkeys from parafoveal LGN neurons driven by drifting gratings that modulated only L-cones or only M-cones (cone isolating) or modulated both in concert (L+M). A receptive field that has few cones in its center should be orientation-selective when

driven by gratings of preferred or higher-than-preferred spatial frequencies. If both L and M cones provide input to the center, preferred orientation should vary with grating chromaticity. If both cone types provide input to the surround, we should see band-pass rather than low-pass spatial frequency tuning for cone-isolating stimuli. Among magnocellular cells, both cone types provided input to center and surround: neurons showed band-pass tuning, and orientation specificity for cone isolating and L+M gratings could vary significantly. Parvocellular (P) cells behaved differently. Receptive field centers were usually driven by one class of cone: orientation specificity was found in most cells, and was strongest in cells with M-cone centers, but did not depend on chromaticity. In cells with M-cone dominated centers, band-pass spatial frequency tuning was rarely observed for M-cone isolating gratings, and spatial resolution for L-cone isolating gratings was low. In cells with L-cone dominated centers, band-pass spatial frequency tuning for cone isolating gratings was more common, and spatial resolution for M-cone gratings was often close to that for L-cone gratings. Nevertheless, L- and M-cone inputs remained antagonistic at high spatial frequencies. Since L-cones are more prevalent, the different characteristics of P-cells that have L- rather than M-cone centers is consistent with unspecific wiring of cone inputs to the surround. Cone inputs to the center seem substantially more specific.

266 A comparison of the BOLD fMRI response to achromatic, L/M opponent and S-cone opponent cardinal stimuli in human visual cortex: II. chromatic vs achromatic stimuli

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Aims: To compare the responsiveness of cortical areas to stimulation of the two cone opponent systems and the achromatic system. The appropriate contrast metric for the comparison of color and luminance sensitivity is unknown and so we made the comparison using both a perceptual match between stimuli (in multiples of detection threshold), a direct contrast match (in cone contrast).

Methods: MR images were acquired on a 4T Bruker MedSpec. Stimuli were sinewave counter-phasing rings (2Hz, 0.5cpd) and cardinal for the selective activation of the L/M cone-opponent (RG), S cone-opponent (BY) and achromatic (Ach) systems. In different scans, stimuli were matched either at 25x detection threshold (determined psychophysically), or in cone contrast (6%). Both stereotaxic and a region of interest analysis on early visual areas (V1-V4v, and hMT+) were performed, with the latter identified in separate scanning sessions.

Results: In extra-striate visual cortex two different response profiles were observed, differential for chromatic and achromatic stimuli. These profiles were independent of the metric by which the stimuli were equated. Two loci in dorsal and lateral occipital cortex, corresponding to areas V3A and hMT+, had a markedly stronger response to achromatic than to chromatic stimuli. This is in contrast to a region in the ventral occipital cortex (beyond V4v) that exhibited stronger fMRI signals to chromatic compared to achromatic stimuli.

Conclusions: In areas V3A and hMT+, a selective response to achromatic stimuli was observed, suggesting a predominantly magnocellular input in these motion-sensitive areas. On the other hand, a region in ventral occipital cortex was activated more by chromatic than achromatic stimuli, which may reflect a predominant parvocellular input. These two types of response profiles are independent of the metric used to equate the stimuli. Data on V1-V4v do not follow these patterns and are discussed in a related abstract (Mullen et al.).

267 Multiple-channel characteristics from chromatic notched-noise adaptation

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[Background] It has been suggested that the higher order color mechanism consists of multiple channels, but the precise of the channels are unclear. On the other hand, color stimulus with a certain range of hue to adapt a channel, for example, yields opposite hue appearance according to color-constancy mechanism. This is not the best method to investigate the characteristics of multiple-channel systems.

[Methods] Notched-noise adaptation technique has been often used to study multiple-channel mechanisms in visual system. We modified dynamic random-color-mosaic pattern (20 frames/s) to produce a chromatic notched-noise stimulus by eliminating a certain range of hue from the colors in the mosaic pattern. The channels sensitive to the hues presented in the stimulus will be desensitized by adaptation, but the sensitivity of channels with selectivity in the direction of 'notch' will be retained. Afterimage from this notched-noise stimulus is expected to reveal the characteristics of the channels. We varied the direction and the range of the notch in a cone-contrast color space. The afterimages were measured by the method of adjustment.

[Results & Discussion] All subjects perceived chromatic afterimages, when a uniform gray field was presented immediately after the adaptation. The afterimage had roughly same hue as the direction of notch, but there were systematic deviations. This systematic deviation was common to all subjects, and was not found after adaptation to a uniform color field with a mean chromaticity of the notched noise. We examined a simple computational model to account for this hue deviation in the notched-noise adaptation afterimages. The model analysis revealed that at least five channels are necessary to account for the data. Also, the hue selectivity of each channel was estimated.

[Conclusion] The use of dynamic color-notched-noise stimulus is an effective method to investigate the characteristics of multiple-color mechanisms in the higher order human color vision.

268 The effect of spectrally selective filters on perception

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Under many circumstances the spectral composition of our visual world is purposefully filtered. For example, military pilots, industrial safety inspectors and workers, and participants in mountain or undersea activities often utilize spectrally selective filters. Such filters create a novel spectral environment that the visual system must adapt to and contend with. Though the physical and visual response to a given filter should be predictable from current models of color and contrast adaptation. Such predictions are not always supported by measures of performance. This study examined and compared the theoretical and actual visual performance of subjects using spectrally selective filters. The theoretical experience was obtained by using established mathematical models of vision to calculate the visual response toward a given filter and stimuli. The actual effects of spectrally selective filters on visual capacity were measured by testing human subjects on a battery of color vision tests while wearing filters. The discrepancy between theoretical and actual experience of wearing filters was analyzed individually for each test, for each filter. It was found that theoretical models are not adequate for all stimuli. Filters appeared to be affected by aperture stimuli more than object stimuli resulting in an alteration of color perception for most subjects. While these results in part support the accuracy of low-level theoretical models, they also show the inability to describe visual processes of color appearance at higher, perceptual levels. The application of higher-level models that include color constancy will be discussed.

269 Cone Tuning Curves and Natural Color Statistics

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We investigate whether the wavelength tuning of cones gives the maximum possible information about color and lightness in natural scenes?

Humans and other old-world primates have a large overlap in the sensitivity curves of their M- and L-cones, which peak at approximately 535 and 560nm. It is often assumed that a smaller overlap would be better for general purpose vision because it would make information from the two cone types less redundant. Consequently, most theories on evolution of the cones emphasize the specific tasks of finding reddish and yellowish foods.

We compute the mutual information between cone responses and the colors in natural scenes. We find that this information would be larger if the L-cone peaked at a longer wavelength, because the correlation of M- and L-cones would be reduced and because natural scenes show most variation at long wavelengths. However, the M- and S- cones are close to their optimum positions, and little or no information would be gained if the M-cone peaked at a lower wavelength. These results remain true for color statistics for rural scenes dominated by leaves and grass, and for statistics of tropical fruit colors.

While information about colors would increase if the L-cones were sensitive to longer wavelengths, it would reduce visual acuity at high spatial frequencies, due to increased diffraction and chromatic aberration. Color discrimination performance in near-threshold conditions would also be reduced, as information is highest when the M- and L-cones are sensitive to the same part of the spectrum when signal-to-noise is low.

These results do not contradict the popular theory that the cone sensitivities are adapted to be optimal for finding fruits. However, a simpler explanation could be that the cones are designed to give maximum information about color in natural scenes across all spatial scales and illuminations, thus giving good performance in all ecological tasks.

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270 Effects of Learning and Language on Colour Categorical Perception as Measured by Simultaneous Presentation Threshold Estimates

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Categorical perception (CP) is characterised as a superior ability to discriminate stimuli when they belong to different categories (cross-category) than when they are the members of the same category (within-category). Colour perception is well-documented to show this pattern. This property of colour perception has been used to test effects of language and learning, with some findings suggesting that colour CP may not be inherited but acquired as a result of learning the colour categories of a language (Ozgen and Davies, 2002, JEP: General, 131(4), 477-493). Although such findings lend support to the well-known Linguistic Relativity Hypothesis, there is a serious problem in the literature. Virtually no study of colour CP has really tested perception of colour directly. Instead, tasks involving memory (e.g. successive same-different judgements with an ISI of variable duration) or sometimes subjective judgements of similarity have been commonly used to infer perception of colour.

We used a 2-Alternative-Temporal-Forced choice task where two hues to be discriminated were presented side-by-side simultaneously (without a spatial or temporal gap in between), making it an edge-detection task. In two experiments we investigated effects of category learning and language on colour CP using discrimination thresholds (with ZEST) as our measure.

In Experiment 1 we trained observers on a novel category boundary (separating two kinds of green) and obtained threshold measurements before and after category learning. We found that following training, thresholds dropped considerably along the novel boundary (cross-category) but stayed unchanged elsewhere (within-category). In Experiment 2 we compared native English speakers with speakers of African languages which encode blue and green with a single term (no blue-green boundary). Africans had higher detection thresholds across the blue-green boundary than English speakers, while in neighbouring regions no such difference was found.

271 Implications of variability in color constancy across different methods and individuals

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Measures of color constancy vary widely across different experimental techniques within an individual (i.e., 9-85% in Kraft & Brainard, 1999, PNAS, 96, 307-312) and across different individuals within one technique (i.e., 15-57% in the paper cited above). The first observation shows that a person's apparent capacity to be color constant is highly dependent on the method used to assess that capacity, and that although it might be reasonable to attribute color constancy to an organism as a goal, it might not be reasonable to attribute it to the organism as a well defined, intrinsic characteristic. This dependence on technique is potentially confusing because the term "color constancy" suggests an enduring, all-purpose capacity of the human visual system rather than a transitory phenomenon. Color constancy might be better understood as a property emerging from interactions among subtle forms of chromatic adaptation which could not individually support color constancy in a meaningful way.

The second observation - that measures of color constancy vary significantly across individuals - implies that different individuals adjust perceived color in scenes according to different algorithms, or at least differently tuned versions of the same algorithm. To investigate these differences efficiently, experiments should compare environments in which one aspect of the environment (or potential illuminant cue or signal for chromatic adaptation) is changed, while variation in other aspects is minimized. Recent experiments will be reconsidered within the framework of these two observations.

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272 Color Constancy: the role of judgement

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Studies of color constancy (CC) have frequently used simulated Mondrian patterns to isolate sensory and perceptual processes from long-term memory or expectation (which could affect the perception of natural scenes). Indices of CC in such studies have been wildly variable, spanning the range from 5% to over 80% (as is not untypical of other constancies, e.g. size constancy in Holway & Boring, *Amer.J.Psych.*, 1941, 21-37). We controlled the direction of illumination change and pattern chromaticities to clarify the sources of such variability. Our naïve observers rated how well the central squares in pairs of successive Mondrians matched in material or in hue and saturation. Display duration was 1 sec to limit chromatic adaptation. The simulated Mondrians comprised 49 (7x7) abutting surfaces, whose global illuminants were 4000K or 16000K (first Mondrian) and 6700K (second). Results: a major source of variability is whether the task requires the observer to attend to the proximal stimulus to judge appearance (hue, saturation) by introspection, or to the distal stimulus (the simulated surface property) to form a 'judgment of origin' of the real-world change in chromaticity. We speculate that attention selects among chromatic signals which are local to each patch and specify the proximal stimulus, or which encode edge ratios and specify the distal

stimulus, these signals probably being available in parallel (Foster et al., 2001, PNAS, 98, 8151).

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273 Categorical color constancy for dichromats

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It was reported that dichromats showed categorical color perception similar to that of normal trichromats under a white illuminant, which suggested rod contribution to the chromatic mechanisms, along with lightness cues, to categorize surface colors (Montag and Boynton, 1987, *Vision Res.*, 27, 2153-2162). In the present study we tested whether dichromats could have categorical color perception under various chromatic illuminants in a manner resembling normal trichromats in order to investigate color constancy mechanism. We employed the categorical color naming method using the Berlin-Kay 11 basic color terms (red, green, yellow, blue, brown, purple, orange, pink, gray, white, and black), and the 424 OSA uniform color chips as stimuli. A liquid crystal projector (LCP) illuminated both the test color chip (2.7deg) and its large surrounding gray with illuminance of about 500lx. Test illuminants were Blue (LCP single blue light), 25000K, 6500K (white illuminant), 3000K and Red (LCP single red light). The observer saw the test color chip, one at a time, under a test illuminant. The observer adapted for 3 minutes to the test illuminant before starting a session. Dichromats and normal trichromats participated in this experiment. We found that categorical color regions of the dichromats are surprisingly similar to those of the normal trichromats under all chromatic illuminants. The dichromats used all categorical color names, and the centroids of their color categories spread also along the r/g direction in the OSA color space. Since rod is less sensitive for longer wavelengths it is likely that the dichromats could utilize only lightness cues under the Red illuminant (peak wavelength: 600nm) to categorize colors. This suggests that, for normal trichromats, lightness of surface colors might be a critical cue in categorical color constancy.

274 A probabilistic approach to color constancy using articulation, brightness, and gamut cues

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The neural mechanisms underlying color constancy remain poorly understood. It is generally accepted that the key operation underlying color constancy is the estimation of the scene illuminant(s), but as illuminant estimation has proven to be a very difficult computational problem, color constancy algorithms continue to fall far short of human performance. Many existing color constancy algorithms attempt to determine the illuminant based solely on the information contained within the scene. We have developed a Bayesian-inspired approach to color constancy involving the following five heuristics: (1) the most probable illuminant in a scene lies along the line (in color space) that connects the scene average M and the a priori most probable illuminant L; (2) the scene average M is computed using a single chromaticity estimate per object surface (i.e. one surface one vote), rather than a single estimate per image pixel; (3) object surface contributions to the scene average M are weighted by surface brightness, reflecting the well known brightest-is-illuminantest principle; (4) scenes with high surface counts, which contain relatively more illuminant information, pull illuminant estimates radially outward towards M; and (5) scenes with large color gamuts pull the illuminant estimate radially inward towards L. To test our algorithm, we developed (1) a database methodology in which we produce large numbers of color image composites with varying backgrounds constructed from the images of 100 real objects shot under 5 different illuminants, and (2) a color-histogramming recognition benchmark which we have used to test our approach to color constancy against several other published algorithms. In our most recent tests, our algorithm achieved 67.4% recognition rates

compared to 37.4% for unprocessed images, outperforming all other algorithms tested.

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275 Simultaneous contrast and color constancy in authentic environments: Impoverished vs. rich scenes

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Simultaneous contrast adaptation was measured using actual illuminated surfaces in a large experimental chamber (82 cm wide x 112 cm tall x 164 cm deep). Three walls and the floor of the chamber, all formed from identical colored cardboard (gray, pink, or blue), were visible. In some conditions, two ceramic mugs and a piece of cardboard having 24 colored patches were placed in the chamber to add a variety of illuminant cues to the scene. A square cardboard annulus (3 sizes, same or different color to the walls) was attached to the back wall of the chamber. In the center of the annulus was a test square whose chromaticity and luminance could be varied continuously by the observer. Two color-normal observers adjusted the test square to appear perfectly achromatic and so that the achromatic sensation was composed of 50% black and 50% white (three-dimensional RGB adjustment, 32 settings/condition). Illumination was identical in all 21 conditions [CIE (x,y,Y)=(0.34, 0.34, 20.9)]. **Results:** Simultaneous contrast was weaker for both observers when objects were placed in the chamber, indicating that the objects reduced the influence of the local surround on color perception. Since the objects should not alter the information provided by the local surround, the result also suggests that the objects caused the visual system to depend more on other illumination cues. Although difficult to estimate precisely, changes in more global image statistics (i.e. weighted spatial mean) would seem to be too small to explain the observed reduction in simultaneous contrast. The reduction in simultaneous contrast was much greater for one observer than for the other, implying significant individual differences in the way that information from different illuminant cues is combined. Shifts in achromatic settings due to simultaneous contrast represent failures of color constancy (illumination was constant), but the shifts suggest how the visual system might achieve color constancy when illumination does change.

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276 Infants' spontaneous hue preferences are not due solely to variations in chromatic detection thresholds

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Infants show spontaneous looking preferences for red and blue over yellow and green (Bornstein, 1975). To extend Bornstein's work, we recently tested 3-month-old infants' spontaneous preferences with 4.5 cd/m² test disks embedded in a 0.45 cd/m² white surround on a video monitor. Twenty three chromatic stimuli varying in dominant wavelength and colorimetric purity were tested against white (CIE x,y=.33,.33). Infants preferred all chromatic stimuli to white (cf. Adams, 1987) and for each dominant wavelength, preference increased with increasing purity. In general confirmation of Bornstein's results, blue, purple, and red were more strongly preferred than yellow, green, and blue-green.

Might infants' preferences be accounted for by differences in the detectability of stimuli of different dominant wavelengths? To test this hypothesis, we obtained infants' purity detection thresholds for lights of six dominant wavelengths. In general confirmation of the hypothesis, infants' purity detection thresholds were lower for blue, purple and red than for yellow, green and blue-green.

To compare the two data sets quantitatively, we generated infant iso-preference and iso-detection contours in CIE 1931 space. Neither contour was centered at white. Both contours were stretched toward the green region of CIE space, but by different amounts. After normalizing infants' preference data by their purity threshold data, some residual preference differences remained, especially for purple stimuli. We conclude that infants' spontaneous hue preferences are not due solely to variations in detection thresholds.

We have previously shown that infants' spontaneous hue preferences are not due solely to adult-like variations in perceived brightness (Teller et al., VSS 2003) or perceived saturation (Zemach & Teller, VSS 2004). Thus, infants' spontaneous preferences are partially controlled by true preferences for different hues, rather than just by differences in brightness, saturation, or detectability.

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277 Color appearance in the peripheral retina as a function of stimulus size and intensity under rod-bleach conditions

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Changes in color appearance were investigated for a range of stimulus sizes (.098, .125, .25, .5, 1, & 28) at four intensity levels (0.3, 1.3, 2.3, & 3.3 log td), at 108 along the horizontal meridian of the temporal retina. Stimuli were presented in a Maxwellian-view optical system, and a rod-bleach procedure was employed to eliminate rod input (approx. 99% of rod photopigment bleached). Using the '4+1' color-naming paradigm (blue, green, yellow, red, and saturation), observers assigned percents to describe the color appearance of a series of monochromatic stimuli ranging from 440 to 660nm in 10 nm steps. At the two lower intensities (0.3 & 1.3 log td), systematic changes in color appearance were found for stimulus sizes =.258 in two distinct spectral ranges, 490-520nm & 540-570nm. In the 490-520nm range, as stimulus size was decreased, the perception of green was reduced while the perception of yellow was enhanced. In the 540-570nm range, as stimulus size was decreased, the perception of yellow was reduced while the perception of red was enhanced. When size was kept constant, and intensity was manipulated, similar patterns were revealed. This combination of results demonstrates a size-intensity trade-off with changes of color appearance. Interestingly, the perception of blue was unaffected by manipulations of stimulus size and intensity. The reduction of green, the enhancement of red, and the dynamic changes of yellow evident for small (or dim) stimuli may explain some of the previously reported differences in the literature regarding chromatic perceptible field sizes. These changes in color appearance due to size and intensity parameters are discussed in terms of cone receptor populations as well as neural summation.

278 Sensitivity to color and luminance transformations in real versus phase-scrambled natural scenes

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Aim

Traditionally, thresholds for discriminating colour and luminance differences have been measured using stimuli such as disks, gratings or gabors, and accounted for in terms of the responses of relatively low-level mechanisms in the visual pathway. On this basis we would not expect the higher-order structure of, for example, natural scenes to be a factor determining colour and luminance discrimination thresholds. We therefore decided to compare discrimination thresholds between natural scenes and phase-scrambled versions of the same scenes.

Method

The stimuli were fifty calibrated color photographs of everyday scenes and fifty phase-scrambled images. The chromaticity and saturation of every

pixel was represented as a vector in a modified version of the MacLeod-Boynton color space, and could be translated, rotated, compressed, or randomly repositioned within that color space. Thresholds for detection of each type of transformation were measured using a two-alternate forced choice method.

Results

Thresholds for all types of transformations in color space were significantly lower in natural scenes compared to phase-scrambled images. Thresholds for detecting random changes in color, in the form of either Gaussian or fractal noise, were considerably lower in natural compared to phase-scrambled images.

Conclusion

The structure of natural scenes plays a significant role in our ability to discriminate colour and luminance differences.

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279 Spatial Arrangement of Irrelevant Color in Visual Search

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The colors of nearby regions in natural scenes tend to be similar. The purpose of this study was to determine if visual-search performance could be affected by the spatial arrangement of color when color is not a relevant feature.

The task consisted of searching for a vertical Gabor among oblique ones tilted at 15 deg clockwise against a gray background. Spatial distribution of color was manipulated in 3 conditions. In the "random" condition, the Gabors were randomly assigned to be red or green with matched luminance. In the "cluster" condition, an imaginary line divided the display vertically in half; the Gabors were red in one half and green in the other half. In the "uniform" condition, all Gabors were either red or green. Set sizes were 2, 8, 14 and 20.

The mean accuracy of 9 Ss was 95%. Log transformed RTs of the correct trials were subjected to ANOVA. Spatial distribution of color (COLOR) had a main effect on RT, in that the random condition led to significantly longer RTs ($p < .05$), but no difference was found between the cluster and uniform conditions ($p = .704$). There was an interaction between COLOR and TARGET (present or absent), with COLOR having a greater impact on RT for target-absent trials. There was also an interaction between COLOR and SETSIZE. The average search slopes were 127 (random), 98 (cluster), and 107 (uniform) ms/item for target-absent trials, and 55, 52, and 54 ms/item, respectively, for target-present trials.

Overall, random spatial arrangement of color, as opposed to uniform color or clusters of uniform colors, significantly increased search time, in terms of both setup time and search slope. The effect was disproportionately large when the target was absent. It appears that spatial discontinuity of color receives obligatory processing that disrupts visual search both at the onset and during the search.

280 Motion-Induced Colour Segregation

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Against the general notion of separate processing of colour and motion, recent studies have revealed various forms of colour influence on motion perception. On the other hand, it remains unknown how motion information contributes to colour perception. Last year, we reported "motion-induced colour mixture" (Nishida et al. VSS'04; Watanabe et al. ECV'04), in which moving bars whose colour temporally alternates between two colours (e.g., red and green) at each jump is perceived to be in the mixed colour (yellow). This phenomenon suggests that the visual

system may integrate colour signals presented at different locations on the retina, but along the trajectories of the same moving objects. However, an alternative interpretation is that motion signals simply lower the spatial resolution of the colour mechanisms. If colour signals are indeed integrated along motion trajectories, motion signals should also facilitate segregation of colours if they are presented at the same retinal locations, but along different motion trajectories. To test this, we asked the subjects to rate the magnitude of colour segregation/mixture for gratings in which red and green bars (6' in width) spatially alternated with a constant dark interval (variable between 6' and 66'). The grating shifted every 6.25 ms by 6' in the orthogonal direction. This gave rise to an alternation of red and green at each retinal location. The alternation rate varied between 6.7 to 40 Hz depending on the inter-bar spacing. As the alternation rate was increased, the perceived colour gradually changed from red/green to yellow. We compared this function with that measured with a non-motion display where the same temporal pattern was seen as stationary chromatic flickers. As we expected, the rating of segregation of red/green was significantly higher in the motion display than in the non-motion display. This "motion-induced colour segregation" strongly supports colour integration along motion trajectory.

281 Variation in focal color choices across languages of the World Color Survey

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Focal choices for basic color terms in different languages are tightly clustered around similar regions of color space, pointing to strong universal tendencies in color naming (Kay and Regier, PNAS 2003). We asked whether the foci within these clusters can also show significant variation across languages, by analyzing data from the World Color Survey (WCS), which includes data from an average of 24 speakers from each of 110 unwritten languages (available at <http://www.icsi.berkeley.edu/wcs/data.html>). For each language we tested for consensus terms (used by a majority of speakers) whose foci were closest to the foci for one of the 11 basic terms for English. Variations in the mean foci for the cluster of terms corresponding to English 'red', 'green', 'blue' or 'yellow' were then compared to the variation predicted by randomly sampling the foci for 20 individuals across different languages. Clusters for 'blue' and 'green' were restricted to the subset of languages that included distinct consensus terms for both color regions. For all four terms the variance in both the mean hue and mean lightness of foci across languages was significantly greater than expected by a single population. This within-cluster variability suggests that the choice of exemplars for color categories can be modulated by unknown factors differing among the languages. However, these variations were small compared to the differences between clusters (e.g. 'red' and 'yellow' clusters were separated by ~10 times the standard deviation of foci within each cluster, with only one WCS language with a consensus term nearer to the intermediate English term 'orange') while variability among speakers of a common language was pronounced. This suggests that factors contributing to focal color differences between languages - and in particular language per se - impose only a weak constraint on color naming by the WCS respondents.

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282 Missing links: Some examples from color vision on how binding theory may fill gaps in theoretical frameworks for perceptual phenomena

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Binding theory is used to understand how the activity of distributed cortical cells, driven by different parts or aspects of the same image, may be integrated into a coherent percept. It has found widespread application

to feature integration and figure/ground segmentation problems. Much evidence points to a type of oscillatory synchronization as a binding mechanism. Recently we showed how ideas from binding theory could be used to understand the fading and fragmentation of stabilized images and the melting of equiluminant images (Billock & Tsou, TINS, 2004; JCNS, 2004). Here, I consider some additional applications of binding theory to color psychophysics: (1) It is possible to use oscillatory synchronization to recode sensory information from two or more channels; for example, it is relatively straightforward to use oscillatory synchronization to create a chromatic brightness channel using the compromise frequency of nonlinear coupled hue and luminance channels. (2) The same principle can be used to recode brightness and hue mechanisms, to compute chromatic saturation. Both this saturation signal and the brightness signal obey a power law scaling that is an emergent bonus of the nonlinear dynamic interactions between the channels. (3) It has long been a mystery why both parvo- and magno-driven mechanisms converge on nearly identical spectral sensitivities. Synchronization of two neural mechanisms is better behaved when the correlation between the two channels is high; it may be easier to synchronize luminance inputs from different neural mechanisms if this sensitivity-induced-correlation is present. Even if direct addition of luminance mechanism is employed, a high correlation leading to synchronization eliminates two sources of contrast demodulation. Treating oscillatory binding as a generic neural mechanism rather than a special case may be quite useful in understanding psychophysical phenomena and neural processing.

283 Compensation of white for macular filtering

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Introduction. S cone excitation is lower in the fovea because short wavelength light is filtered by the foveal macular pigment. Despite reduced S cone excitation, white fields appear uniform -- there is no yellow spot in the center of the visual field. This could be due to filling-in across space of the macular shadow, or it could be due to local compensation of chromatic signals for white. By measuring white rings in a dark surround, we eliminated the effect of filling-in across eccentricity. **Methods.** In the first experiment, rings of various diameters were repeatedly, briefly, flashed on a dark surround while subjects fixated the center. Subjects adjusted the chromaticity of the rings until they appeared colorless. Luminance was kept constant. In a second experiment to rule out simple Weber adaptation, we measured achromatic settings for very dim rings. In addition, to estimate the density of macular pigment across the retina for each subject, we used minimum motion photometry. **Results.** The estimated macular pigment density was on the average 2 times greater in the fovea than in the periphery. However, despite greater filtering in the fovea, S cone light required for neutral white was approximately the same at all eccentricities, different at most by a factor of 1.2. This was true even for very dim rings which were unlikely to cause Weber adaptation of S cones. **Conclusions.** The perception of white is locally neurally compensated for reduced foveal S-cone excitation due to macular pigment. Since the compensation is found even at low intensities it is apparently not due to Weber adaptation of the cones.

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Visual Disorders and Blindsight

284 Visual Perceptual Organization In Adults With Autism

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Whether or not individuals with autism are 'local processors', focusing on the elements of a display rather than on the global whole, remains controversial. To examine the extent to which local elements are integrated perceptually into a global shape in autism, we first examined the ability of 10 autistic adults and matched controls to identify compound hierarchical letters (e.g. global 'H' made of small 'h's or global 'H' made of small 's's) at the global or local level. Normal global precedence, characterized by increased interference from the global level while reporting the local elements, was observed in the control but not in the autism group. Closer scrutiny, however, suggested that a subset of autistic individuals did show global precedence ('global' subgroup) while a second subset ('local' subgroup) did not. In a second experiment, in a visual search task, the same individuals and controls detected the presence or absence of a target (composed of few or many elements), defined either by the global configuration or by the local elements, among an increasing number of distractors. While the local autism subgroup performed as well or even better than the controls at detecting the target at a local level across display size when it was made of many local elements, this was not the case for the global autism subgroup, confirming the bimodal distribution within the autism group. These results suggest that the autism population may consist of sub-populations whose predispositions for processing the local or global aspects of the visual world varies along a continuum and, as such, these findings offer a means for reconciling the apparent discrepancies in the literature.

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285 Does eye dominance predict fMRI signals in retinotopic cortex?

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In studies of human amblyopia with fMRI techniques, we have considered the relationship between psychophysical measures of eye dominance and measured BOLD signals. To obtain comparable control data, eye dominance should be defined in normal subjects. There have been attempts to define eye dominance in normal subjects, although limited consensus exists. In this study, we consider two different definitions of eye dominance: one based on cognitive sighting preference, and the other based on superior resolution acuity. Sighting eye dominance was assessed with two standard tests, the Porta Test, and a 'hole in hand' variation of the Miles Test. We tested visual acuity with a Snellen eye chart as well as a computerized test of grating acuity, with greater expected sensitivity and selectivity. We found little correspondence between the dominance assignments made on the basis of sighting versus acuity. We next compared the fMRI signal magnitude generated by the dominant eye to that generated by non-dominant eye stimulation, according to either of the criteria, in 7 control subjects. Experiment 1 used a high contrast achromatic hemifield stimulus alternating with no stimulus in a blocked paradigm. Experiment 2 employed chromatic phase-encoded eccentricity and polar angle stimuli. The results from Experiment 2 provided a field-sign map for each subject that was used to define regions of interest (ROIs) corresponding to six visual areas (V1, V2, V3, VP, V4, V3A). We found that fMRI signals were significantly stronger in the dominant eye according to the acuity criterion. This consistent dominance effect was apparent for all retinotopic areas, especially those located in the ventral occipital territory (V1v, V2v, VP, V4). In contrast, using the cognitive criterion produced no significant interocular fMRI differences. We conclude that interocular BOLD differences in normal subjects are substantial, and may be predicted by acuity measures.

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286 Unconscious orientation and color processing without primary visual cortex

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In humans, the primary visual cortex (V1) is essential for subserving conscious vision. However, even without V1 and in the absence of awareness, some preserved ability to accurately respond to visual inputs has been demonstrated, a phenomenon referred to as blindsight. Here we used transcranial magnetic stimulation (TMS) to deactivate V1, producing transient blindness for visual targets presented in the foveal, TMS-induced scotoma. Despite complete unawareness of these targets, performance on forced choice discrimination tasks for orientation (Experiment 1) and color (Experiment 2) were both significantly above chance. In addition to demonstrating that TMS can be successfully used to induce blindsight within a normal population, these results suggest the existence of visual pathways that bypass V1 and can process orientation and color in the absence of awareness.

287 Revisiting manual localisation in the cortically blind field

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Background: Sensorimotor localisation in blindsight patients has been linked with residual activity in the occipito-parietal cortex. Despite the theoretical relevance of this claim, very few systematic group studies have been performed. Purpose: To investigate the incidence of and inter-relationships between manual localisation and other residual visual behaviours in a group of cortically-blind patients. Methods: Detailed perimetry was performed in the same testing session. Manual localisation was assessed using a touchscreen, and stimuli were generated using a SVGA graphics card (Cambridge Research Systems, UK) and presented on a 21" CRT monitor at 37cm viewing distance. Appropriate adjustments were made to account for parallax errors. To minimise possible light scatter, the stimulus consisted of two adjacent semi-circular discs with opposite contrasts, and average luminance the same as the background. These were presented for 100ms. The fixation was monitored using a video eyetracker. Using a commentary-key paradigm, awareness of location judgment was recorded on a binary scale for each trial. Results: Although some residual localisation ability for some targets was suggested, considered analysis implies strategic behaviour on the patients' part. As some awareness for one or more of the stimuli was obtained, patients could reach to the restricted number of other target locations when no awareness was experienced. Conclusions: Data to date suggest caution should be applied when claiming residual manual localisation in the cortically blind. Nevertheless, the combination of eye-movement monitoring, controlled stimuli which minimise light scatter as a cue, simultaneous spatial awareness judgments and detailed analysis of the location and the extent of the brain damage will allow for detailed evaluation of the dorsal stream localisation hypothesis for the first time.

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288 When Does a Boy Look Like a Gate? Form Discrimination in Blindsight?

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Background: DB, the first blindsight case to be tested extensively, has demonstrated the ability to detect and discriminate certain stimuli presented within his perimetrically blind field defect. Recent testing has revealed an improvement in DB's residual visual abilities. He is able to detect and discriminate visual stimuli that are considerably 'less detectable' than the optimal stimulus parameters often required to elicit

blindsight (Sahraie et al 2003), and is now able to discriminate between certain shapes and make a 'same/different' judgement within his field defect (Trevelyan et al, VSS 2004). Purpose: To investigate DB's ability to identify simple outline shapes, low-contrast line drawings and complex images (digital photographs) within his cortically blind field defect. Methods: Using a forced response paradigm, we investigated DB's ability to identify outline shapes (circle, oval, square, rectangle). DB was then tested on his ability to identify low-contrast (2%) line drawings of animals and modes of transport. Finally, DB was tested on his ability to spontaneously identify complex images (digital photographs) presented within his field defect. Results: In his field defect, DB demonstrated the ability to identify some simple outline shapes (choice of four shapes). DB was also able to identify some line drawings of animals and modes of transport (DB was told the category of stimuli before testing). Finally, DB demonstrated the ability to successfully identify some complex images within his field defect (given no indication of category). Conclusions: The ability to identify simple shapes and complex images within a cortically blind area of visual field has been demonstrated in DB. Analysis of DB's errors suggests that his performance cannot be explained on the basis of degraded normal vision. Results will be discussed in relation to the potential neuronal mediation of these abilities.

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289 Imaging Visual Deficits in Autistic Spectrum Disorder

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Previous studies of autism have identified deficits in motion processing (Spencer et al, 2000 *Neuroreport* **11** 2765-2767) and spatial form processing (O'Brien & Spencer, 2004 *Perception* **33** S28) which may contribute to widely reported deficits in visuomotor control and object recognition or central coherence. To examine the neural bases of these visual deficits we conducted an event-related fMRI study of form and motion coherence processing on a group of adults with autism; a group with Asperger syndrome, and a group comprising matched controls. We measured responses to form and motion stimuli using a Glass stimulus of varying coherence in a field of random dots. A coherent visual patch was depicted by dots separated by a rotational transformation in space (form coherence) or space-time (motion coherence). Five fixed coherence levels were used (0.0, 0.125, 0.25, 0.5, 1.0). Stimuli were presented for 250ms. Participants responded according to the location (left or right of fixation) of the coherent patch. The order of events was pseudo-randomly permuted. The regions of interest in our analysis were based on those previously identified as responding differentially to coherent motion and coherent form (Braddick et al, 2000 *Current Biology* **10** 731-734). The BOLD response in all 4 form ROIs and all 4 motion ROIs was significantly lower in autism than controls, though this finding cannot at this stage be attributed specifically to visual deficits over non-perceptual experimental factors such as attention. A non-linear relationship between the change in BOLD signal and motion coherence was found for autism in V5/MT compared to a linear relationship for controls. Participants with Asperger syndrome did not show results significantly different from the control group.

290 Implicit Object Recognition in Visual Integrative Agnosia: Patient SE

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The present study investigates implicit object recognition in a patient with visual integrative agnosia. Consequent to a bilateral infarct due to CVA of the posterior cerebral arteries, patient SE exhibited severe object and face recognition impairments. Although he was unable to identify hierarchical stimuli at the global level, SE's performance on the local components of these figures suggested implicit processing of global identity, however. The goal of the present study was to investigate whether objects that SE fails to identify explicitly were identified implicitly. In Experiment 1, a target word (the probe) was preceded by a drawing of an object or animal (the prime). SE performed a word categorization task (animate/inanimate) on the probe. Picture primes represented either the same exemplar as that of the probe (e.g. a picture of a dog followed by the word probe 'DOG'), or a different exemplar from the same category (e.g. a picture of a camel followed by the probe 'DOG') or an unrelated noun from a different category (e.g. a picture of a chair followed by the probe 'DOG'). In Experiment 2, the prime was a word and the probe was a picture. The task was to determine whether the picture represented a possible or an impossible object or animal. Pictures in the impossible condition were created by seamlessly combining the parts of different objects or animals. For possible pictures the word primes denoted either the same exemplar or a different exemplar from the same category. A third condition presented a noun followed by a picture of an impossible object. In both experiments the response to the probe was facilitated in the same condition compared to the different condition, providing clear evidence for bi-directional semantic mediation (from words to pictures, and from picture to words) without explicit identification of the pictures. These findings will be discussed in the context of theories of perceptual organization of visual input and visual awareness.

291 How Would You Catch A Ball If You Had Visual Form Agnosia?

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Visual form agnosia offers a means for exploring the capabilities and, to some degree, the limitations of the human dorsal visual stream. Wann et al (2001) observed that a patient with visual form agnosia (DF) could modify appropriately her reach towards an object if there was a rapid change in its disparity-specified distance but in contrast to control participants a sudden change of optical size did not produce an equivalent modification in reach distance. This raises the question of how sensitive is DF to looming information that ordinarily signals object approach and time to collision (TTC)? We first established that DF has a reasonable ability to catch a ball that is thrown to her in a straightforward fashion. We next presented DF with a range of looming and changing size stimuli. DF was able to report verbally whether an object was approaching or receding when shown a simulation of a looming or contracting ball but was unable to make the same judgment when presented with an equivalent step-change in the size of static images (a task that appeared trivially easy to controls). When asked to hit a button when she gauged a looming ball would hit her, she graded her responses with changing TTC but seemed to rely upon optic size rather than the relative rate of dilation (Tau: Lee, 1976). We tested control participants (female, 48-56yrs) and found that they also failed to grade their responses in line with Tau. We will discuss how the skilled performer might extract a perceptual estimate equivalent to Tau from changing size, how this might degrade if high precision tasks are not practised and why this mechanism might fail in the case of visual form agnosia.

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292 Orientation Integration is Intact in Integrative Agnosia

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HJA has a lesion of the lingual and fusiform gyri. He is unable to integrate local object features into global form and is poor at grouping and segmenting overlapping objects¹. In the mean orientation task² observers must integrate local Gabor elements to judge an arrays overall orientation. This task is probably mediated by V1 or V2, but observers' ability to vary how orientation samples are pooled suggests that something more complex than the filter-rectify-filter model is needed.

Method

HJA indicated whether the mean orientation of arrays of Gabor elements (sf approx 2 cycles/deg, env s.d approx 4 cycles/deg) was to the left, or right of vertical. The orientation of the modulation in each Gabor was selected from a Gaussian distribution with a variable bandwidth. The bandwidth's standard deviation was varied from 0 (all aligned) upwards. The density of the array was varied by changing the diameter of the stimulus (3, 6, 12 deg) and the number of elements (4, 64). Mean orientation thresholds for each array bandwidth were fitted with a variance summation model to estimate internal noise and sampling efficiency.

Results

HJA's performance judging the orientation of individual Gabors, arrays of aligned Gabors and arrays with increasing bandwidth was similar to non-lesioned observers, although he appeared to use slightly less samples. Increasing the density of the gabor array affected his performance much less than non-lesioned observers.

Conclusion

HJA appears to be able to integrate low level local information for this task. His performance does not deteriorate with crowded displays, suggesting anomalous lateral interactions. Like non-lesioned observers he is able to change his sampling strategy with the number of display elements. This flexibility must, therefore, be a property of V2 or V1 neurones or a hitherto unrecognised top-down pathway must exist that by-passes the lesion.

¹Giersch et al (2000) *Cognitive Neuroscience* 17 p731; ²Dakin (2001) *JOSA A* 18 p1016

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293 Low-level and high-level maximum motion displacement deficits in amblyopic children

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Direction discrimination thresholds for maximum motion displacement (Dmax) are not fixed values but are highly dependent on stimulus parameters. Dmax increases with reduced dot probability (Boulton & Baker, 1993; Ramachandran & Anstis, 1983) or increased dot size (Cavanagh et al., 1985; Morgan, 1992). It has been theorized that the increase in Dmax under these conditions might reflect a switch in processing from low-level to high-level motion mechanisms in normal observers (Nishida & Sato, 1995; Sato, 1998). The proposed low-level process is reliant on spatial-frequency-tuned motion detectors and the high-level process is mediated by feature matching mechanisms. To determine whether this 'switch' in motion mechanisms is observed in amblyopic individuals, thresholds were obtained in both eyes of 9 children with unilateral amblyopia and 9 controls. Each subject performed the task under three random dot display parameters: 20 min size at 5% density (baseline condition), 20 min size at 0.5% density (reduced probability condition), and 1 deg size at 5% density (increased dot size condition). A significant increase in Dmax was observed for displays with reduced dot probability and increased dot size relative to baseline in both groups. However, on the baseline and reduced dot probability conditions, Dmax

was significantly lower in both eyes of the amblyopic group compared to the control group. For the increased dot size condition, Dmax was significantly lower in the amblyopic eye but significantly higher in the fellow eye compared to the control group. Extent of binocularity and subtype of amblyopia were not predictive of abnormal performance in this small sample. The results suggest that amblyopic children show the expected shift from low- to high-level motion mechanisms, but both mechanisms appear to be deficient. Our findings implicate abnormal binocular motion processing mechanisms in the neural deficit underlying amblyopia.

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294 Temporal instability of amblyopic vision: Evidence for an involvement of the dorsal visual pathway

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The purpose of the experiments was to investigate the spatial and especially the temporal distortions in amblyopic vision, and to relate them to the orthoptic status and the contrast sensitivity of the amblyopic subjects, as well as to their performance in psychophysical tasks. In the first experiment participants were asked to describe their perception of the amblyopic eye for patterns of different spatial frequencies (0.4 - 3.2 c/deg). In the second and third experiments, subjects had to reconstruct concentric circles point by point. The radial position of each point was to be reconstructed after visual presentation, while the angular position was presented either auditively (second experiment) or visually (third experiment). Twelve out of 14 amblyopes perceived spatial distortions. Five out of 10 strabismic and strabismic-anisometropic, but only 1 out of 4 anisometropic amblyopes perceived temporal instability. Temporal distortions were seen only for spatial frequencies higher than 1.6 c/deg. Temporal instability involved either the whole pattern or only some parts of it. There was no relationship of contrast sensitivity loss to the type or severity of distortion. In experiments 2 and 3, considerable distortions were perceived in the amblyopic eye for strabismic and strabismic-anisometropic amblyopes. In addition, subjects who perceived temporal instability showed a significantly impaired performance in adjusting the auditively presented points. The experiments suggest that strabismus, in addition to amblyopia, is needed to elicit significant spatial and temporal distortions. Temporal instability appears in addition to spatial distortions and has a negative impact on the performance in psychophysical tasks. Strabismic amblyopes show deficits in auditory-to-visual mapping, suggesting an impairment of the dorsal pathway, in addition to the known deficits of the ventral visual pathway.

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295 Assessment of contrast sensitivity in infants and children with neurological impairment: a novel test using steady-state visual evoked potentials (ssVEPs)

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Purpose: Children with neurological impairment often have visual dysfunction, including reduced contrast sensitivity. However, a lack of co-operation or developmental delay can make subjective testing slow and inaccurate. We have previously developed an automated objective visual acuity test using ssVEPs (Bradnam et al. 1994, 2001; Mackay, 2003, 2003a &

b). In the present study we report a similar technique to objectively and rapidly assess contrast sensitivity thresholds.

Methods: The rationale for our technique is to acquire the most important information as quickly as possible, before the child loses co-operation. This is accomplished by real-time analysis of the individual's ssVEP, which determines the subsequent contrast levels to be presented. The stimulus presentation technique is based on an adaptive staircase method, usually used in psychophysical experiments. The starting point is a high contrast pattern, large initial steps in contrast allow the threshold region to be identified and subsequent smaller steps allow an accurate threshold to be established.

Results: The stimulus parameters and presentation protocol were optimized in order to obtain a rapid and accurate contrast threshold. The contrast range, contrast step size, stimulus presentation algorithm, spatial frequency, temporal frequency, scalp recording sites and length of recording time before accepting 'no response' were all investigated. As a result, it takes less than three minutes to estimate a contrast sensitivity threshold, with the threshold estimates being comparable to psychophysical estimates.

Conclusions: The use of ssVEPs, combined with sensitive objective signal detection and a staircase stimulus presentation is an effective strategy for determining contrast sensitivity.

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296 What does an amblyopic eye tell human visual cortex?

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Amblyopia is a developmental disorder known to result in abnormalities in the human visual cortex, although the extent of involvement of cortical areas beyond V1 remains unclear. We report here an updated analysis of an ongoing study (VSS 2003) of amblyopic visual cortex. This fMRI study of 12 adult amblyopes (6 esotropic strabismic, 6 anisometropes) and 6 controls directly compared the BOLD signals produced by monocular stimulation of each eye. Measures were made in three cortical regions-of-interest (ROIs) corresponding to extrafoveal V1 and V2 and the foveal representation at the occipital pole, individually defined using standard retinotopic mapping in the fellow (nonamblyopic) eye. Fixation stability was found to not differ significantly between subject groups, and correlated with signal magnitude only in the foveal ROI for strabismic eyes. Results showed that mean fMRI signal for amblyopic eyes was consistently lower than for fellow eyes in all ROIs, although a few amblyopes did not show this trend. Nevertheless, the interocular difference in extent of activation was significantly larger for both strabismic and anisometropes compared with controls. In addition, both subtypes showed significantly fewer voxels able to be driven by both eyes (significantly for V1 and V2 in anisometropes). Comparison of individual phase-encoded retinotopic maps obtained from amblyopic versus fellow eyes revealed less activation in the occipital pole corresponding to foveal stimuli, consistent with known psychophysical losses. Finally, a few amblyopes demonstrated the novel finding of more activity in parietal and temporal cortex from the amblyopic than the fellow eye. These results confirm that the amblyopic eye is deficient in driving visual cortex compared with both the fellow eye and control eyes, and demonstrate that both strabismic and anisometropic amblyopes have abnormal cortical representations of foveal stimuli.

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297 Visual Completion in Children with Pervasive Developmental Disorder: Effects of Shape Complexity

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Much evidence has been gathered for differences in visual perceptual processing in individuals with Autistic Spectrum Disorder. These individuals show detail-focused processing in which features are perceived and retained at the expense of global configuration and contextualized understanding. The presence of the fundamental process of visual completion was tested in a subgroup of children with Pervasive Developmental Disorder (PDD), as this requires perceptually integrating visual information into wholes. In Experiment 1, it was investigated whether visual completion is present for simple partly occluded shapes in a group of children with PDD and a typically developing group. In Experiment 2, the influence of local and global processes in visual completion was investigated for the two groups. Nineteen children with PDD and twenty-eight controls who were matched for chronological age and IQ took part in two primed-matching tasks. For both groups, visual completion was found and for both groups, global influences were found to be dominant. However, the group with PDD did not have priming effects from local primes on local test pairs. We conclude that the group with PDD did integrate visual information into wholes, and also did this in a global, not a local way. However, for more complex shapes, visual completion is weaker for this group.

298 Procedure- and Stimulus-Dependent Differences in Perceptual Filling-In after Macular Hole Surgery

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Traditionally, perceptual filling-in has been investigated at the optic nerve head as well as with artificial scotomas in the periphery. Research into this phenomenon related to central scotomas remains extremely limited, especially if they occur in the process of ocular disease. Recently, central retinal defects due to Age-Related Macular Degeneration, where scotomas are due to photoreceptor degeneration, have been examined from the perspective of filling-in. The present study took advantage of another ocular pathology, Macular Hole (MH), which results in central field defects due to circular and localized dislocation of photoreceptors in the macula. A surgical procedure (vitrectomy) facilitates closure of the MH, restoring visual function, yet, not always completely. Frequently, patients complain about distortions postoperatively.

Anatomical closure of the MH is clinically assessed with the Watzke-Allen (WA) Test, the projection of a bright white line across the surgical site. The present study investigated the parameters of this test (in 32 eyes) and established guidelines for a standardized version (in 17 eyes). Levels of distortion and perceptual filling-in were examined and compared with a new Line Resolution Test (LRT) in all 49 eyes. The clinically controllable parameters of the WA were line width and luminance. Stimulus display time could only be controlled in the LRT (500 ms) while assessing levels of perceptual filling-in and distortion (solid, bent or broken perception of the line). Overall, line perception on the LRT contradicted the WA in 15 eyes (31%). This disagreement was independent of the type of WA used. The large amount of contradiction in line perception between the two tests can, in part, be attributed to display time in the WA as patients have the opportunity to scan the stimulus. Furthermore, even the standardized WA was displayed at an extremely high level of luminance, facilitating the possibility of perceptual filling-in.

299 Abnormal spatial integration in Williams Syndrome is distance-dependent

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The cognitive profile of Williams Syndrome (WS), a genetic disorder, exhibits a profound weakness in visuospatial abilities and a relative

strength in language. Evidence from visuomotor tasks such as drawing and block construction suggests that WS individuals may be impaired in integrating information over space (see Bellugi et al., 1999; Hoffman et al., 2003). We characterized how WS individuals integrate spatial information by measuring positional acuity thresholds. We asked people with WS, normal children and normal adults to judge the position of a target square relative to two flanking squares. We found three notable results: 1) Positional thresholds normally decrease with age, and reach mature levels after 8-9 years old. 2) Doubling the flanker distance from 3 deg to 6 deg doubled positional acuity thresholds in normal adults, 8-9 year olds and 5-6 year olds, while it increased 6 times in WS participants. 3) For flankers at 3 deg, WS participants have thresholds better than 8-9 year olds. For flankers at 6 deg, WS people have thresholds worse than 3-4 year olds. These data suggest that WS people may be good at integrating proximal information, but may be impaired in integrating distal information perhaps reflecting abnormal parietal lobe functions.

300 Limited Retinotopic Reorganization in Age-related Macular Degeneration

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Purpose: Age-related macular degeneration (AMD) afflicts the central 58 to 108 of the retina. Studies of retinotopy of the primary visual cortex (V1) among normally sighted humans have shown that the central retinal area projects to a disproportionately large area at the posterior end of V1. It is not yet known what happens to the retinotopy in AMD patients with central visual field loss (CFL). The current study investigates the possible retinotopic reorganization in AMD patients using fMRI.

Methods: Four AMD patients aged 81 to 84 were studied. Macular perimetry was performed using a scanning laser ophthalmoscope prior to the fMRI session. Averaged size of CFL in the tested eye was 118. Two stimulus sequences were used. (1) Full-field vs. control vs. fixation. A change detection task at the 1.58 fixation cross was used to encourage stable fixation. The whole display (428 x 308) was filled with flickering checks during the full-field blocks. A check-filled 28 disc was presented to the estimated foveal location in the CFL area during the control blocks. (2) Whole-field scene vs. blank. Participants performed a 1-back picture matching task with free viewing of the pictures during the scene blocks. Functional and anatomical MR images were obtained with a Siemens 3T TRIO system and analyzed using BrainVoyager software.

Results: Macular perimetry confirmed that all participants used a preferred retinal locus (PRL) for fixation outside the CFL area. Posterior V1 showed activation in one of the four patients for both full-field and scene conditions. Anterior V1 showed activation in all four patients for both full-field and scene conditions. No V1 activation was detected in the control condition.

Conclusions: A substantial region of V1 remains unresponsive to visual stimulation in the majority of patients, suggesting the lack of extensive retinotopic reorganization in the elderly with AMD, despite evidence for behavioral adaptation in the use of a non-foveal PRL.

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301 Low Vision Differences between Static and Moving Patterns in Central and Peripheral Fields

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Impaired visual function is often described by reduced visual acuity, with effects thought to be qualitatively similar for various types of stimuli. Visual fields may be locally impaired, but little is known about how such local field deficits might interact with different visual discrimination tasks. Now, we report that (a) children with different low-vision etiologies may have differing deficits for static and moving patterns, and (b) these deficits may differ in the central and peripheral fields.

Vision was evaluated simultaneously in central and peripheral fields, using three adjacent monitors, each perpendicular to the visual direction - one central and two peripheral displays, at ± 30 deg eccentricity. Stimuli were Gabor patches. Static form perception was measured by orientation discrimination thresholds; and motion perception was measured by temporal thresholds for direction discrimination. In addition to single-stimulus discrimination tasks in which a test pattern appeared in a randomly selected field, attentional selection was also studied with multiple simultaneous Gabor patches and a spatial cue designating an individual target patch. Children with several different types of low vision have been tested, as well as normally sighted children and adults in the same visual tasks.

Normally sighted children and adults exhibited little or no difference in performance on these tasks. Low-vision children, however, exhibited dramatically different deficits not predictable from previous knowledge about acuity, visual fields, or etiology - deficits substantially different for static forms and moving patterns, and different for the central and peripheral fields. Evidently, perception of static forms and motion entail qualitatively different mechanisms and visual skills that differ between central and peripheral fields.

302 Psychophysical evidence for abnormal magnocellular processing in 6-month olds infants with autism in their family

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Previous psychophysical studies have shown impairments in motion processing, a dorsal visual stream function, in children with autism (e.g., Spencer et al., 2000). Since the dorsal stream receives input mainly from the magnocellular (M), and little from the parvocellular (P), pathway, these findings may reflect abnormal processing in the M pathway in autism. To test this abnormal M pathway hypothesis, and to determine whether such abnormalities are present early in life, we compared M and P pathway function in infants with an older sibling with autism (i.e., 'at-risk' infants, who have a ~10% chance of ultimately being diagnosed with autism, and added risk for sub-clinical social and communication deficits) with typical infants. M and P pathway function was assessed by obtaining luminance (L) and red/green chromatic (C) contrast sensitivities, respectively (see Dobkins et al., 1999). L and C sensitivities were determined in 88 typical and 11 at-risk 6-month-olds, using forced-choice preferential looking. The results of a 2-factor ANOVA (factor 1=subject group: at-risk vs. typical, factor 2=stimulus type: L vs. C) yielded a significant interaction ($(F(1,97) = 5.4, p < 0.05)$). These results suggest abnormalities in the relative integrity of M vs. P pathways in at-risk infants. Specifically, differences were observed for L sensitivity (at-risk: mean log = 1.53, se = 0.07; typical: mean log = 1.38, se = 0.04), but not C sensitivity (at-risk: mean log = 1.51, se = 0.08; typical: mean log = 1.54, se = 0.03). Although L sensitivity in at-risk infants was actually enhanced, this nonetheless suggests abnormalities in M pathway processing, which could potentially serve as a phenotypic marker for autism, and may explain some of the cognitive/behavioral problems of individuals with autism. Preliminary data will be presented investigating correlations between these visual data at 6-months and social-communicative behaviors at 10-months, and diagnostic outcomes at 24-months.

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303 In Vivo Characterization of laser Induced Photoreceptor Damage and Recovery in the High Numerical Aperture of the Snake Eye

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The high numerical aperture of the garter snake eye (*Thamnophis m. Marcianus*) permits in vivo imaging of the photoreceptor layer and anterior retinal blood cell activity. A Rodenstock confocal scanning laser ophthalmoscope (CSLO) was employed with laser imaging sources at 488, 514.5, 633, and 790 nm. Photoreceptor damage was examined for both thermal/mechanical as well as non-thermal/mechanical photoreceptor damage mechanisms. Anesthesia was induced with ketamine-xylezine, IM. Acute thermal/mechanical laser induced photoreceptor injury from external laser sources causes visible photoreceptor damage, characterized by high reflectivity in photoreceptors at the edge of the lesion site and loss of photoreceptors at the lesion center. During the first 60 seconds post exposure, photoreceptors may migrate in various directions away from the lesion site and individual photoreceptor orientations may be altered. Utilization of the 790 nm CSLO imaging source revealed maximal in vivo photoreceptor reflectivity as compared with shorter wavelengths (488 nm), as longer wavelength imaging sources focus within the altered outer segment lamellae, while shorter wavelength sources focus closer to the posterior edge of the photoreceptor outer segment. Examining comparable exposure conditions at the level of the retinal vasculature reveals the appearance of 'sticky' blood cells which cumulate in the retinal photoreceptor and retinal nerve fiber layer (RNFL) injury sites and have been identified with acridine orange as leukocytes. At non-thermal levels of exposure, photoreceptors undergoing oxidative stress have been identified with H2DCF_{DA}, adjacent to photoreceptors injured under thermal mechanical conditions. Long term evaluation of photoreceptor damage sites show a decrease in photoreceptor lesion site size, suggesting photoreceptor reorganization and replacement and raises the issue that such migration might be driven by active as well as passive photoreceptor recovery mechanisms.

Locomotion, Steering and Posture

304 The Roles of Spatial Knowledge and Visual Landmarks in Navigation

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We recently reported that human participants rely on ordinal rather than metric spatial knowledge when navigating to known locations in a virtual hedge maze (Harrison et al, VSS 2001). Ordinal structure refers to the sequential relationship among junctions and paths in the maze, whereas metric structure refers to Euclidean distances and angles between them. In other experiments, we found that participants depend heavily on visual landmarks rather than spatial knowledge acquired from path integration when taking a shortcut between two known locations (Foo et al, JEP: LMC, in press; VSS 2004). Here we compare the contributions of ordinal structure and visual landmarks when navigating in the maze. Participants actively walk in an immersive virtual environment (12m x 12m) with a head-mounted display (60 deg H x 40 deg V) and a sonic/inertial tracking system (latency 50 ms). In the learning phase, participants freely explore a hedge maze with visual landmarks at some junctions, in order to learn 10 places. In the testing phase, they are instructed to walk to these places from a home location. On control trials, the environment is the same as during learning. On probe trials, the environment is changed in one of three ways. In the first condition, the maze layout remains constant while the landmarks are shifted by one junction; thus, metric and ordinal structure are preserved but landmark positions are changed. In the second condition, the maze is stretched along its major axis, preserving its ordinal

structure, while landmark positions remain constant. In the third condition, a radial arm section of the maze is rotated by 45 deg, while landmark positions remain constant. If participants follow the landmarks, they turn onto incorrect paths in the probe trials. If they rely on ordinal knowledge of the maze, they ignore landmarks and take the correct paths. The results allow us to compare the relative contributions of ordinal spatial knowledge and visual landmarks in active navigation.

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305 Investigating the effects of occlusion time on the visual guidance of blind-walking, veering, and distance perception

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Previous researchers have explored the effects of visual occlusion on egocentric distance perception and blind-walking down straight pathways. For example, Rieser et al. (1990) reported no systematic error in blind-walking distance of up to 22 m following an 8 sec occlusion time (OT). Tyrrell et al. (1993) reported a gradual decay in the distance blind-walked down a straight pathway as OTs increased. More recently, Tyrrell et al. (1997) and Brown et al. (2004) found that even after longer OTs, blind-walking participants did know where straight ahead was, but still suffered from decay in path-walking performance. To further explore the characteristics of blind-walking, the present study tested 25 college-aged participants using a 40 cm wide by 15 m long pathway laid out on a gymnasium floor. Their instructions were to blind-walk down the pathway following 5, 30, or 60 sec OTs. On some trials, a target cone was placed in the path's center at 4 or 12 m, and instructions were to stop when they believed they had reached the cone. Distance walked within the path was measured on every trial; total distance walked and stopping location's lateral position from the path's center (veering) was measured on target-present trials. Similar to previous studies, there was an OT effect as participants walked shorter distances following longer OTs. Interestingly, when targets were present, path distances walked tended to be shorter at all OTs. There was more veering on 12 m target trials, and longer OTs tended to increase veer. On average, participants walked about 85% of target distances. Although inconclusive, preliminary results tended to show that longer OTs increase distances walked to shorter targets and reduce distances walked to further targets. In conclusion, longer OTs do seem to affect blind-walking, veering and distance perception differently from shorter ones.

306 The Influence of Vision on the Estimation of Walked Distance

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Traversed distance estimation is influenced by both visual cues (particularly optic flow) and locomotor cues (proprioceptive/efferent copy and vestibular). While evidence suggests that locomotor cues alone can be used to estimate distance, little is known about the role of optic flow when both visual and locomotor cues are available simultaneously. The current study employed a consecutive cue-conflict paradigm to compare distance estimates obtained via locomotor cues alone to those obtained via both locomotor and optic flow cues. This experiment took place in a large, open, outdoor environment. Subjects (Ss) were presented with two distances, which they were informed were identical in magnitude; one via blindfolded locomotion (L) and one via locomotion with vision (LV) (with the order of the two randomized). For the majority of the trials, the magnitude of the two stimulus distances was indeed the same (congruent), but for a small subset of trials the two distances differed in magnitude (incongruent). Subsequently, Ss produced an estimate by adjusting the distance of a visual target to match the learned distance. Overall, a small underestimation was observed in all cases. For congruent trials, when the same cues were present in both stimulus distances, estimates were slightly

shorter for LV than for L. However, when different cues were present in the two stimulus distances, there was also an effect of cue presentation order. When LV occurred second, distance estimates were much shorter than when LV occurred first. For incongruent trials, the effect of cue was compounded with a powerful effect of distance presentation order. When the longer distance was presented second, estimates more closely approximated the longer distance, whereas when the shorter distance was presented second, estimates more closely approximated the shorter distance. This effect was more prominent when LV occurred second, indicating a dominant effect of vision and an interaction between cue and presentation order.

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<http://www.cog.brown.edu/>

307 Speed of Visual Flow Affects Comfortable Walking Speed

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When a person is instructed to walk at a comfortable speed, their actual walking speed is influenced by the velocity of visual flow that they experience. This is a surprising result, given that "walking comfortably" would seem to depend on purely biomechanical factors. To demonstrate this result, we utilized a computer controlled treadmill with a 6' by 10' walking surface, surrounded by three 8' by 8' projection screens oriented to provide an approximately 180 degree horizontal field of view. Users were able to walk at any speed of their choosing on the treadmill, with the speed of the treadmill belt automatically adjusting as needed. Ten subjects participated. Each subject had three minutes to gain familiarity with the user-controlled treadmill. Following this, each subject was directed to walk comfortably in three different conditions, visually slower (0.5X), visually same (1.0X) and visually faster (2.0X) than their walking speed. The practice and each of the three conditions on the treadmill were separated by five minutes of walking around in an actual hallway. The conditions were randomly ordered for each subject. Subjects on average chose 1.41 m/s for the visually slower condition, 1.21 m/s for the visually faster condition and 1.29 m/s for the visually same condition. This indicates that subjects use the speed of the visual flow when deciding their own comfortable walking speed. The result is consistent with a previous finding of ours, using the same treadmill but with the belt speed under computer control, that the speed at which walk/run and run/walk transitions occur is also affected by the speed of visual flow (Mohler et al., 2004, SIGGRAPH-APGV).

308 Does the location of visual field loss change mobility and fixation behaviour when walking an unfamiliar environment?

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Purpose: Recent data challenges the assumption that observers use optic flow at walking speeds in real environments (Rushton et al, 1998, Current Biology 1191). We compared mobility and eye movement behaviour in low vision observers with central (age-related macular disease) or peripheral (glaucoma) field loss. In the former, wide-field motion (optic flow) cues are spared, but central high resolution acuity is impoverished, in the latter, the opposite is true. This is a preliminary study investigating 2 normal observers and 5 patients.

Methods: Mobility, fixation behaviour and direction of gaze were measured with a video-based mobile head-mounted eye-tracker (ASL 501) in patients and age-matched controls while walking a 132m course. The course was divided into six sections, including corridors, stairs and road-crossings. Instructions were given at the beginning of each section. Gaze position was classified into scene categories that were analysed manually and computationally by cross-correlation of the image at fixation over time.

Results: Patients with central and peripheral field loss showed impaired mobility and fixation behaviour compared to age-matched controls. Performance was not dependent on the location of the visual field loss. Age-matched controls primarily fixated the pre-determined goal points. Patients had larger and more variable fixations and saccades, viewed more scene categories and took longer to reach the goal. This was confirmed with the objective cross-correlation analysis.

Conclusions: Loss of visual field impairs mobility in patients when walking an unfamiliar real environment, independent of the location of the scotoma. Age-matched controls directed their fixations mainly towards the goals, while patients fixated many other objects in the scene indicating that they spent longer searching for the goal or potential obstacles. Both high resolution central vision and wide field sensitivity are critical components of walking behaviour in real environments.

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309 Rapid recalibration of locomotion during non-visual walking

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Purpose: Blindfolded walking has increasingly been used to measure perceived target location. In this technique, observers view targets and attempt to walk to them without vision. This response involves a mismatch between visual and proprioceptive self-motion signals. As such, walking could become recalibrated over the course of successive trials, resulting in increasingly biased responding. This study tested the idea that small amounts of non-visual walking might systematically bias indications of target location in blindfolded walking tasks.

Method: During a Pre-Test phase, subjects (N = 20) walked for 3 min at 5 km/hr, either with or without vision. Then, they binocularly viewed targets in a well-lit room and either verbally estimated the target distance or attempted to walk to it without vision. Target distances ranged from 1.0 to 6.5 m. In a second session occurring at least 5 days later, subjects completed a similar set of trials, with the exception that the availability of vision during the Pre-Test phase was switched.

Results: When participants walked WITH vision during the Pre-Test, the mean signed error in subsequent blindfolded walking trials was -2, -8, -23 and -25 cm for targets at 1.5, 3.0, 4.5 and 6.0 m, respectively. When the same participants walked WITHOUT vision during the Pre-Test, the analogous errors were 13, 13, 2, and 30 cm. On average, blindfolded walking responses preceded by non-visual walking during the Pre-Test phase were 29.2 cm greater than those preceded by walking with vision during the Pre-Test phase ($p < .001$). Verbal responses were not affected by vision during the Pre-Test ($p = .83$); the mean signed error was -10 cm.

Conclusion: Even 3 min of exposure to non-visual walking is sufficient to significantly recalibrate subsequent indications of target distance using blindfolded walking. This suggests that blindfolded walking responses are themselves likely to change the calibration of walking during lengthy experiments.

310 The effect of HMD mass and inertia on visually directed walking in virtual environments

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Research has shown that people are able to judge distances accurately in full-cue, real-world environments using visually directed actions. However, in virtual environments viewed with head-mounted display (HMD) systems, there is evidence that people act as though the virtual space is smaller than intended. This has been a surprising result given how well people act in real environments. The behavior in the virtual setting may be linked to distortions in the available visual cues or to a person's ability to locomote without vision. Either could result from issues related

to added mass, moments of inertia, and restricted field of view in HMDs. In previous studies, subjects showed a reliable effect of compression compared to unrestricted viewing while wearing a mock HMD in a real room. The mock HMD replicated the mass, moments of inertia, and field of view of our HMD. The current investigation dealt specifically with understanding how the additional mass and moments of inertia associated with the HMD might affect distance judgments. Subjects wore an inertial headband designed to replicate the moments of inertia and mass found with our HMD. The headband was constructed to not restrict the field of view of the observer or otherwise feel like wearing a helmet. Subjects performed either a direct walking task or a triangulated walking task without vision to previously seen targets on the ground in a real room while wearing the inertial headband. We compared their performance to the same tasks performed in a real room with no viewing or inertial restrictions, in a real room with the mock HMD, and in the virtual environment wearing the HMD. Indicated distances with the inertial headband were somewhat compressed relative to those with no restrictions, but this difference was not statistically significant. This is in contrast to the mock HMD combining mass, moments, and field of view restrictions, which does show a reliable difference from the no restriction condition.

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311 Intercepting moving targets on foot: Can people learn to anticipate target motion?

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Humans walk to moving targets by turning onto a straight interception path that achieves a constant target-heading angle. Warren & Fajen (2004) proposed a dynamical model of interception based on first-order information about target motion, which nulls change in the target-heading angle. The model successfully reproduces human paths to constant velocity targets, as well as to targets with accelerating or curved trajectories. Accelerating and curved trajectories provide a strong test of the model, for it predicts continually curving paths that lag the target and do not anticipate its motion. These predictions were confirmed in experiments where the target's trajectory was randomized on each trial. Here we test whether people can learn to anticipate target motion when the same trajectory is repeatedly presented. Participants walk to intercept virtual targets in the VENLab, a 12m x 12m virtual environment with a head-mounted display (60 deg H x 40 deg V) and a sonic/inertial tracking system (latency 50 ms). There are four blocks of 20 repeated trials. Each block presents a target trajectory that was tested previously, including two straight trajectories with accelerations of 0.1 m/s/s and 0.15 m/s/s, and two curved trajectories with radii of 1.5 m ($v=0.9$ m/s) and 2 m ($v=1.3$ m/s). The initial direction of target motion is randomly leftward or rightward on each trial. The model predicts consistently lagging paths across trials in a block, with no learning to anticipate target motion. If learning occurs we expect to see straighter, more direct paths to intercept the target.

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312 Integrating Target Interception and Obstacle Avoidance

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Background: Fajen & Warren (JEP:HPP, 2003) modeled locomotor behavior as a dynamical system in which stationary targets and obstacles function as attractors and repellers of an agent's target-heading angle. Subsequent work extended this model to the case of a moving target (Warren & Fajen, *Psychonomics* 2002) or a moving obstacle (Warren, Sun, & Fajen, *VSS* 2003). Our purpose is to test whether these four components can be integrated into a general model of locomotor behavior. The present study examines intercepting a moving target in the presence of a stationary obstacle.

Research Question: Participants are asked to intercept a moving target when a stationary obstacle is placed in the vicinity of their interception path. We test model predictions about (1) when and where participants start to avoid the obstacle, and (2) under what conditions participants pass left or right of the obstacle.

Design: Testing is done in the VENLab, a 12 x 12 m virtual environment in which participants can walk freely. Participants wear a head-mounted display (60 deg H x 40 deg V) that presents a textured ground plane with colored poles that serve as obstacles and targets. Head position is recorded at 30Hz, and we analyze the 2D path and the time series of target-heading angle. The moving target's trajectory (90 deg (frontal plane) or 120 deg) and speed (.4, .5, .6 m/s) are varied, as is the presence of a stationary obstacle near the interception path.

Implications: This study is part of a research program to develop a general model of locomotor behavior that can predict human paths through complex environments. Such a model demonstrates that locomotor paths may emerge on-line from the interaction between an agent and a structured environment, rather than being explicitly planned.

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<http://www.mapageweb.umontreal.ca/gosselif/co.html>

313 Switching Behavior in Moving Obstacle Avoidance

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Purpose: Previous work by Warren, Di, & Fajen (*VSS*, 2003) investigated the paths people take to avoid a moving obstacle en route to a goal. These results were used to extend a dynamical model for stationary and moving obstacle avoidance (Fajen & Warren, *JEP:HPP*, 2003). The current study tests the model for the critical conditions in which participants switch from passing in front of a moving obstacle to passing behind it. We then generalize the model to environments containing both moving and stationary obstacles.

Methods: Studies are conducted in the Virtual Environment Navigation Lab, a 12m x 12m space allowing for free movement in a virtual world. Participants wear a head-mounted display (HMD) with a 608 (H) x 408 (V) field of view of a virtual environment consisting of a textured ground plane. They are instructed to walk towards a stationary goal (blue post) while avoiding a moving obstacle (red post). Head position and orientation are recorded using a hybrid inertial/ultrasonic tracking system that samples their movements at 60 Hz, and updates the display with a 50 ms latency.

Design: To create critical switching conditions, the speed and direction of the moving obstacle are manipulated. In Experiment 1, the obstacle moves on a 708, 908 (frontal plane), or 1108 trajectory, crossed with speeds of 0.4, 0.6, and 0.8 m/s. Experiment 2 adds a stationary obstacle near the participant's observed path.

Implications: Results from these studies test and refine the obstacle avoidance components of the steering dynamics model. Related studies test the component for moving target interception (Owens & Warren, *VSS* 2004, 2005; Bruggeman & Warren, *VSS* 2005), with the aim of integrating these components into a general model of locomotor behavior in complex environments.

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314 Heading off the beaten path

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Theoretically, one can recover instantaneous direction of 3D translation (heading) from a single 2D retinal velocity field created by the instantaneous motion of points in a rigid 3D environment. However, recovering the trajectory through the environment (path) requires more (e.g. motion over time of environmental points, displacement with respect

to recognizable landmarks, or eye-rotation information). Confusion between heading and path has made interpretation of many earlier studies difficult (see Royden, 1994). Although Stone & Perrone (1997), careful to avoid this problem, showed that humans can estimate heading in the absence of landmarks, static depth cues, or eye-movement information, they did not resolve whether heading was estimated directly from the velocity field or indirectly by first estimating path and then inferring its tangent. To isolate heading from path, we used dynamic random-dot motion stimuli in which environmental points are periodically redrawn. The display simulated an observer travelling on a circular path (yaw rate: 5-208/s) through a random-dot 3D cloud (depth range: 6-50 m) at three translation speeds (7.5, 10, & 15 m/s) under two conditions: 'static scene' in which dots were displayed until they left the field of view and 'dynamic scene' in which dot lifetime was limited to 100 ms to match the integration time of human motion processing. Observers received feedback during initial practice only with static scenes. On each trial, observers used a joystick to rotate their line of sight until deemed aligned with true heading (method of adjustment). For 5 observers (4 naïve), performance was similar in both conditions (mean heading bias \pm mean heading uncertainty across observers: 1.98 ± 4.18 and 0.18 ± 4.38 , for static and dynamic scenes, respectively). Humans can accurately adjust their heading with no visual path information (from the velocity field and an *a priori* assumption of a curved path), showing that heading is available for active steering.

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315 In steering without visual feedback, subjects can properly initiate the return phase of a 'lane change' maneuver

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Can driver steering behaviors, such as a lane change maneuver, be executed without visual feedback? According to Wallis et al. (2002), drivers fail to execute the return phase of a lane change when steering without vision. The authors report systematic final heading errors biased in the direction of the lane change as evidence that drivers do not have knowledge of the relationship between steering angle and heading. Is lane changing a special case, due to the instruction to change position and minor required changes in heading, or does this result generalize to other steering behaviors? Suppose that, when asked to perform a lane (position) change, drivers fail to recognize that a heading change is required to make a position change with a car. However, given an explicit path, the necessary heading changes become apparent. Here we show that when heading requirements are made explicit, on average, subjects accurately implement the return phase. As a measure, final heading error provides minimal information about the relative phases of the maneuver. A more representative measure is the ratio of the heading change of the return phase to the heading change of the initial phase. In our experiment, subjects executed 'lane change' maneuvers with and without explicit heading information in a virtual reality driving simulator. Without explicit heading information, the return ratio was 0.28, essentially replicating the results of Wallis et al. (2002). With explicit heading information, however, the return ratio was 0.96. We will also be reporting results with an electric vehicle outfitted with a portable virtual reality system.

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316 A neural model of visually-guided steering and obstacle avoidance

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How does a human steer toward a stationary goal while avoiding contact with obstacles in a cluttered environment? Successful steering behavior

involves a dynamical interaction between a person's perceived heading and the egocentric locations of the goal and obstacles. Psychophysical data suggest that a goal acts as an attractor of heading, while obstacles act as repellers of heading (Fajen and Warren, 2003, JEP:HPP, 29:343-362). We propose a neural network model that combines neural representations of heading and goal and obstacle positions to generate realistic steering behavior. The model extracts heading from an optic flow field using network layers that model properties of cells in cortical areas MT and MST, and it constructs goal and obstacle representations by combining form and motion cues. The model also contains a circuit that controls smooth pursuit eye movements to maintain fixation on the goal during locomotion. Rotating the eye during locomotion introduces systematic distortion of the optic flow field, and the model corrects for the effects of eye rotation using extra-retinal signals. The model's architecture captures the attractor/repeller dynamics of steering behavior, while clarifying the role of heading perception and eye movements in complex steering tasks. Computer simulations demonstrate model properties on several steering tasks, including approaching goals at different distances and initial viewing angles, and steering in the presence of single and multiple obstacles. Simulation results are compared with the psychophysical data of Fajen and Warren (2003). Supported in part by NSF, ONR, AFOSR, and NGA.

317 Covert orienting of attention and the perception of heading

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Previous studies in locomotion have focused on the perceptual information present in the scene. The purpose of the current study was to investigate the role of attention on performance on heading judgment tasks. Subjects viewed a 3D scene containing objects lying on a ground plane. The scenes were presented in two frames: the first frame showed the subjects' initial position, and the second frame showed the scene from a different viewpoint as if the subject walked from the first to the second position. Subjects were judged their heading direction relative to a pole in the distance. The first frame contained 12 objects, of which 4 were red, 4 were green, and 4 were blue. The second frame contained only one set of the colored objects; for example, 4 red objects remained while the green and blue objects disappeared. An ISI (blank screen of 50 or 1000ms) was presented between the frames to simulate the presence or absence of apparent motion. Subjects were validly cued, invalidly cued, or neutrally cued to a set of colored objects. In the valid-cue condition, subjects were cued to attend to the color of the objects that remained from the first frame to the second frame. In the invalid-cue condition, the participants were cued to attend to one color of objects that will not be present in the second frame. In the neutral-cue condition, the participants were cued to attend to all 12 objects. Our results show that accuracy in heading judgments increased as heading angle increased. Subjects had greater accuracy when apparent motion was present than when apparent motion was absent. Most importantly, subjects had greater accuracy at the valid condition as compared to the invalid and neutral conditions. The results suggest that attention operates during locomotion, and subjects can selectively attend to specific objects or groups of objects in the scene that are relevant for heading judgments. The role of attention in extracting landmark information will be discussed.

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318 Visual control of braking behind a moving lead vehicle

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Previous research on visually guided braking has focused on avoiding collisions with stationary objects in the path of motion. We extended the investigation of braking to the situation of decelerating behind a lead vehicle moving at a constant speed. Our model, an extension of Fajen's (in

press; VSS 04) model for braking behind a stationary obstacle, predicts that braking is controlled by keeping the perceived 'ideal deceleration' between zero and maximum deceleration. For stationary objects, ideal deceleration is optically specified by optical angle, expansion rate, and global optic flow rate (GOFR). Because GOFR specifies absolute rather than relative speed, the extended model predicts a bias to brake harder than necessary when following a moving lead vehicle. The magnitude of the bias should increase at higher absolute speeds, even when relative speed is held constant. Participants performed a simulated braking task, using a joystick to slow down and maintain a short but safe headway behind a moving lead vehicle. Subject vehicle absolute speed and subject vehicle/lead vehicle relative speed were independently manipulated. Analyses focused on ideal deceleration at the onset of braking and brake adjustment magnitude. If braking behind a moving lead vehicle is biased by GOFR, then participants should brake earlier and/or harder when absolute speed is higher. To test whether participants compensated for this bias after practice braking behind a moving lead vehicle, we included a second block of trials in which the range of absolute speeds was slower, but the range of relative speeds was the same. If participants learn to compensate for the bias, then there should be an aftereffect in the opposite direction to brake too weakly behind slowly moving or stationary lead vehicles. The resulting pattern of biases is the consequence of using an identical strategy for braking behind stationary and moving lead vehicles.

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319 Rapid recalibration in visually guided braking

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The limitations of our action capabilities impose a critical constraint on successful performance. When braking to avoid a collision, for example, the deceleration required to stop (the 'ideal deceleration') must be kept below the maximum possible deceleration. Ideal deceleration is optically specified, but maximum deceleration is a property of the observer's body or vehicle for which there is no information. Fajen (VSS 04; submitted) proposed that calibration to brake strength involves learning to detect information about ideal deceleration in intrinsic units of maximum deceleration. The focus of the present study is on the rate of recalibration to changes in brake strength. Participants viewed computer generated displays simulating approaches to a stop sign, and used a joystick as a brake to stop as closely as possible to the sign. When brake strength was manipulated as a randomly presented within-subjects variable in Experiment 1, there was evidence of partial recalibration on a trial-by-trial basis. In Experiment 2, trials were presented in ten blocks of 25. In Blocks #1 through #4, brake strength was either weak (Group 1) or strong (Group 2). Participants in Group 1 initiated braking at lower values of ideal deceleration (in extrinsic units of m/s^2), but ideal deceleration at onset expressed in intrinsic units as a percentage of maximum deceleration was the same for both groups, suggesting that participants completely calibrated to the strength of the brake within the first block. In Blocks #5 through #10, brake strength was switched for both groups to a moderate level between weak and strong. Both groups recalibrated, but Group 1 took longer to completely recalibrate. The results suggest that observers are capable of rapidly recalibrating to changes in brake strength, but that the rate of recalibration depends on factors such as the direction of change in brake strength.

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320 The direction of vection is controlled by perceived motion

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Several past studies have demonstrated that internal motion signals that do not reflect in subjective perception do affect other aspects such as motion aftereffect. In this study, we examined whether such hidden motion signals affect vection by using pedestal and a type of missing fundamental stimuli (2f+3f motion). The pedestal stimulus was generated by adding static gratings to drifting gratings of the same spatial frequency.

These stimuli contained motion energy to one direction but no directionality for feature-based system, and motion perception actually became ambiguous when the contrast of static gratings was high. In these occasions, vection should occur according to the first-order direction, if vection is mediated solely by low-level motions. In the experiment we asked subjects to judge the direction of vection and perceived motion in separate sessions. The pedestal stimuli and regular drifting gratings were presented for 30 sec each in a randomized order. Whereas as normal vection was perceived with regular gratings, no systematic vection was found for pedestal stimuli when perceived motion was ambiguous. A similar experiment was conducted with 2f+3f stimuli. These stimuli had 2nd and 3rd harmonics of a fundamental frequency, and the first- and second-order components moved in opposite directions when motion was created by shifting the pattern a quarter wave-length of the fundamental at a time. The dominance of the two types of motion, i.e. the direction of perceived motion depended on SOA. The direction of vection should follow the first-order direction regardless of the perceived motion, if vection is controlled by low-level motion. As a result, we found a high correlation between the directions of vection and perceived motion. These results together indicate relatively weak contribution of low-level motion to vection. Rather, they demonstrate a strong influence of higher-order motion systems.

321 Effect of Visual Sway on Postural Balance in a Full Immersive Environment

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The role of visual input on postural balance remains relatively unknown. As the population ages, it becomes important to determine possible effects of visual distortion induced from ophthalmic lenses used to correct presbyopia on the capacity to interact with the environment. One of the consequences of progressive ophthalmic lenses used for presbyopia correction is induced sway. i.e. the world appears to move up and down in peripheral vision under certain viewing conditions. A full immersive environment is ideal to answer such questions as the virtual world is not limited to screen size and we can therefore measure the full impact of sway on the ability to keep our balance. We used a CAVE composed of four projection surfaces (3 walls and the floor) equipped with a motion tracking system (Flock of Birds) to determine the effect of a variety of speeds and amplitudes of sway movement on posture. Sensors were positioned at the head and lower back and recordings were made while the subjects were observing visual stimuli. Three amplitudes (1, 2 & 4 deg max slope) and 10 speeds (from 0.03 to 2 Hz) were evaluated. The virtual image was a checkerboard pattern composed of 0.25x0.25m squares on a 10x10m floor size. The subjects were asked to remove their shoes and stand looking straight ahead with both feet together and side-by-side. Five young healthy observers participated in the study. The results show a clear effect of visual sway on posture particularly at lower temporal frequencies. Amplitude effects were only evident at the lowest temporal frequency. The amplitude of displacement responses show a low-pass tuning function as a function of speed. Phase delays are also clearly evident for the 5 lower temporal frequencies but appear to break down with higher speeds. In conclusion, we show that visual input is extremely important for maintaining postural balance, particularly under low speed conditions. Further work, will evaluate the effect of sway on older observers.

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322 Effects of motion and tilt of large-visual-stimulus on perception and postural control

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When you are on a still train and the train next to your train is moving, you would feel you are moving and you might lose your body balance. Thus, visual stimuli influence postural control and the perception of self-motion. Our previous research (Tsuruhara & Kaneko, 2004) showed that the center of subjects' body shifted along with the rotation of a large-stimulus of natural scene, and returned back with a bias remained after the stimulus stopped with a tilt. The perceived stimulus-tilt and self-tilt for the same stimulus, on the other hand, didn't change with time systematically. These results indicate that the bias of center of balance wouldn't cause the inaccurate stimulus-tilt or self-tilt perception, or vice versa.

Many studies have claimed that dorsal pathway would be mainly responsible for action, and ventral pathway for perception. So postural control might be more sensitive to motion than static tilt. This study investigated the effects of motion and tilt of large-visual-stimulus on postural control and on the perception of stimulus-tilt and self-tilt.

A photo slide was projected onto a large hemispheric screen (2 m in diameter). Initially the slide was upright for 10 sec, then presented with a tilt (0 - ± 20 deg; + : cw, - : ccw). Right after or 10 sec after presenting tilted stimulus, subjects responded the perceived stimulus-tilt or self-tilt. The center of body was measured using force-plate for 70 sec. These three measures were collected in different sessions. Subjects kept standing upright and seeing the center of screen throughout a trial. Results showed that even when subjects didn't see the rotating motion, their center of body, as well as stimulus-tilt or self-tilt perception, was affected by static tilt with the same amount and time course as rotating motion presented. Information about vertical or horizontal axis in natural-scene might have strong effects on postural control.

323 Gaze Polling and Fixation Shifting of Cyclists Negotiating a Slalom

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Following on from our work investigating gaze and steering along simulated roadways (Wilkie & Wann, 2003; 2004) we examined gaze behaviour in a steering task that supported a greater degree of route selection. We integrated a bicycle with our simulation rig that allowed more precise measurement of the paths taken, due to narrowness of the bicycle wheel. Participants steered around a series of obstacles in a simulated slalom of varying complexity. We recorded patterns of gaze sampling alongside the mean passing distance from obstacles, the overall variability of paths, and the smoothness of each trajectory. Gaze responses were categorized as either gaze 'fixations' on the most proximal obstacle (O_n), gaze 'polling' of more distal obstacles (a saccade to O_{n+1} and then refixation of O_n) or gaze 'shifting' (saccade and fixation of O_{n+1} with no refixation of O_n). Increased course complexity caused more steering errors, with greater path variability and reduced steering smoothness. The mean timing of gaze shifts did not change, though there was variability across obstacles (reflecting the changing demands of the task) and participants (related to their steering skill). Gaze polling was only intermittently observed, except in one participant who was particularly well practiced. She also displayed the greatest accuracy and smoothness in steering, suggesting that polling is only employed at an advanced state of locomotor control. We then examined how enforced timings for gaze fixations and shifting disrupted steering. These results and the relationship between gaze polling, fixation shifting and steering performance are discussed in the context of our current steering model (Wann & Wilkie, 2004).

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http://www.psico.units.it/users/fantoni/surface_interpolation

324 Seeing into the Future: An interaction between perception and action

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Starting with J. J. Gibson (1979), researchers have been interested in the relationship between the perceiver and perception. In our experiments, we have specifically looked at how the perceiver's ability to reach to targets influences perceived distance to the targets. Participants estimated the distance to targets that were placed beyond their reach. However, during half of the trials, participants reached with a tool, which allowed them to reach to all of the targets. This allowed us to manipulate reachability while keeping distance constant. There was a main effect of distance, which demonstrates the well-known fact that optical cues provide information about the target's location. Moreover, there was also a main effect of reachability. Targets within reach as a result of holding the tool looked closer than when the participants did not wield the tool and the targets were beyond reach. This result demonstrates that the perceiver's ability to act on the environment influences the perception of the environment. Several follow-up experiments suggest that the mechanism responsible for these effects involves a motor simulation of reaching. Participants were able to anticipate their reaching abilities even when they waited to pick up the tool and when they simply imagined holding the tool. However, reachability did not affect perceived distance when participants did not run a motor simulation nor when participants could not run a motor simulation. Motor simulations are important for planning actions that will allow perceivers to achieve their goals, so we think that these effects demonstrate that conscious perception is future-oriented. More research is needed to truly understand the mechanisms underlying these effects; however, these results provide strong evidence for an important interaction between the perceiver and his or her perception of the environment.

Motion in Depth 1

325 Effects of Binocular Disparity and Optic Flow Noise on Visual Cue Integration for Motion-in-Depth

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Previous work on cue combination of optic flow and disparity cues for surface shape perception has suggested that these cues are processed independently to generate separate shape estimates which are combined in a statistically optimal fashion. In this study, we investigate whether these cues are independently processed for velocity perception of motion-in-depth. We psychophysically investigated visual cue integration of optic flow and disparity by testing 3 subjects on a 2AFC-relative velocity-in-depth judgment task. The velocity-in-depth specified by each cue was independently manipulated for a flat mesh object randomly generated each trial by a Delaunay triangulation. We examined the effects of adding each of two types of noise, disparity noise and optic flow noise, to the stimuli to determine the effect on discrimination thresholds for each cue in isolation and in combination. Independence predicts that cue thresholds will only be affected by noise to that cue. The results did not support independent processing of the cues. In particular, optic flow noise resulted in a concomitant increase in both optic flow and disparity thresholds. Disparity noise, on the other hand, only affected disparity thresholds, without affecting optic flow thresholds. Cue combination thresholds in every condition were significantly greater than predictions of an independence (weak fusion) model of cue combination. A strong fusion (dependence) model of disparity and optic flow cue combination for relative velocity-in-depth discriminations is suggested by our findings. This research was partially supported by NIH EY015261-01.

326 Effects of object and background spatial frequency on the perceived shape of a moving object

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Objects in a visual scene are not usually isolated and their surroundings may alter their perceived attributes. The speed of a moving background, for instance, can affect the perceived shape of an object moving in front of the background (Zhong & Braunstein, 2004). The present study investigated the effect of the spatial frequency content of a stationary background on the perceived shape of a moving object. The background was a frontally oriented horizontal or vertical sinusoidal grating with a spatial frequency of 0.6, 1.2 or 3.5 cycles/degree. A horizontally or vertically oriented cylinder rotated in front of the background. The texture pattern on the cylinder was also a sinusoidal grating with one of these three spatial frequencies. The observer's task was to adjust the length of a line presented on a separate monitor to match the perceived distance between the most convex part of the cylinder and the plane of the background. The perceived width of the cylinder was estimated in separate blocks of trials. We found a significant effect of the spatial frequency of the background on the perceived depth of the cylinder, with judged depth increasing with a decrease in spatial frequency. Judged width of the object did not vary significantly with the spatial frequency of the background. An increase in the spatial frequency of the texture grating on the cylinder resulted in an increase in judged depth and width, although this effect was less consistent across observers than the effect of the background. These effects may be due to changes in the perceived distance of the cylinder and background, associated with the spatial frequencies of the textures and the resulting variations in edge rate as the cylinder rotates.

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327 Quadri-Stable Percepts For a Rotating Non-Transparent Object

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Continuous viewing of a rotating transparent object with an axis inside of the object may lead to perceptual alternation between two opposite rotations. The current consensus maintains that the bi-stable phenomenon depends on simultaneous stimulation by multiple depths defined by elements moving in different directions (1). By using a single specifically designed non-transparent object with a rotation axis outside of the object, this abstract shows that for perceiving rotation alternation the requirement for simultaneous stimulation by the elements in different depth moving in different directions is not necessary. If the rotation axis is outside, the object when moving rightward does not appear simultaneously with the same object when moving leftward at a different time, or vice versa, regardless of the real rotation leftward or rightward. Our experiments demonstrate that continuous viewing of the rotation leads to perceptual alternation also. In addition to the commonly perceived two opposite rotations, two new stable percepts occur as well. In other words, total four different stable percepts may occur (a quadri-stable phenomenon): rightward rotation; leftward rotation; two rotations following the infinite symbol 8-like tracks: ? ?8 ?? and ?8?. The arrow symbol indicates the moving direction of the object towards the viewer (?) or away from the viewer (?) at the both ends of the 8-like track. Because the elements of different depth moving in different directions do not appear simultaneously, the quadri-stable phenomenon signifies that some kinds of perceptual memory facilitate perceptual alternation. It is interesting to note that the perceptual memory, on the contrary, also stabilize percepts in perceptual rivalry (2). The quadri-stable phenomenon also suggests that using depth ambiguity to explain depth reversal is not completely satisfactory (2).

(1) Nawrot & Blake, *Science* 244, 716-718(1989).

(2) Leopold, et al. *Nature Neuroscience* 5, 605-609(2002).

328 Early Development of Anisotropic Sensitivities for Expansion/contraction Detection

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The visual system has higher sensitivity to expansion than to contraction (e.g. Ptito et al., 2002; Takeuchi, 1997). Early development of the anisotropy for expansion/contraction detection have investigated by Shirai et al. (2004a). They tested 2-8 month olds' sensitivity to expansion/contraction by using visual search displays and demonstrated that the anisotropy for expansion/contraction detection emerges at about 3 months of age.

In the present study, we re-examined development of the anisotropy by using dynamic random dot patterns (RDPs). RDP is a popular stimulus to measure young infants' motion sensitivity (e.g., Banton & Bertenthal, 1996; Shirai et al., 2004b; Wattam-Bell, 1996).

A total of 115 2-4 month-old infants participated. We presented two RDPs to the infants side by side. One was a target composed of radially moved signal dots and randomly moved noise dots. The other was a distractor composed of noise dots only. There were 4 experimental blocks: 2 target motions (expansion/contraction) X 2 signal strengths (a ratio of the number of signal dots to that of signal + noise dots in a target; 1 or 0.5). Each experimental block consisted of 4 presentations of a pair of RDPs. Each infant participated in only one experimental block. We calculated the infant's preference score (PS) for target based on a videotaped infant's looking behavior. The PS was defined as the ratio of total looking time for target to that for target + distractor in an experimental block.

The results indicated that the infants aged over 3 months showed significant preference for the expansion target only when the target had strong (=1) signal strength. None of the infants showed significant preference for the contraction target even the target has strong signal strength. These results suggest that the anisotropy for expansion/contraction detection emerges at about 3 months of age independent of stimulus types.

329 Metric estimation of visual-deformation motions

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Optic flow has been shown to be used in navigation and self-orientation. Flow patterns caused by relative motions of small planar surface patches can be broken down into four elementary motion types: translation, rotation, expansion, and deformation (Koenderink & van Doorn, 1976). Many studies addressed the first three motion types. Results show that humans can finely discriminate between directions and speeds of translations (De Bruyn & Orban, 1988; McKee, 1981; Welch & Bowne, 1990; Bravo & Watamaniuk, 1995), angular velocities of rotations (Barraza & Grzywacz, 2002 & 2003), and rates of expansion (Wurfel, Barraza, & Grzywacz, 2003). In contrast, deformation and its rate have been studied comparatively less than the other motion types. Using a 2AFC test, we show that subjects can also finely discriminate between rates of deformation. Moreover, we show that subjects can discriminate accurately between orientations of the axis of deformation. Another similarity between deformation and the other elementary optic-flow types is in the quantity of information needed for fine discrimination. A certain amount of motion information is required to make angular-velocity and rate-of-expansion judgments in rotation and expansion respectively. The rate of deformation is also subject to similar motion-information constraints. In other words, deformation stimuli with few moving elements will typically be judged through local speeds, whereas deformations with many moving elements will be judged by the global rate of deformation. Finally, we show that the rate of deformation can be discriminated with short stimulus durations (155ms), like the other elementary motion types. In conclusion,

although deformation is a less intuitive type of optic flow than translation, expansion, and rotation, it seems to be discriminated using a similar strategy. This supports the hypothesis that the brain decomposes optic flows into the components derived by Koenderink and van Doorn.

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330 Perception of motion trajectory from the moving cast shadow in human infants

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Moving cast shadow affects perception of an object's trajectory in adults (Kersten et al., 1997). A ball is perceived to recede in depth when a cast shadow moves diagonally on a parallel with a ball, and float above the floor when a cast shadow trajectory is horizontal. In the present study, we investigated whether infants at 4- to 7-month-old discriminate the motion trajectory of the ball from the moving cast shadows using habituation-dishabituation procedure. In Experiment 1, we tested 12 4-5-month-olds and 12 6-7-month-olds' discrimination between $\dot{Y}gdepth\dot{Y}h$ display containing a ball and a cast shadow with diagonal trajectory and $\dot{Y}gup\dot{Y}h$ display containing a ball with diagonal trajectory and a cast shadow with horizontal trajectory. Infants were habituated to $\dot{Y}gdepth\dot{Y}h$ display and presented both $\dot{Y}gup\dot{Y}h$ and $\dot{Y}gdepth\dot{Y}h$ displays during test. Six- and 7-month-old, but not 4- and 5-month-old, infants looked significantly longer $\dot{Y}gup\dot{Y}h$ display than $\dot{Y}gdepth\dot{Y}h$ display. These results suggest that 6- and 7-month-old infants perceive the ball as moving in depth during habituation. In Experiment 2, we tested whether infants would perceive $\dot{Y}gup\dot{Y}h$ motion as categorically different from $\dot{Y}gdepth\dot{Y}h$ depending on the object's 3-D trajectory. Nine 4-5-month-olds and 12 6-7-month-olds infants were habituated to and tested with the displays containing a ball and a cast shadow with the same trajectory as Experiment 1 except that cast shadows were attached above the ball. These displays did not produce 3-D impressions in adults. Both age groups of infants did not exhibit significant differences between $\dot{Y}gup\dot{Y}h$ and $\dot{Y}gdepth\dot{Y}h$ displays. These results suggest that infants did not discriminate these displays. When the results from two experiments are considered, 6- and 7-month-old infants discriminated the motion trajectory of the ball from the moving cast shadows. This developmental emergence of depth perception from moving cast shadow at 6 months of age is consistent with that of other pictorial depth cues.

331 Effective Information for TTC Judgments Varies During an Approach Event

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Purpose. Prior studies of time-to-contact (TTC) typically measured one judgment at the end of an approach event (e.g., DeLucia, 1991; Todd, 1981) and tacitly assumed that Os used the same source of information throughout the event. However, TTC judgments are influenced by multiple sources of information (DeLucia, 2004), and the quality of some information sources varies with distance (e.g., optical expansion; Cutting & Vishton, 1995). We hypothesized that the sources of information that affect performance vary throughout an approach event (DeLucia, 2004; DeLucia & Warren, 1994). **Method.** Two computer-generated spheres approached the O for 8 s. The optical parameters of the spheres were controlled systematically throughout the event. During the first 5.6 s, the right sphere maintained a larger optical size and a smaller tau compared with the left sphere. After 5.6 s, the right sphere's optical size was still relatively larger, but the left sphere's tau was smaller. Relative TTC judgments were measured throughout the event. 16 Os moved a control stick to the left (or right), and kept it there as long as they thought the left (or right) sphere would reach their observation plane first. They reversed the stick's position to indicate a reversal in judgment. The stick's position was analyzed to determine whether response reversals coincided with

reversals in the spheres' optical properties. **Results.** During the first 5.6 s, a significant number of Os selected the right sphere, $p < .05$. Judgments were consistent with both optical size and tau. After 5.6 s, a significant number of Os reversed their response and selected the left sphere, $p < .05$. This reversal was consistent with tau rather than optical size. **Conclusions.** The information sources that affect relative TTC judgments can change during an approach event. It is important to develop methods to measure such changes. The manner in which effective information varies throughout an event must be considered in models of TTC perception.

332 Object velocity relative to the head and depth order from object-produced motion parallax

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The geometry underlying the recovery of depth order from motion is that the angular velocity originating from the rigid translation of objects relative to the observer is inversely proportional to the distance from the observer to the objects. Previous studies revealed that the calculation of angular velocity requires either retinal (Braunstein & Andersen, 1981, P&P, 29, 145-55; Naji & Freeman, 2004, Vision Res, 44, 3025-34) or extraretinal signals (Nawrot, 2003, Vision Res, 43, 1553-62). We explored how the visual system integrates retinal signals with extraretinal ones to determine depth order. We used a stimulus in which four rows of horizontally moving random-dots had a common motion component and a relative motion component. The direction of common motion relative to the moving pursuit point was opposite to that of the pursuit point, and the velocities of the common motion and of the pursuit point were manipulated independently. The relative motion component consisted of the dots in all four rows moving in the same direction but the dots in the first/third rows and the second/fourth rows had different speeds. Observers were required to report which rows appeared in front. Possible cues for scaling the amplitude of eye-movements were eliminated by presenting the stimulus on a black screen in a darkened room so that the frame of the screen was invisible. We tested the prediction that the depth order produced by retinal motion (i.e., dots moving faster on the retina appear closer) can be reversed by an eye-movement velocity signal that exceeds that of the retinal motion (i.e., dots moving slower on the retina now appear in front). The prediction was confirmed with three different velocities of common motion. The result suggests that object-velocity relative to the head is calculated by adding eye-movement velocity to retinal velocity and is processed for determining depth order from object-produced motion parallax.

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333 Visual-Vestibular Dissociation: Differential Sensitivity to Acceleration and Velocity

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Vision contributes to balance, and vision is thought to dominate vestibular (or inertial) information in the perception of linear self-motion (Lishman & Lee, 1973; Mittelstaedt & Mittelstaedt, 2001). Is the visual system more sensitive to linear whole-field accelerations than are inertial systems? This would be surprising because the visual system is regarded as being much less sensitive to local acceleration signals than to local velocity signals (e.g., Eagle, 1996). We measured discrimination thresholds (JNDs) for peak velocity and for peak acceleration using immersive whole-field visual signals for linear motion (in an HMD) as well as non-visual whole-body inertial experiences (on a motorized cart). In both modalities, motion stimuli were developed in which peak acceleration and peak velocity were decoupled. The initial acceleration profiles in each case were roughly Gaussian, while the resulting velocity profiles were S-shaped. Acceleration duration was varied between 1 and 1.5 seconds, so that peak velocity could not be used to substitute for peak acceleration, nor could acceleration substitute for velocity without precise temporal integration. In a 2 X 2

design, stimuli were either visual (virtual hallway presented in a 60 deg FOV HMD) or inertial (on a computer-controlled cart), and judgments were either of peak velocity or peak acceleration. Observers made comparisons to an internal standard, with feedback. Despite the feedback, observers in the inertial experiments confounded velocity with acceleration, and JNDs for peak velocity discrimination from inertial senses were about 10% of the standard, whereas JNDs for peak acceleration were about 5%. Conversely JNDs for peak visual velocity were about 5% of the standard, while those for acceleration were about 10%. Evidently, visual superiority is limited to the perception of velocity. Visual and vestibular sensitivities may be complementary in perceiving accelerative and non-accelerative phases of self-motion.

334 The role of binocular cues in scaling the retinal velocities of objects moving in space

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The retinal velocity of an object moving in space depends on its distance from us. Thus, to interpret retinal motions the visual system must estimate an object's distance. Which sources of information are used? Here we consider the use of horizontal binocular disparity and vergence cues to distance. Specifically, we investigated whether disparity and vergence cues provide a depth distance estimate required to judge the physical velocity of objects moving at different distances (velocity constancy). Observers (n=6) viewed computer-rendered objects (either wire-frame spheres or small points) translating in the fronto-parallel plane. A trial consisted of two objects presented sequentially; observers judged whether the first or second moved faster. A staircase procedure was used to adjust the velocity of the second object to obtain the point of subjective equality between the two presented motions. Trials for objects moving with different velocities, directions and displacements were randomly interleaved. Velocity judgments were made for objects presented at different distances defined by disparity, vergence angle and changing size cues. Judgments of perceived velocity were systematically affected by the depth distance between the objects, with velocity matches close to those expected for perfect velocity constancy. This was true even for small points, suggesting that, in contrast a previous report (McKee & Welch, Vision Research, 29, 553), disparity-defined depth can provide a sufficient distance cue for judgments of object velocity. However, settings made under conditions of different states of eye vergence had little effect on velocity matches. These results support a constancy mechanism for velocity that takes disparity-defined depth as an input, but that is little affected by static vergence posture.

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335 Adaptive sensory coding: Enhanced visual velocity discrimination during self-motion

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Whereas cue-combination theories classically articulate the benefits to discrimination of combining multiple sources of information, there is another class of theory that supposes that the mere presence of a signal in one channel or modality can actually enhance the processing of a signal in another by narrowing the range of possible values to be coded. Barlow's (1990) inhibitory interaction theory, for example, suggests that the perceptual value of one stimulus can be altered by the co-occurrence of another, normally correlated stimulus, even when that stimulus presently adds no information. Thus, for example, the visual velocity of the environment during self-motion is reduced relative to how the same visual stimulation appears to a stationary observer (Durgin, Gigone & Scott, in press). Motor-prediction theories make similar predictions regarding the muting of perceptual outcomes of actions compared to those experienced without concomitant and correlated motor signals. Here we show that

discrimination thresholds for 3D velocity of structured flow-fields moving near walking speed are lowered, not only during active walking, where both motor-prediction and inter-sensory inhibition theory make a common prediction, but also during passive self-motion. Thus, even though the self-motion information contributes no discriminative information about the specific visual motion stimuli presented, visual motion stimuli experienced during self-motion are nonetheless represented in an altered coding space where discriminations of unusually low velocities are rendered nearly impossible (since they all appear to be zero), whereas those of higher velocities especially those near the rate of self-motion, are better discriminated. The ability of sensory systems to adaptively alter their coding spaces in response to otherwise uninformative cues is of obvious importance, and must be considered as an alternative source of improved discrimination in tasks where multiple cues are combined.

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336 Contrast Gradients Increase Apparent Egospeed While Moving Through Simulated Fog

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When fog is simulated as a global reduction in contrast, apparent egospeed decreases as fog becomes denser (Snowden, Stimpson, and Ruddle, 1998, *Nature*). However, fog is more realistically modeled as Mei scattering of ambient light, which reduces contrast exponentially as distance increases. In addition to reducing global contrast, this exponential fog model introduces a contrast gradient in depth, which may change the sampling of optical flow to emphasize nearer objects, thereby increasing the rate of global optical flow, which may result in increases in apparent egospeed (Larish & Flach, 1990, *JEP:HPP* </i>). We examined whether apparent egospeed is affected by this contrast gradient when global contrast is held constant and fog is modeled exponentially. Observers sequentially viewed pairs of 1-3 s computer simulations of observer translation over a textured groundplane. The display pairs consisted of a standard, for which the simulated translational speed and fog density remained fixed throughout the experiment, and a comparison, for which the speed and density each varied independently over five levels. Observers indicated which display produced greater apparent egospeed. For each level of fog density, apparent egospeed and Weber fractions for egospeed discrimination were estimated by fitting 2-parameter sigmoid functions to the proportion of faster judgments as functions of translational speed. Results showed that apparent egospeed increased linearly by approximately 5% as the exponential fog density parameter increased 67%. Weber fractions were unaffected ($O=0.069$). While moving through real fog, this increase in apparent egospeed due to the contrast gradient opposes the decrease in apparent egospeed due to the global reduction in contrast. Hence, a more accurate understanding of how fog density affects apparent egospeed must account for changes in both the contrast gradient and global contrast. Further experiments examining these variables simultaneously will be discussed.

337 Comparing the relative accuracy of perception and action in ball catching

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We quantified the accuracy of the perception of the absolute direction of motion in depth (MID) of a simulated approaching object using a passive judgment and an active simulated catching task. In contrast with previous research, our passive judgment task utilized a staircase tracking procedure that provided precise estimates of the perceived direction of MID and did not require the observer to make an interceptive motor response. For the active task, movements of the index finger and thumb of the observer's

hand were tracked as participants tried to 'catch' the simulated approaching object (Gray & Sieffert, 2005). A sensation of MID was created using monocular and/or binocular information sources and visual stimuli were identical for both tasks. For the judgment task, observers overestimated the angular trajectory of the approaching object i.e., they judged the object to pass wider than the head than indicated by the visual information provided. When auditory feedback was added to the judgment task consistent overestimates were still observed. For the active task, observers consistently overreached i.e., the hand was further away from the midline than the simulated object at the time of hand closure. When auditory feedback was added to the active task errors were significantly reduced and were within the margin of error for successful catching. The relative accuracy in binocular and monocular conditions for individual observers could be partially explained by thresholds for unidirectional changes in angular size and changes in relative disparity. These findings suggest that adaptation of the motor component to the information provided by the visual system is the basis of successful interception.

338 A Bayesian theory for intercepting objects moving in 3D

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In order to intercept an object moving in a scene, the future position of that object must be estimated. We developed an ideal observer model that uses monocular visual information to estimate the optimal interception point—that point where a moving object is most likely to cross an arbitrary line through the observer's viewpoint. We compared optimal interception points with human reaches to intercept an object in a virtual 3D environment. Specifically, we explored how prior knowledge of the object's size influences optimal and human interception performance.

The ideal observer uses Bayes' rule to combine available visual image information with prior statistical knowledge about the object's size, starting position, and velocities to compute a probability distribution over intersection points along a specified line through the viewpoint. The optimal interception point was defined as the crossing point with the highest posterior probability given the image data and prior knowledge. With only one eye, the visual information for estimating the crossing point is ambiguous. For a given image size, an object that is small and near must cross nearer than an object that is large and far. Thus, prior knowledge about the object's 3D size can be used to disambiguate the interception point.

We asked human participants to intercept two different moving objects. Participants first performed an interception task with no information about the objects' sizes. They were then taught distinct object sizes, through visual and haptic feedback, so that they could use size as prior knowledge in subsequent interception tasks. Differences in interception performance before and after training should reflect the impact of training. Participants learned the size of the objects in the experiment and used this information to improve their interception performance. This use of prior knowledge supports a Bayesian model for object trajectory inference.

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339 Bayesian Models of 3-D Motion Perception

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Two Bayesian models are proposed that extend existing models of 3-D motion encoding. The first model uses velocity constraints in the left and right eye to recover trajectory angle and velocity of a target stimulus moving in x-z space. The prior of this model is defined in velocity space and favours slow motion in 3-D. Uncertainty in velocity encoding produces blurred velocity constraint lines in the left and right eye. Applying a decision rule to a posterior distribution results in biased estimates of trajectory angle and velocity (cf. Weiss, Simoncelli & Adelson, 2002). The second model is based on changing binocular

disparity and spatial position with disparity encoding as the primary source of uncertainty. The prior in this model favours zero disparity. A posterior is derived from integration of estimated target positions over time also resulting in biased estimates of trajectory angle and velocity. Predictions from both models were tested in an experiment where binocular disparity and interocular velocity difference served as main depth cues. Stimuli were presented to the left and right eye on a flat CRT screen with a refresh rate of 120 Hz using a split-screen Wheatstone configuration. On each trial Ss verged on a fixation-cross flanked by nonius lines at 114 cm before a Gaussian dot of approximately 3 arcmin moved in depth with constant velocity. Trajectory angle (0 to 360 deg) and distance travelled in depth varied in randomly intermixed trials and between conditions. After each presentation Ss indicated trajectory angle and distance travelled by adjusting markers on screen. The results show that under these conditions Ss systematically overestimate trajectory angle (Harris & Dean, 2003) and underestimate velocity of motion towards the observer. A similar bias was found for trajectories away from the observer supporting a stereo-motion system that encodes disparity first. Additional testing may help to clearly distinguish between the two statistical models. <http://search.bwh.harvard.edu/>

Perceptual Organization 1

340 Relative Salience of Number, Shape, Color, and Surface Area in Rhesus Monkeys

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Many species have been shown to discriminate number as a property of a set of objects however, little is known about how salient number is relative to other object properties like size, shape, and color. Some researchers have suggested that animals only attend to number as a 'last resort strategy' (Davis & Memmott, 1982). In this study we investigated the relative salience of number versus alternative stimulus dimensions for macaque monkeys. Monkeys with varying degrees of experience on numerical tasks were trained to a 70% criterion on a delayed match-to-sample task where the correct choice matched the sample in both number and a second nonnumerical property (shape, color, or surface area). Following training, monkeys were tested with nondifferentially reinforced probe trials in which one choice was a number match and the other was a shape, color, or area match (e.g., sample = 2 red tulips and choices = 4 red tulips or 2 red cars). Results indicate that monkeys' propensity to use number as a basis for matching increased with the numerical difference between the nonnumerical and numerical match. Thus when number was highly discriminable, monkeys were more likely to use it as a basis for matching over other object features. In addition, monkeys were more likely to use number than area even at the closest distance.

341 When is preattentive grouping sensitive to contrast polarity?

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Preattentive visual representations have been studied with visual search, and it is known that both primitive features and configurations of features can be represented preattentively. Rensink and Enns (1995) presented evidence for preattentive grouping, in which the groups act as a single functional unit. They proposed that proximity allows for grouping which is insensitive to contrast polarity (CP). Later on, Gilchrist, Humphreys, Riddoch & Neumann (1997) found evidences of CP-insensitivity only for colinearity but not for proximity. In this study, two experiments were carried out to address this issue. In Experiment 1, participants searched for a half-arrow among distractors formed by the target and another opposite pointing arrow, with either its same or opposite CP, separated by a small gap. Searches were efficient when distractor arrow pairs had the same CP,

but were inefficient when the CP was different. As colinearity cues were present in distractors, this result contrasts with previous suggestions. In Experiment 2, arrows were replaced with circles and rectangles; results were consistent with Gilchrist et al., rather than Experiment 1. Another experiment was carried out to investigate CP-sensitivity in containment groups. In Experiment 3, participants were asked to search for: A: a short line among long lines; B: a long rounded rectangle among short ones, containing an equal length line; C: a short line among long lines, surrounded by equal length rounded rectangles. The rectangles and lines were of either the same or opposite CP. Search was efficient for conditions A & B but not C, implying that the lines and rectangles were grouped; unlike in Experiments 1 & 2, search efficiency did not vary with same or different CP. Taken together, these experiments suggest that preattentive grouping is CP-sensitive when defined by proximity, CP-insensitive when defined by containment, and the effect of colinearity may be dependent on stimulus forms.

342 Surface interpolation and 3D relatability

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Models of visual interpolation emphasize contour relationships. Although the role of surface-level processes has been demonstrated (Yin, Kellman & Shipley, 1998; Fantoni, Bertamini & Gerbino, 2004; for a recent review see Kellman, 2003), specific surface properties and geometric constraints that govern surface interpolation are not well understood. In this study we hypothesize that, even in the absence of contour information, visual interpolation can occur as a product of surface-based processes grounded on orientation information derived from image cues such as scale and shear disparities.

To investigate 3D surface interpolation we asked observers to classify pairs of planar surfaces specified by random dot disparities, visible through circular apertures on a fronto-parallel occluder. Surface slant was manipulated by varying scale and shear disparities. On each trial, slanted textures belonged to either parallel or intersecting planar surfaces with the same absolute slant. Observers made a speeded parallel/intersecting classification of texture pairs of different slants. Surfaces were presented in 20 conditions resulting from the combination of three factors: 3D relatability of the surface pair (relatable vs. non-relatable); tilt of the aperture pair (aligned vs. tilted), absolute surface orientation (20, 35, 46, 54, 60 deg). As in contour interpolation (Kellman et al., in press) observers performed better on the parallel/intersecting classification task when surfaces were 3D-relatable. The orientation of the aperture pair did not play a clear role. The effect of absolute slant was stronger on non-relatable than relatable surfaces.

Results support the notion that visual interpolation includes surface-based processes, independent of contour information and specified by the 3D orientation of visible patches. Scale and shear disparities of isolated textures provide sufficient information for surface interpolation.

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<http://www.rdg.ac.uk/arl/>

343 Correct Grouping of Contours Is Required for Symmetry to Operate As a Configurational Cue

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Symmetry has long been considered a configurational cue, but we failed to find evidence for this claim in previous experiments using brief exposures, leading us to suppose that other processes were necessary to bootstrap the symmetry cue. In our displays, symmetric regions with rectilinear stepped contours alternated with same-area asymmetric regions with the same contour type. Similar results were obtained with curved contour displays. Here we examine whether our results reflect a failure to correctly group the bounding contours of the symmetric regions. In Exp. 1 we tested

whether correct contour grouping is necessary for symmetry to operate as a configurational cue by manipulating the shape of an asymmetric region sharing one rectilinear stepped contour with a symmetric region. The asymmetric region's non-shared contour either was also a rectilinear stepped contour or it was a curvilinear contour comprised of local curves that were all either convex or concave. We presented such displays for 100 ms with a probe square located on either the symmetric or the asymmetric region. Subjects reported whether the probe was located on the region they saw as the figure at the border shared by the two regions. The symmetric region was more likely to be seen as figure when the unshared edge of the asymmetric region was curvilinear (64% and 68% for concave and convex curvature), than when it was rectilinear (51%). In Exp. 2 we investigated whether these effects were due to grouping alone or to symmetry by replacing the symmetric regions in the Exp. 1 displays with asymmetric regions. Subjects were no more likely to see the asymmetric region as figure when the non-shared contour of the asymmetric region was curvilinear (49%) than when it was rectilinear (51%). Thus, when the two contours of the symmetric region were similar and different from the third contour in the display, symmetric regions were more likely to be seen as figure, implicating grouping as an essential factor.

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344 Activity in early visual areas reflects perceived surface layout in scene segmentation

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When visual information enters the brain, segregating scenes into figures and background is one of the first processes established by the visual system. Previous research has shown that early visual areas are engaged in low-level feature detection, and probably also in sub-processes related to texture segregation, such as the detection of orientation discontinuities. We conjecture that in addition, V1 and other early areas are involved in the perception of the surface layout, i.e. the final stage of figure-ground segregation. To test this, we manipulated the perceptibility of a texture-defined figure by interposing a 'frame' between figure and ground textures. For example, the orientation of the figure texture was 45°, the background texture was 135°, and the intervening frame texture was 90°. Subjects had to distinguish between figure-ground textures surrounded by a frame and isolated frames on a homogeneously textured background. Subjects could easily discriminate between the two when the frame thickness was relatively small, yet were strongly impaired when the frame thickness was relatively large. Apparently, in the latter condition the proper perception of the different texture surfaces is lost. We measured BOLD activity during the performance of this task. Preliminary results showed a direct parametric relation between frame thickness on the one hand and the BOLD contrast between figures surrounded by a frame and isolated frames on the other hand, in areas V1, V2, and V3. This indicates that activity in these early visual areas reflects the perceived surface layout of texture displays. This supports a role of these areas in perception, in addition to their established role in lower level feature detection.

345 Familiar configuration enables figure/ground assignment in natural scenes

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Figure/ground organization is a step of perceptual organization that assigns a contour to one of the two abutting regions. Peterson et al showed that familiar configurations of contours, such as outlines of recognizable objects, provide a powerful cue that can dominate traditional f/g cues such as symmetry. In this work we: (1) provide an operationalization of "familiar configuration" in terms of prototypical local shapes, without

requiring global object recognition; (2) show that a classifier based on this cue works well on images of natural scenes.

A dataset of 200 natural images was hand segmented into disjoint regions by human subjects. Subjects then provided a f/g label for each contour associated with a pair of abutting segments [Fowlkes, Martin & Malik ECCV03]. Our goal is to correctly predict these f/g labels from image measurements.

We use "shape context" to represent local shape configuration at each point. Shape context [Belongie, Malik & Puzicha ICCV01] is a shape descriptor which summarizes local arrangement of edges, relative to the center point, in a log-polar fashion. In order to work with grayscale images, we use a variant of shape context, geometric blur [Berg & Malik CVPR01], aligned to local tangent direction. We cluster a large set of these descriptors to construct a small list of prototypical shape configurations, or "shapemes" (analogous to phonemes). Shapemes capture important local structures such as convexity and parallelism.

For each point along a contour, we measure the similarity of its local shape descriptor to each shapeme. These measurements are combined using a logistic regression classifier to predict the f/g label. By averaging the classifier outputs over all points on each contour, we obtain an error rate of 30% (chance is 50%). This compares favorably to the traditional f/g cues used in [Fowlkes et al 03]. Enforcing consistency constraints at junctions reduces the error rate further to 22%, making it a promising model of figure/ground organization.

<http://www-bcs.mit.edu:16080/>

346 Role of non-targets in detection of a target in visual search

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Introduction: A recent study (Rauschenberger, Peterson, Mosca, & Bruno, 2004 *Psychological Science*) argued for an 'ambiguity' account of amodal completion. This account holds that once an incomplete 2-D figure has been amodally completed, either the complete or the mosaic representation is accessible. The representation accessed may depend on external factors like set or context. In a visual search experiment, they used two types of target: a complete disk next to a complete square (separate) and a notched disk abutting a complete square (adjacent). Each non-target was a notched disk and complete square pair, where the notch was aligned with, but a short distance from, the corner of the square. A subject was instructed (set) to respond whether a complete disk appeared. Two display durations were used: 100 and 250 ms. They found search to be comparably efficient between the separate and adjacent target conditions at 100 ms, but not at 250 ms, where search in the adjacent condition was inefficient. They concluded that 'set' influenced perception toward the complete representation for adjacent targets at 100 ms, but that 'context' of the non-distractors influenced perception toward the mosaic representation at 250 ms. However, due to the alignment of the notch with the corner of a square for a non-target, a partial illusory square boundary may appear to occlude the notched disk. Thus, notched disks in the non-targets may (weakly) appear complete at 250 ms, rendering them similar to an adjacent target. This may explain inefficient search for adjacent targets at 250 ms.

Method: We replicated their experiment, but gave explicit boundaries to all disks and squares, in order to inhibit formation of illusory square boundaries for non-targets.

Results: Search was comparably efficient between separate and adjacent targets at both 100 and 250 ms.

Conclusion: The 'ambiguity' account of amodal completion and the new effect of 'context' are not supported by these results.

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347 Human Movement Coordination Implicates Relative Direction as the Information for Relative Phase

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The current studies explore the informational (perceptual) basis of the coupling in human rhythmic movement coordination tasks. Movement stability in these tasks is an asymmetric U-shaped function of mean relative phase; 0° is maximally stable, 90° is maximally unstable and 180° is intermediate. Bingham (2001, 2004a, 2004b) hypothesized that the information used to perform coordinated rhythmic movement is the relative direction of movement, the resolution of which is determined by relative speed. We used an experimental paradigm that entails using a circular movement to produce a linear motion of a dot on a screen, which must then be coordinated with a linearly moving computer controlled dot. The circularity adds a component to the movement that is orthogonal to the display. Relative direction is not uniquely defined between orthogonal components of motion, but relative speed is; based on Bingham (2001, 2004a, 2004b) it was predicted that the addition of the component would only introduce a symmetric noise component and not otherwise contribute to the U-shape structure of movement stability. Results for Experiment 1 supported the hypothesis; movement that involved the additional component was uniformly less stable than movement that involved only parallel component along which relative direction can be defined. Two additional studies ruled out alternative explanations for the pattern of data in Experiment 1. Overall, the results strongly implicate relative direction as the information underlying performance in rhythmic movement coordination tasks.

348 The Effect of Synaesthetically Induced Colors on Perceptual Organization

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We tested the perceptual reality of synaesthesia in two phases. During the first phase, four color-grapheme synaesthetes reported on the synaesthetically induced colors of the letters A-Z and the numbers 0-9 in two sessions. We computed consistency within and between the two sessions and identified letters and numbers whose colors are consistently chosen, taking into account the strength of the synaesthetic association and the ability of the computer display to adequately represent the synaesthetic color.

In the second phase, we pitted grouping by proximity against grouping by similarity, using letters that induced colors either strongly or weakly. We measured the strength of grouping by proximity and grouping by similarity. Synaesthetes are more likely to group a dot pattern according to the similarity of synaesthetic colors than by proximity. This effect is greater for alphanumeric symbols that induced colors strongly than for alphanumeric symbols that induced them weakly. For control subjects the alphanumeric symbols had no effect on perceptual organization and the difference between strong and weak symbols was absent.

The results show that synaesthetes choose induced colors with high consistency and that synaesthetically induced colors affect perceptual organization. Since these results are based on precise quantitative methods, they constitute evidence that synaesthesia is a genuine perceptual phenomenon.

349 A Higher-Order Mechanism Beyond Good Continuation in Contour Integration

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Concerns regarding a reported effect of closure in contour integration include: Whether closure alone is a sufficient condition for enhanced

contour visibility; the small observed magnitude of the effect; and the need for positing a separate global mechanism beyond low-level local association or 'good continuation'. We show that a higher-level mechanism responsible for closure does exist and that this mechanism affects the integration of orientation information into contours. In Exp. 1, we compared the visibility of oriented Gabor elements positioned and aligned to form two half-circle arcs, arranged an enclosed configuration (I) versus the same two arcs arranged in a non-enclosed configuration (II). The two configurations were equal in terms of local curvature, but differed on a global level (i.e., one enclosed a common area and the other did not). The enclosure condition in a 2AFC task was more detectable, suggestive of an effect of closure in contour detection. There remained, however, the possibility that a good continuation effect bound the oriented elements on the ends of the arcs in the enclosed configuration through secondary or tertiary local association (i.e., a smooth line could be extended across the spacing between the arcs). In Exp. 2, we controlled for this possibility by using pairs of arcs that formed sharp corners on the ends in the enclosed configuration. A good continuation account would need to bind oriented elements on the arc ends across path curvatures of at least 75 degrees, which previous research has shown to be highly unlikely. The enclosed condition was still easier to detect than the non-enclosed configuration. We conclude that a closure effect beyond good continuation does exist in contour integration. The effect is most observable in situations where good continuation cannot assign edges to contours with sufficient statistical confidence (e.g., in cases where path curvature is high or where contour path is short).

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350 Perversible Figures: An Ironic Process in Perception

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Wegner and colleagues found an *ironic* hyperaccessibility to thoughts Ss were instructed to suppress under conditions of high cognitive load which they called the *Ironic Effect*. Wegner proposed that the Ironic Process underlying this effect entails the integration of two parallel processes: an effortful cognitive process which searches for distractors, and an automatic process which monitors the occurrence of the forbidden target thought (Wegner, et al. 1987). We explored whether there might be a perceptual analogue to this effect by presenting Ss with one of two reversible figures (Duck/Rabbit, Cat/Swan) and asking them either to hold (maintain) or to try not to see (suppress) one of the two views. Using two computer keys, Ss recorded which construal they were perceiving during a two-minute observation period. In comparison to a control group (N=32) that were given no suppression or maintain instructions, the experimental Ss (N=64) perceived the undesired view of the figure for significantly greater periods of time than its alternative. We conclude that instructions to suppress or maintain one construal of a reversible figure creates a high perceptual load resulting in a perverse effect that appears to be the perceptual analogue of the ironic effect. This phenomenon has the potential to increase our understanding of the mechanisms underlying the perception of reversible figures and the Ironic Process itself.

Wegner, D. M., Schneider, D. J., Carter, S., & White, T. (1987). Paradoxical effects of thought suppression. *Journal of Personality and Social Psychology*, *53*, 5-13.

351 Evaluating grouping via emergent features: A systematic approach

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When basic elements combine and Gestalt grouping occurs, emergent features (EFs) arise. We identify the presence of EFs through configurational superiority effects (CSEs) in an odd-quadrant task in which RT and accuracy measures are obtained for locating which of four stimuli differs from the other three. Our experiments introduce a systematic method in which EFs can be created from the ground up and in a hierarchical fashion.

This allows for direct comparisons of grouping strength among EFs, something that up until now has been impossible. Thus we may be able to determine whether grouping based on certain EFs is stronger than that based on others and also whether the effects of multiple EFs are additive. We start with the simplest stimulus, namely a single dot. Making the identical change in the position of this single dot can yield sharply different EFs depending on the configuration of other contextual dots: with a one-dot context, changing the position of the target dot alters the proximity or angle between the two dots of the target-context pair. Similarly, with a two-dot context, the same change in the target dot position alters the linearity or symmetry among the three dots of the target-context triplet. (Note that asymmetric and non-linear configurations are impossible with two-dot patterns; they can emerge only with three). With a three-dot context, the same procedure yields the EF of surroundedness. Replacing pairs of dots with line segments connecting them, and then using these lines as primitives in place of the dots, yields the EFs of parallelism and collinearity. Thus, locating the odd quadrant becomes easier when that quadrant differs from the others on the basis of an EF such as proximity or orientation (defined by the distance or angle between two dots) than when it differs only in the position of a single dot. We demonstrate CSEs for the first four EFs and provide pilot data for some higher order ones.

352 The perceptual organization of curvilinear contours in structurally ambiguous dot patterns

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Grouping by proximity is one of several Gestalt principles that characterize the human visual system's propensity to perceptually organize an array of discrete elements. Previous work by Kubovy and colleagues (1995, 1998) showed that a 'pure distance model' (PDM) of grouping by proximity predicts the perceptual organization of all dot lattices (DLs). DLs are multi-stable and typically exhibit at least two predominant perceptual organizations. The PDM quantifies the strength of opposing organizations in terms of perceptual stability, a function of relative inter-dot distance. We have since discovered a larger domain of stimuli we call 'dot-sampled structured grids' (DSGs) that can be defined by arbitrary differentiable functions along two axes. Like DLs, DSGs are multi-stable. Unlike DLs, DSGs are not defined by purely local geometric properties and can elicit the perception of curvilinear structure.

We argue that DSGs are a useful tool for the study of perceptual organization. If DLs are to be used effectively we must first understand their geometric properties. We present a geometric analysis of DSGs analogous to Kubovy's (1994) two-parameter space of DLs. We also present results from two experiments in which we used the psychophysical procedure developed by Kubovy and colleagues (1995, 1998) in their work with DLs. We present data from experiments in which we manipulated the density, relative proximity, and curvature of possible contours in DSGs. We found significant effects of each in addition to effects of stimulus duration. In a control experiment we manipulated aperture shape and orientation and found no effect. We show that although grouping by proximity constrains the number predominant organizations in DSGs it does not predict our results: the perceptual organization of DSGs violates the PDM. We conclude that current models of perceptual grouping do not suffice to characterize perceptual organization.

353 Cues to object persistence in infancy: Tracking objects through occlusion vs. implosion

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Objects in the real world frequently move in and out of view, as when they pass behind occluding surfaces. Even infants are able to keep track of objects over time and motion in such situations, despite long occlusion intervals. What factors support and constrain this ability? Research on

mid-level vision in adults suggests that persisting object representations are constrained by the precise manner of an item's disappearance at an occluding boundary. Here we explore the power of this cue, in a study of infants' numerical representations. Infants were habituated to dynamic displays of either 2 or 3 randomly moving identical items, which disappeared and reappeared from behind occluders. In the Occlusion condition, the items disappeared and reappeared gradually, via normal accretion and deletion cues along a single edge. In the Implosion condition, the items still disappeared and reappeared gradually (and at the same rate), but did so from all contours simultaneously -- 'imploding' out of existence and then 'exploding' into existence. In a test phase, which was identical across both conditions, infants' looking times were then assessed to 2 versus 3 moving objects without occluders. Infants in the Occlusion condition looked longer to test displays with a novel number of objects compared to habituation, but infants in the Implosion condition showed no such preference for the number of objects. Thus, only infants in the Occlusion condition were able to establish representations of a constant number of items over habituation. We conclude that the local manner in which an item disappears and reappears serves as a fundamental cue to the maintenance of numerical identity over time: occlusion is a cue that an object has gone out of sight, while implosion is a cue that an object has gone out of existence. More generally, these results are consistent with the idea that the same types of representations are being studied in adult mid-level vision and infant object cognition.

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354 Visual De-fragmentation via High Spatial Frequencies

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In the study of visual development, researchers have observed two key progressions. First, infants' percepts of the visual world apparently start out fragmented, and over several months, come to cohere into assemblies that correspond to objects. Second, along a similar timeline, children's acuity gradually improves from being rather poor at birth to near adult levels. While the underlying reasons for the second progression are reasonably well understood, the causes for the first one are still largely unknown. Here, we suggest that these two progressions might not be independent, but rather may be causally linked, with improving acuity facilitating the extraction of integrative cues. Low-resolution information permits image segmentation into regions of homogenous color and luminance attributes. But, since objects can include regions of different photometric attributes, a purely region-based parsing will lead to over-fragmentation. High-resolution information, as it becomes available, acts as 'perceptual glue' to link together regions based on cues such as good-continuation, contour alignment across occluders and junction structure. To test this theory, we conducted experiments, as part of Project Prakash, with a 28 year old individual who has an unusual condition of congenital aphakia (lack of lenses) in both eyes, preventing the normal progression of acuity. We find that his analysis of images exhibits a marked tendency to over-segment them, and an inability to use cues of contour reliability or junction geometry. These results provide tentative support to our theory of the developmental role of high spatial frequencies in 'de-fragmenting' the visual image, and thereby, facilitating the extraction of object-concepts for recognition. Additionally, the findings suggest that extended visual experience and neuronal maturation, in the absence of high spatial frequency information, are inadequate for explaining the development of visual integration abilities.

Hand Movements 2

355 Perceptual Illusions Affect Visually-Guided Actions With The Non-Dominant But Not with the Dominant Hand

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The visuomotor system that controls real-time target-directed movements is remarkably resistant to a wide range of perceptual illusions. The fact that the visual control of action is refractory to visual illusions has been used as evidence to suggest that vision-for-action and vision-for-perception are functionally and neurally dissociable. Nevertheless, one might expect that more deliberate and less-practiced actions, which would involve more cognitive control, might be susceptible to perceptual illusions. To test this idea, we asked subjects to reach out and grasp simple objects with their non-dominant (left) hand and compared their performance to that of their dominant (right) hand in the context of two pictorial illusions. In Experiment 1, we found that even though grasping movements using the dominant hand were completely unaffected by the Ponzo illusion, the illusion had a significant effect on grasping movements with the non-dominant hand. In Experiment 2, we replicated these results using the Ebbinghaus illusion. In other words, in both experiments, grip aperture was scaled to the real size of the target when participants used their right hand but to the apparent (illusory) size of target when they used their left hand. This dissociation was accompanied by longer movement times, as well as by greater variability in movement trajectories in the left hand. These results indicate that qualitative differences exist between the visual control of actions that are performed by the dominant and non-dominant hands. The fact that actions with the right hand but not with the left are resistant to perceptual illusions may reflect a basic distinction in the neural substrates of the visual control of automatic and controlled movements. In addition, our findings suggest that one must be careful in the selection of actions when testing predictions about possible dissociations between vision-for-perception and vision-for-action.

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356 Inverted Vision-Action Dissociation With Induced Motion

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In vision-action dissociation, visual illusions influence motor responses directed toward the stimulus less than might be predicted from the size of the illusion. One example may be provided by induced motion (IM), wherein a dot appears to move opposite the real motion of a surrounding stimulus. Open loop pointing directed at the apparent endpoints of the dot's motion is displaced in the direction of the preceding IM, but less than would be predicted from the IM's velocity and duration. The comparison of pointing measures of the apparent location of the dot with measures of perceived motion of the dot is problematic, however, as the motor and perceptual measures concern different properties of the stimulus. Specifically, open loop pointing addresses the dot's perceived location, whereas perceptual IM measures typically address the target's perceived velocity. To avoid this potential confound, we assessed the same property of the stimulus (apparent location) with both perceptual and motor measures following IM. Specifically, perceptual measures of perceived location obtained with a vernier task were compared to open loop pointing measures of perceived location. Consistent with prior reports, results showed a small, but reliable effect of IM on open loop pointing. However, there was no effect on the perceived location of the stimulus as assessed by the vernier task. Therefore, IM was found to influence motor measures, but not perceptual measures. This is the inverse of the pattern typically reported as vision-action dissociation. The lack of an effect of IM on the vernier task also suggests that IM does not display the flash-lag effect, as the vernier markers were flashed briefly near the IM target and their alignment was perceived correctly.

357 Metacontrast masking: Effects of barely visible stimuli on pointing movements

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Stimuli which are masked by metacontrast can nevertheless affect motoric responses. In a typical experiment, two squares are presented sequentially (both rotated by either 0 or 45 degree). The first square (the "prime") is masked by the second square ("the target"), such that perceptual discrimination of the orientation of the prime is very low. However, if subjects are asked to respond quickly to the orientation of the target by pointing left or right, the prime still affects the trajectory: If the orientation of the prime is inconsistent with the orientation of the target, pointing first goes in the wrong direction. This result might be interpreted as dissociation between perception (we cannot discriminate the prime's orientation) and action (the prime's orientation nevertheless affects pointing). However, it is very difficult to get discrimination performance really to zero, such that this dissociation might not be very convincing. Here, I tested whether the effect on action breaks down after taking very serious measures to suppress discrimination performance. For this, I used stimuli which are known to produce a good metacontrast suppression, reduced the contrast of the prime to very low values, and also presented the stimuli at unpredictable positions circular around the fixation point (metacontrast is known to be stronger if the stimuli are not fixated). Results show that with this procedure discrimination performance is almost zero, but the cost of this "perfect" suppression in perception is that the effect on action also breaks down. These results are consistent with the notion that the effects on action under normal conditions (with imperfect suppression of discrimination performance) are generated by similar sources as the residual discrimination performance.

358 Does Inattentional Blindness Potentiate Action?

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Briefly presented masked images (subliminal) of graspable objects (tools, utensils, etc.) with their handles oriented left or right influence subsequent motor responses. Reaction time (RT) is significantly faster when the handle and response finger are congruent (Pappas & Mack, 2003). We questioned whether the same effect could be obtained under supraliminal conditions when these objects again are not seen but here due to an attentional blink (AB). Using a RSVP, subjects searched for a red colored target in a series of 8-10 images of common objects. On 75% of the trials, a graspable object (probe) appeared with its handle oriented left or right within 180-240 msec of the target. On the other trials no probe appeared. Immediately following the probe or the last item a blue or yellow dot appeared at the center of a gray screen. Subjects reported the color of the dot by pressing a left or right key with their left or right index finger as quickly as possible. Participants were later asked to report which target item was presented and whether they had detected the probe. On trials where none of the probe items were detected because of the AB, a congruency effect was found. RTs were faster when the unseen object's handle was oriented to the same side as the response finger. This finding demonstrates that unseen, because unattended, supraliminal stimuli that afford a motor response produce motor priming. This suggests some similarity in the processing of subliminal and supraliminal stimuli, neither of which is consciously perceived. These findings parallel those demonstrating that blindsight patients can orient towards unseen objects (Weiskrantz, Warrington & Sanders, 1974).

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359 Efficacy of Image-Guided Action is Controlled by Perception

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Researchers on human perception have devised a number of methods for measuring perceived location and using it to assess perceptually guided action. Such work has primarily been performed in space accessible by reaching and walking. Here we use the same approach to assess perceptually guided action in very near space, specifically, in the applied context of ultrasound-guided surgical manipulation. Our approach measured the ultrasound user's perception of the location of a target independently from assessing the action employed to reach it. Experiments were conducted with the Sonic Flashlight (SF), a visualization device that creates a virtual in situ image, and conventional ultrasound (CUS). Two studies determined subjects' perception of target location with a triangulation-by-pointing task. Depth perception with the SF was comparable to direct vision, while the CUS caused considerable underestimation of target depth. Binocular depth information in the SF was shown to significantly contribute to its superiority. A third experiment tested subjects in an ultrasound-guided needle insertion task. With direct visualization of the target, subjects performed insertions faster and more accurately by using the SF rather than CUS. Furthermore, the trajectory analysis showed that insertions with the SF generally went directly to the target along the desired path, while the CUS led to an arch-shaped deviation from the ideal path, as predicted by the previously measured underestimation of target depth. Ongoing research is further examining the time-course of learning with the two devices, measuring precise trajectories for needle insertion. This work extends the demonstration of the perception/action linkage to near space and provides a very practical application for such research. In particular, different image methods, which lead to different percepts, will lead to actions with differential efficacy.

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360 Disruption of binocular cues affects reaching and grasping to a greater extent than their absence

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Purpose: It is known that binocular cues provide important information for prehensile movements of reaching and grasping. Studies have generally explored conditions where binocular cues are present (binocular viewing) compared to when they are absent (monocular viewing). Little is known about how disrupting binocular cues affects prehensile movement behaviour. Method: Binocular cues were disrupted by means of a blurring lens (+6.00DS) placed in front of one eye. Measurements were obtained in a group of 10 young subjects with normal binocular vision. Prehensile movements for transport and grasp components were measured. Results: Kinematics indices were compared for conditions where binocular cues were present to when they were absent, and when disrupted. Repeated measures (ANOVA) revealed a significant effect with maximum velocity ($F_{2,27}=6.93$ $p=0.005$). Post hoc analysis demonstrated that maximum velocity did not change significantly in the absence of binocular cues ($p=0.79$). However it was significantly lower when binocular cues were disrupted ($p=0.027$). In addition, the velocity was also significantly lower in the disrupted cue condition compared to monocular ($p=0.06$). Maximum grip aperture demonstrated a significant effect ($F_{2,27}=20.98$ $p=0.002$) with the different conditions. Post hoc analysis showed that the grip aperture was significantly larger when cues were absent ($p=0.02$), and when disrupted ($p=0.0015$) compared to binocular condition. Further, grip apertures in disrupted cue conditions were significantly larger than no-cue condition ($p=0.07$). Conclusions: Although only the grasp component is affected when binocular cues were removed, both the transport and grasp

behaviour change when binocular cues are disrupted. Factors other than stereopsis which may also contribute, are discussed.

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361 The Proximal/Distal Model Explains Hand-to-Body Distance-Dependent Accuracy of Visually-Guided Manual Behavior

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Large changes in manual accuracy that are linear with distance of the hand from the body have been measured for three different sorts of visually-guided (open-loop) behavior under visual induction that also generates perceptual errors in visually perceived eye level (VPEL; up to 18°) and visually perceived vertical (VPV; up to 12°) (Welch & Post, 1996; Li & Matin, 1999, 2004, in press; Post, et al., 2004). The three manual behaviors are: (1) pointing/reaching to a visual target, (2) height matching to a visual target, and (3) roll-tilting the hand to feel vertical. In each case, accuracy of the unseen hand increased linearly with distance of the hand from the body, approaching complete accuracy at full extension; with the hand close to the body, the manual errors equalled the magnitude of the perceptual error. The large errors are generated by visual induction by a single eccentric, pitched-from-vertical line, or by two roll-tilted lines in darkness; the inducers also induced separately-measured distance-dependent errors in the felt elevation or roll-tilt orientation of the arm. Both the manual errors and the perceptual errors are quantitatively well-accounted for by a new development (Proximal/Distal Model) of an earlier treatment that explained changes in VPEL and VPV as a consequence of a weighted average of inputs from vision and from the body-referenced mechanism (extraretinal inputs); relative weights change systematically with distance of the hand from the body. The large errors in felt elevation of the arm at full extension brought pointing/reaching to nearly complete accuracy but errors in felt roll-tilt of the arm only brought the manual roll-tilt to about half accuracy. These results show that accuracy at full arm extension is not a consequence of motoric immunity from the distorting influences of visual stimulation; perception and action are not dissociated as suggested by a recent version of the two visual system hypothesis.

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362 Dual-Task Interference is Greater in Memory-Guided Grasping Than in Visually Guided Grasping

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Previous research showing different kinematics for visually guided and memory-guided grasping suggests that there are two control systems for object directed action. Visually guided grasping relies on a highly accurate real-time system in the dorsal stream, whereas memory-guided grasping relies on less accurate information from the perception-based system in the ventral stream. In the present study we explored this difference further by combining a primary grasping task consisting of interleaved visually guided and memory-guided trials, with a secondary auditory perceptual task. In the primary task, participants were cued by an auditory tone to grasp 3-D target objects of varying size. On half of the trials, targets were visible during the interval between the auditory cue and movement onset (visually guided). On the remaining trials, targets were occluded from view at the time of the auditory cue (memory-guided). In the second task, participants listened to object names presented via headphones and gave a vocal response when the object was a particular shape (20% probability). There were three conditions: 1) grasping in conjunction with the auditory task, 2) grasping alone, and 3) the auditory task alone. The results showed that memory-guided grasping was associated with larger peak grip aperture than visually guided grasping. As well, the introduction of the competing shape-classification task slowed manual reaction time for both

types of grasping. Most importantly, however, the time taken to execute the movement was slowed by the auditory task, and this effect was larger for the memory-guided trials compared with visually guided trials. Furthermore, the vocal response times were slower on memory-guided as compared to visually guided trials. These results provide further support for the idea that memory-guided grasping relies on the processing of stored perception-based information that taps the same cognitive resources as an auditorily-presented shape discrimination task.

363 Dissociating the functions of visual pathways using equisalient stimuli

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PURPOSE: To dissociate the 'where', 'what', and 'how' functions of the visual pathways by showing differential performance among task types. **METHODS:** Stimuli designed to differentially activate the parvocellular and magnocellular pathways, luminance-defined and equiluminant color-defined targets, were adjusted to be equisalient on an allocentric 'where' location identification task. Participants responded to the same stimuli in two other visual tasks, a 'how' aimed movement task and a 'what' shape identification task. **RESULTS:** The same stimuli produced differential performance on the 'what' and 'how' tasks: specifically there was an advantage in both for the luminance-defined targets. **CONCLUSION:** This task-related contrast in visual sensitivity indicates differential recruitment of resources among task types. The results can be interpreted in terms of the 'what', 'where', and 'how' functional dissociations of the ventral and dorsal streams Ungeleider & Mishkin, 1982; Milner & Goodale, 1995; Creem & Proffitt, 2001, and in terms of differences in sensitivity to low vs. high spatial frequencies of the processes carrying out these tasks.

364 Implicit sensorimotor control: Rapid motor responses of arm and eye share the visual motion encoding

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Increasing lines of evidence have suggested that arm reaching is under online visuomotor control. We recently found a short latency manual response induced by a large-field visual motion during arm movement, which we named 'manual following response' (MFR). To explore the sensory processing involved in the MFR, we here examined the effect of image contrast and spatiotemporal frequency of sinusoidal grating patterns on the short latency manual response. In the experiment, vertical sinusoidal grating pattern with a particular image contrast was shown on the monitor. Subjects were asked to hit the center of a computer monitor with their index finger with an assistance of beeps for movement timing. The grating pattern started to move either rightward or leftward (randomized) 120 ms after the beginning of the arm movement. The MFR amplitude was quantified by the difference, between the rightward and leftward moving conditions, in the hand velocity averaged over a brief period after the stimulus onset. In the first experiment, the image contrast was changed between blocks. As the image contrast was increased, the MFR amplitude increased, and its latency decreased, up to the image contrast of ~10 %, and almost leveled off thereafter. In the second experiment, the spatiotemporal frequency of the grating was changed. The MFR amplitude increased as the grating temporal frequency increased, but decreased beyond the peak temporal frequency around 15 - 20 Hz independent to the spatial frequency. For the stimulus < 15 Hz, the MFR amplitude was almost linearly proportional to the log-velocity of the stimulus. Moreover, the spatiotemporal tuning functions, as well as short response latencies, are similar to those of the ocular response induced by a large-field visual motion known as 'ocular following response' (OFR). This suggests that MFR and OFR share a common visual motion processing mechanism.

365 The Visual Control of Goal Directed Action in Developmental Co-ordination Disorder

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The aim of this study was to investigate visuo-motor control in children with developmental coordination disorder (DCD). Children with DCD show impairments in a wide range of basic movement skills. This includes the ability to utilise partial (but not complete) advance information to speed up their movement times in a reach-to-grasp paradigm. We hypothesised that children with DCD are impaired in their ability to use visual information in order to rapidly adjust on-going movements (i.e. they lack 'on-line' visual control). To test this hypothesis we studied 10 children with DCD with a control group matched on age, and another control group matched on motor ability, on a perturbation paradigm. The task required the children to move a hand held stylus 25cm from a starting location to a target 2cm in diameter on a computer screen. The starting location and the computer screen were embedded within a flat horizontal surface. The experimental task involved the children making simple aiming movements when they knew that the target would not alter position (baseline condition). Following the baseline trials, the children made aiming movements after being told that the target would 'jump' on some trials. On the 'jumping' trials, the target changed position by jumping either 10cm to the left or 10cm to the right 10ms following the movement commencement. Electromagnetic tracking equipment was used to monitor the reaction times and movement accuracy including the speed with which children could respond to the change of target location. We will discuss the findings in the context of assessing children with DCD and distinguishing between neurodevelopmental disorders.

Talk Sessions

May 8, 2005 – Sunday AM

Brain Stimulation, Activity and Perception (366-371), Natural Images (372-377), Face Recognition (378-382), Perception and Action (383-388)

Brain Stimulation, Activity and Perception

8:30 - 10:00 am

Hyatt North Hall

Moderator: Ione Fine

366 Occipital Activations and Deactivations Induced by Stimulation of the Right Human Frontal Eye Field

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The frontal eye fields (FEF) are traditionally thought to be involved in the preparation and execution of eye movements, but more recent evidence suggests a role in covert spatial attention also. Projections from this putative control area in frontal cortex may modulate activity in visual cortex, but direct evidence for this is lacking in humans, despite recent breakthroughs in monkey studies. Here we used a combination of fMRI and Transcranial Magnetic Stimulation (TMS) in the scanner to show that stimulation of human FEF can modulate activity in retinotopically mapped visual cortex. Right FEF stimulation activated bilaterally sectors of retinotopic visual cortex (V1-V3, and beyond) that represent the peripheral visual field; but it deactivated sectors representing the central visual field. This FEF-induced retinotopic pattern did not depend on resting activation in visual cortex, as it was equivalently present with or without concurrent visual stimulation. Nor was it due to TMS-induced eye movements, blinks, or pupil changes. These data (1) provide direct support for FEF modulation of visual cortex, (2) are consistent with recent anatomical and physiological studies in other primates, which suggest distinct FEF-occipital connections for central and peripheral visual field representations, and (3) illustrate how concurrent TMS and fMRI can now be used to study functional influences between remote but interconnected brain areas.

367 The Perceptual Effects of Retinal Electrical Stimulation

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Photoreceptor loss due to severe retinitis pigmentosa or macular degeneration is one of the major causes of blindness in the Western world, and the prevalence of these diseases is likely to increase dramatically as the popu-

lation ages. Currently there are several groups trying to develop retinal prostheses, analogous to cochlear implants, in which photoreceptor input is replaced by direct electrical stimulation. Recently six patients have been implanted chronically with simple 4x4 retinal prostheses lying over the inner retinal layer. We report here psychophysical data examining the perceptual consequences of electrical stimulation on a single electrode. These data include (1) how thresholds decrease with pulse duration and decrease as a function of electrode height above the retinal surface, (2) how brightness increases as a function of stimulation intensity, and (3) how pulses interact over time.

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368 Microstimulation in LGN produces focal visual percepts: proof of concept for a visual prosthesis

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Existing efforts to develop a visual prosthesis have concentrated on stimulation of the retina or the primary visual cortex. We are pursuing a third approach which targets the dorsal lateral geniculate nucleus of the thalamus (LGN). We hypothesized that highly localized electrical stimulation of the LGN would generate focal percepts corresponding to the receptive fields of cells at the electrode tip. To test this we compared visually-guided saccades made to targets presented on a computer monitor against those made to targets presented through electrical stimulation in the LGN.

Daily tetrode penetrations were made in the LGN of one alert behaving monkey. Receptive field locations were mapped for each electrode position using 2D white noise stimuli. Eye positions were then recorded while a center-out saccade task was performed by the animal where, in interleaved fashion, saccade targets were presented optically as points flashed on a computer monitor or electrically through brief stimulation between two wires in a tetrode.

Our primary observation is that the animal could readily saccade to electrical targets consistent with electrical stimulation generating small, focal percepts. Correspondence between electrical saccade endpoints and receptive-field centers was $3.0 \pm 0.6^\circ$ ($n=18$, with eccentricities of $3-26^\circ$), versus optical saccade accuracy of $1.7 \pm 0.5^\circ$. Electrical and optical saccades were comparable: endpoint scatter was $1.4 \pm 1.2^\circ$ vs $0.8 \pm 0.2^\circ$, latency was 185 vs 160 ms. At times, however, rather than saccading to a presumed phosphene, in electrical trials the animal held its gaze steady, as if continuing to foveate the extinguished fixation point.

Our observations demonstrate the possibility of creating artificial visual percepts through electrical stimulation in the LGN. Such percepts are visual in nature insofar as an animal immediately generalized to them in a visual task. Further, these percepts are focal as saccades to them are tightly clustered.

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369 TMS Induced Affective Blindsight Reverts to Affective Blindness When Stimulus Visibility is Increased

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Some patients with a lesion to primary visual cortex (V1) show the remarkable capability of guessing correctly about stimulus attributes presented to the blind hemifield, a phenomenon called 'blindsight'. Recently, blindsight has been demonstrated for the emotional expression of unseen faces. Here, we show that affective blindsight can also be induced in normal observers, where stimuli are rendered invisible through transcranial magnetic stimulation (TMS) of the striate cortex. Surprisingly, however, access to the emotional content of TMS-suppressed stimuli disappears when overall stimulus visibility is increased. We explain this paradoxical finding by taking into account two processing routes for affective information: a fast, but crude subcortical route, and a slower, but more accurate cortical route. We assert that under normal viewing conditions, human subjects primarily rely on cortically processed information. Only when visibility is low, and uncertainty increases, subcortical information is used, revealing the affective blindsight capability. We are only 'blindly led by emotions' when all else fails.

370 Visually Modulated Endogenous Activity: A component of active visual processing

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Purpose: In the past electrophysiological investigations of visual processing in the CNS have almost exclusively relied on stimulus-locked averaging. Often all activity that showed no first or higher order correlation with the stimulus was considered additive noise. Clearly, this view is much too limiting. As endogenous activity of the CNS must interact with visual input in the highly nonlinear neural substrate, the resulting neural responses must carry visual information that is no longer stimulus locked and lost in conventional signal processing. We hypothesize that it represents the 'active' component in visual processing. The purpose of this project is to demonstrate and characterize such visually modulated endogenous activity (VMEA) in the human VEP.

Methods: In this first study the stimulus consisted of slow, pseudorandom pattern presentations using different base intervals up to 500 ms. In the first step, we subtracted all response component (kernels) that correlated directly with changes in features of the stimulus. The noise-like residue, presumably Demodulation requires application of a nonlinear operation to the response signal before it is correlated, again with the visual stimulation. We are using the formation of auto-products of the EEG signal immediately preceding the stimulus with various lags as well as rectification for demodulation.

Results: At slow stimulation rates when the stimulus transitions are individually perceived, the VMEA dominates. At fast stimulation rates, when the stimulus appears noise-like, the directly correlated response components dominate and the VMEA becomes negligible in size. The main VMEA components appear at an implicit time of around 300ms and another at 375 to 450 ms.

Conclusions: The response residue, after subtraction of all stimulus-locked components, indeed carries stimulus related information. These VMEA components are well defined and can be derived with excellent signal-to-noise ratios suggesting a large information content.

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371 The topography of the human lateral geniculate nucleus and superior colliculus as revealed by superresolved fMRI

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Superresolution is an image processing technique by which lower-resolution

images captured at slightly different spatial positions are combined to create a higher-resolution image. Previous functional magnetic resonance imaging (fMRI) superresolution studies have relied upon special acquisition protocols to obtain such spatial shifts. However, over the course of a typical fMRI session, subjects' brains are naturally sampled at many different spatial positions due to small inadvertent head movements. By taking advantage of these head movements it is possible to achieve superresolution using standard fMRI acquisition techniques. The first step of this superresolution procedure involves spatially registering the lower-resolution image volumes, which is routinely done in fMRI analysis to compensate for head movements and scanner drift. The second step involves reconstructing a higher-resolution volume from the registered lower-resolution volumes. In addition to more sophisticated reconstruction algorithms that have been developed over the past decade, we also demonstrate resolution increases by simply averaging multiple lower-resolution volumes that were resampled into a higher-resolution registered space.

High-resolution imaging is necessary to reveal the topographic details of small subcortical structures such as the lateral geniculate nucleus (LGN) and superior colliculus (SC), but the deep location of these structures precludes the use of surface coils that are used to increase signal to noise for cortical imaging. With a high resolution scanning sequence on a 3 T scanner we obtained reliable signals using a 1.5 × 1.5 × 2 mm³ voxel size. Using the superresolution algorithm, we are able to increase this spatial resolution by a factor of 1.5 to 2 in each dimension to achieve voxel volumes ~1 mm³ without decreasing the signal to noise. Using this resolution, we report details of the retinotopic structure of the human LGN, SC and nuclei in the pulvinar.

Acknowledgment: Support has been provided by NIH training grant T32 MH065214 02, NIMH grants R01MH-64043 and P50MH-62196 and the Whitehall Foundation.

Natural Images

8:30 - 10:00 am

Hyatt South Hall

Moderator: Jochen Triesch

372 Independence of gain control mechanisms in early visual system matches the statistics of natural images

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Two rapid mechanisms in the early visual system control response gain on the basis of locally prevalent luminance and contrast. We asked whether the arrangement and operation of these gain control mechanisms are matched to the statistics of the environment. First, we measured local luminance and local contrast in random patches of calibrated, 12-bit grayscale natural images (van Hateren and van der Schaaf, 1998). These patches correspond to the images that would fall on a receptive field during successive fixations. We found that luminance and contrast are statistically independent of each other (correlation -0.2). This remarkable independence is a property of real world images, but not of artificial images: In phase-scrambled images, which have the same power spectra as natural images, luminance and contrast are strongly correlated (correlation -0.8). Second, we characterized mechanisms of luminance gain control and contrast gain control in the lateral geniculate nucleus (LGN) of anesthetized and paralyzed cats. Stimuli were temporal frequency sweeps (gratings whose temporal frequency varied exponentially from 0.5 to 40Hz over 5s). From the responses we estimated one impulse response for each of 12-25 combinations of luminance and contrast covering ranges encountered

during natural viewing. The estimated impulse responses explain 85% (median) of the variance in the responses to sweeps. Imposing separability, i.e. that luminance gain control has the same effects at all contrasts, and contrast gain control has the same effects at all luminances, has little effect on the predictions: the best separable set of impulse responses still explains 81% of the variance. Thus, functionally speaking, luminance and contrast gain control operate independently, reflecting the very independence encountered in natural images.

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373 Learning Efficient Codes for Natural Images by Combining Intrinsic and Synaptic Plasticity

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Visual cortical neurons often exhibit an approximately exponential distribution of their firing rates in response to natural stimulation (Baddeley et al., 1997). This may be motivated by a desire to maximize information carrying capacity given a fixed mean firing rate constraint, corresponding to a desired level of metabolic costs. However, it is not clear through what mechanisms cortical neurons may achieve this goal. One important candidate mechanism is intrinsic plasticity, i.e. the ability of a neuron to change its excitability through the adaptation of membrane properties. We have recently proposed a new model of intrinsic plasticity where a model neuron adapts its nonlinear activation function to obtain an approximately exponential distribution of its firing rate (Triesch, 2004). In combination with Hebbian learning at the synapses, we have shown that this leads to the discovery of sparse directions in the input.

In this work we apply the model to learning on natural images. We show that a single model neuron exposed to natural image patches that are processed by a simple LGN model, develops receptive fields that are localized and oriented and resemble Gabor wavelets. The model accounts for the approximately exponential distribution of firing rates observed in visual cortical neurons and the formation of simple-cell-like receptive fields.

When a two-dimensional layer of such model neurons with short ranging excitation and longer ranging inhibition is exposed to natural image input, we observe the formation of orientation maps with smoothly varying orientations between neighboring neurons.

Baddeley, R., Abbott, L.F., Booth, M.C.A., Sengpiel, F., Freeman, T. Wake-man, E.A., and Rolls, E.T. (1997). Responses of neurons in primary and inferior temporal visual cortices to natural scenes. *Proc. R. Soc. Lon. Ser. B*, 264.

Triesch, J. (2004). Synergies between intrinsic and synaptic plasticity in individual model neurons. *Advances in Neural Information Processing Systems (NIPS)* 2004.

374 Learning Visual Representations with Projection Pursuit

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Visual cortex must calibrate the receptive fields of billions of neurons in a hierarchy of maps. Modeling this process is daunting, but a promising direction is minimum description length theory (MDL). In MDL, the cortex builds a theory of itself and does this by trading off the bits to represent receptive fields against the bits representing their residual in fitting the input. Although MDL has an attractive Bayesian formulation, algorithms to implement it may incorporate demanding assumptions [1] or exhibit delicate convergence behavior [2]. We show that a new algorithm based on projection pursuit (PP), has fast convergence properties as well as an implementation in a feedback circuit that models intercortical connections between maps. In our PP formulation, neurons with receptive fields (RFs) most similar to the input are selected to represent it. Next, feedback signals from these neurons subtract their portion of the signal from the input,

leaving a residual. The process repeats, selecting neurons that are most similar to the residual. The algorithm produces good representations of the input with only four sets of projections. To learn, the active neurons' RFs are incrementally adjusted with a Hebb rule and the process repeats until convergence. We demonstrate the algorithm with two sets of simulations. In the first, the input is stereo pairs of whitened natural images such as would be represented in the LGN. Using this input, the projection pursuit algorithm can produce receptive fields for disparity cells, simple cells and color that closely model those observed experimentally. In the second set of demonstrations, we model a two-level hierarchy in the cortical motion pathway, using artificial direction selective input. The algorithm learns pattern motion selective receptive fields observed in area MT as well as large field motion stimuli such as those found in area MST.

1. B. Olshausen, *Nature*, 381:607-609, 1996.

2. Z. Zhang et al, *J. of Neurocomputing*, 44:715-720, 2001.

Acknowledgment: RR09283

375 Fixational Instability and Natural Scene Representation

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Images of natural scenes tend to vary smoothly in space and time. It is a long-standing proposal that an important function of the early stages of the visual system is to minimize this input redundancy to allow efficient visual representations. In particular, it has been observed that the response characteristics of neurons in the retina and LGN may attenuate the broad correlations that characterize natural scenes by processing input spatial frequencies in a way that counter-balance the power-law spectrum of natural images. Here, we extend this hypothesis by proposing that the movement performed by the observer during the acquisition of visual information also contributes to this goal. During natural viewing, the projection of the stimulus on the retina is in constant motion, as small movements of the eye, head, and body prevent maintenance of a steady direction of gaze. To investigate the possible influence of a constantly moving retinal image on the neural coding of visual information, we have analyzed the statistics of retinal input when images of natural scenes were scanned in a way that replicated the physiological instability of visual fixation. We show that during visual fixation the second-order statistics of input signals consist of two components: a first element that corresponds to the broad correlations of natural scenes, and a second component, produced by fixational instability, that is spatially decorrelated. This second component strongly influences neural activity in a model of the LGN. It decorrelates cell responses even if the contrast sensitivity functions of simulated cells are not perfectly tuned to counter-balance the power-law spectrum of natural images. The results of this study suggest that fixational instability contributes to establishing efficient representations of natural stimuli.

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376 Image Statistics and Reflectance Estimation

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Humans are surprisingly good at judging the reflectances of complex surfaces even when they are viewed in isolation, contrary to the Gelb effect. We have previously argued that certain image statistics are useful in this task. We have now collected high dynamic range digital images, using multiple exposures, for a large number of materials, in multiple lighting conditions. After normalizing all images to have the same mean luminance, we used ROC analysis to evaluate the utility of various individual image statistics in classifying surfaces as black or white. We tested the statistical moments of the luminance histograms, i.e., variance, skew, kurto-

sis, and the 5th moment, and found them all to be useful. Extreme percentile statistics (e.g., 2nd and 98th percentile) were also useful. Since the human visual system is unlikely to have direct access to pixel luminances, we also considered the information available after filtering with simple filters such as a center-surround or oriented filter. The same statistics were useful when applied to the outputs of these filters. Single statistics can achieve classification rates of 70-80%. When human observers are asked to classify the images, they achieve similar rates, and tend to make errors on the same images that the machine does. This supports the notion that the image statistics capture information that is being used by humans.

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377 Rapid animal detection in natural scenes: critical features are local

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Thorpe et al (Nature 381, 1996) first showed how rapidly human observers are able to classify natural images as to whether they contain an animal or not. Whilst the basic result has been replicated using different response paradigms (yes-no versus forced-choice), modalities (eye movements versus button presses) as well as while measuring neurophysiological correlates (ERPs), it is still unclear which image features support this rapid categorisation. Recently Torralba and Oliva (Network: Computation in Neural Systems, 14, 2003) suggested that simple global image statistics can be used to predict seemingly complex decisions about the absence and/or presence of objects in natural scenes. They show that the information contained in a small number (N=16) of spectral principal components (SPC)---principal component analysis (PCA) applied to the normalised power spectra of the images---is sufficient to achieve approximately 80% correct animal detection in natural scenes.

Our goal was to test whether human observers make use of the power spectrum when rapidly classifying natural scenes. We measured our subjects' ability to detect animals in natural scenes as a function of presentation time (13 to 167 msec); images were immediately followed by a noise mask. In one condition we used the original images, in the other images whose power spectra were equalised (each power spectrum was set to the mean power spectrum over our ensemble of 1476 images). Thresholds for 75% correct animal detection were in the region of 20-30 msec for all observers, independent of the power spectrum of the images: this result makes it very unlikely that human observers make use of the global power spectrum. Taken together with the results of Gegenfurtner, Braun & Wichmann (Journal of Vision [abstract], 2003), showing the robustness of animal detection to global phase noise, we conclude that humans use local features, like edges and contours, in rapid animal detection.

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Face Recognition

10:15 - 11:45 am

Hyatt North Hall

Moderator: Isabel Gauthier

378 Temporal dissociation of spatial attention and competition effects between face representations

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Scalp event-related potential (ERP) studies in humans indicate that the processing of faces differs from other categories between 130 and 170 ms after stimulus onset, peaking at the occipito-temporal N170. We have recently shown that the N170 response to a face stimulus is strongly reduced when another face - or a non-face object of expertise (Rossion, Kung & Tarr, 2004) - is processed concurrently (Jacques & Rossion, 2004), suggesting that neural representations of individual faces compete in the occipito-temporal cortex. However, this amplitude reduction of the N170 may be related to spatial attentional modulations rather than to a competition between face representations. To test this alternative hypothesis, ERP responses to a lateralized face were recorded while subjects were processing a centrally presented stimulus, either a face or a phase-scrambled face stimulus. Subjects performed either a low-level matching task on the central stimulus - thus allocating minimal attention to the lateralized face -, or a task in which they had to detect the occurrence of the lateralized faces. The results are twofold: first, replicating our previous results, the N170 to the lateralized face was largely reduced, starting at about 130 ms, when the central stimulus was a face relative to the control stimulus. Importantly, this competition effect was of similar amplitude in both attentional conditions. Second, when subjects concentrated on the central stimulus, the N170 to the lateral face was strongly reduced, whether the central stimulus was a face or a scrambled face, i.e. the effects of competition and spatial attention were additive on the N170. Moreover and most importantly, this effect of spatial attention started at about 80 ms after stimulus onset, on the visual P1, much earlier than the competition effect. These results indicate that spatial attention and object competition are distinct mechanisms that both strongly shape the processing of faces in extrastriate cortex.

379 How holistic processing is affected by working memory load

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Holistic processing (HP) for faces (and objects of expertise) can be measured in tasks where subjects selectively attend to and compare a part (e.g., the mouth) of two faces while trying to ignore other parts that may vary. HP is evidenced by a congruency effect between the correct responses on the target and irrelevant parts. Last year we argued that encoding is not the locus of this effect because changing the configuration at encoding did not reduce HP (Gauthier et al., VSS 2003). Working memory load (WML) can increase processing of irrelevant distractors when the relevant and irrelevant information are different objects (e.g., de Fockert, 2001; Yi et al., 2004). Here we ask if WML would reduce selective attention to a face part (increase HP), especially for a WML during the matching judgment. A WML of three items was added to a sequential matching task with face composites during the first (S1) or the second (S2) face. In the main task, always using faces, subjects matched the top parts of the two stimuli, trying to ignore the bottom parts. In the load-at-study condition, three items were shown, then the S1, the WM probe, and finally the S2. In the load-at-test condition, the S1 was presented, followed by the three items, then by the S2 and finally the WM probe. A control condition used scrambled items instead of the WML stimuli and no response was required. Faces and watches were used for the WML in different versions. A face WML reduced HP in all conditions and the reduction was larger in the load-at-test than the load-at-study condition. This supports the idea that manipulations at test affect HP more than those at encoding. The watch WML did not impact face HP at either study or test, presumably because watches did not require HP. Our results suggest that the relationship between WML and selective attention depends on the nature of the load and on the relationship between the relevant and irrelevant information.

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380 Accuracy in face recognition: Better performance for face identification with changes in identity and caricature but not with changes in sex

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Because we encounter faces of only two sexes but recognize faces of innumerable different identities, it is often implicitly assumed that sex determination is easier than identification in face recognition. Many studies support this assumption. For example, we are very accurate at telling the sex of unfamiliar faces in photographs (Bruce, et al., 1993. *Perception*, 22, 131-52) and sex categorization is performed more rapidly, on average, than familiarity or identity decisions (Bruyer, Galvez, & Prairial, 1993. *British Journal of Psychology*, 84, 433-441). The question that we investigated here is how sensitive we are to variations of identity-related features or sex-related features in familiar faces. 38 participants had to pick out the veridical faces of ten familiar work colleagues from amongst distractor faces that were variations of the original faces. Distractor faces varied either in identity, caricature or sex. In the identity face sets, distractor faces were various morphs between the original face and two unfamiliar faces. In the caricature face sets, distractors were various caricatures of the original face. Finally, in the sex face sets, distractor faces were various feminized and masculinized versions of the original face. Participants were most accurate at identifying the original face amongst distractors in the identity sets. They had a tendency to choose positive caricatures over the original faces in caricature sets. However, participants were very poor at finding the original faces in the sex sets. The results suggest that while extracting and processing sex-related information from a face is a comparatively easy task, we do not seem to retain sex-related facial information in memory as accurately as identity-related information. These results have implications for models of face representation and face processing.

381 Three-dimensional shape and surface reflectance contributions to opponent-based face identity adaptation

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People identify a human face more accurately following adaptation to a synthetically created 'anti-face' with 'opposite' features (Leopold et al., 2001). Previous experiments have shown that face adaptation survives two-dimensional scaling and shifts in retinal position, placing the locus of the effect in high-level visual areas, beyond those with strict retinotopic organization. In this study, we first adapted observers to three-quarter profile views of anti-faces and tested with frontal views of anti-caricatures. We found that opponent-based face adaptation survives this change in three-dimensional viewpoint. This indicates that face adaptation taps face encoding mechanisms that operate across view change. To examine the nature of the visual information underlying view-transferable face adaptation, we used opponent-based facial identity adaptation, in combination with stimuli created by a three-dimensional morphing program that operates on laser scans of human heads (Blanz & Vetter, 1999). By adapting and testing with faces that varied from the average only in their three-dimensional shape or surface reflectance, we show that the shape and surface reflectance information in faces can be adapted selectively. In a final experiment, we show that both shape and reflectance adaptation transfer across viewpoint. These findings indicate that neural representation of faces includes both shape and reflectance information in a form that generalizes across changes in three-dimensional viewpoint.

382 The Use of Afterimages in the Study of Categorization of Facial Expressions

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The perception of color afterimages has been recognized for centuries, and

it is widely accepted that color afterimages reveal a categorical relationship between color percepts. The perception of facial expression afterimages is a much more recently recognized phenomenon, and it too can be used to map the categorical relationships between percepts. One theory predicts a symmetric relationship between categories of facial expressions, similar to a color wheel. In contrast, an evolutionary or functional perspective predicts a strongly asymmetrical relationship between categories of facial expressions. A series of three experiments test these predictions. In each experiment, subjects fixate on an image of a facial expression for 40 seconds, and then view a neutral image of the same person for 1000ms. Subject are then asked to report, in a forced choice paradigm, what facial expression the second image appeared to have. The first experiment revealed that happy and sad are opposites of one another, insofar as each symmetrically evokes the other afterimage. The second and third experiments reveals that given an image of fear, anger, surprise or disgust, the afterimage is perceived as a happy facial expression, whereas fixating on a happy face consistently results in the perception of a sad afterimage, suggesting an asymmetric relationship between categories of emotional facial expressions. The evolutionary and functional explanations for this asymmetry are discussed.

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Perception and Action

10:15 - 11:45 am

Hyatt South Hall

Moderator: Jody Culham

383 Don't bite the hand that feeds you: A comparison of mouth and hand kinematics

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There is a long history of work investigating how vision is used to guide the arm and hand in actions such as reaching to grasp an object. Most of these studies, however, have focused on movements directed away from rather than toward the body. Yet one of the most common reasons that primates, including humans, grasp objects is to bring them to their mouths during feeding. In the present study, therefore, we examined the kinematics of arm and mouth movements in a self-directed feeding task. In particular, we were interested in whether the opening of the lips during feeding would show similar properties to the opening between the finger and thumb during grasping with a precision grip. Various sized food items were placed at one of three distances and subjects were instructed to reach out and pick up each item, then bring it to the mouth and bite it. Two, OPTOIRAK infrared tracking systems were linked in order to record the changing positions of infrared-emitting markers placed on the arm, hand, lips and head. As is typical in kinematic studies of grasping, we found that the finger and thumb opened considerably wider than required prior to closure upon the object and that the maximum opening was reached at approximately 70% of the way through the outward reach. By comparison, the mouth opened only slightly wider than the object and did not reach its peak until the very end of the inward reach. This pattern was observed for both small and large food items. In summary, the way in which we open our hand to pick up a food object is quite different from the way in which we open our mouth during feeding. This may reflect in part the different kinds of sensory information that are used to control the two movements.

384 Sources of information for catching balls

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Retinal motion, stereo, and extra-retinal information from pursuit eye movements all provide information for catching a ball. Predicting the ball's path is also important when hitting a cricket ball (Land & McLeod; 2000) and when catching a bouncing ball thrown by another (Hayhoe et al., 2004). In both tasks, gaze was directed to the bounce point just prior to the arrival of the ball, suggesting knowledge of the dynamic properties of the ball allows prediction of the ball's path. When subjects have to catch a ball they throw themselves, is there a greater reliance on prediction, since they have added information from the throw?

We asked subjects to throw a ball against a wall, ensuring that it bounced on the floor prior to contact with the wall, and to catch the returning ball. There were therefore 2 bounce points between each throw/catch. The ball bounced approximately 175ms and 339ms after release. Subjects infrequently looked at the first bounce point (20%), opting instead to direct gaze to the second bounce point (80%), after which subjects pursued the returning ball. Secondly, fixations were significantly closer to the bounce point on the wall than on the floor (7deg v 13deg). In addition, arrival of gaze on the wall preceded the ball by 324ms. This was much earlier than subjects who had to catch the same ball when thrown by another person (53ms ahead of the bounce).

While evidence exists for the role of internal models of the body's dynamics in the control of movement, the need for internal models of the environment is less established. Fixating the wall when throwing the ball off the floor suggests we can rely on internal models of the properties of the ball and the environment in tasks such as throwing and catching a ball. Knowledge of the throw also allows a greater use of prediction.

References.

Land, MF. & McLeod, P. (2000) *Nature Neuroscience*, 3(12), p1340-1345.
Hayhoe, M. M., Mennie, N., Gorgos, K., Semrau, J., & Sullivan, B. (2004). *Journal of Vision*, 4(8), 156a.

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385 Selecting and pointing: Consecutive serial processing?

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Visually guided motor behavior has been generally assumed to comprise two serial stages: response selection followed by motor execution. However, McPeck, Skavenski & Nakayama (2000) showed that multiple saccades could be programmed concurrently with a very short inter-saccadic interval (0-100 msec). Thus the cost of incorrect initial saccades was reduced by short latencies between movements. Does the same pattern occur for manual pointing where the massive arm would cost substantially more in incorrect movements?

Subjects were required to point to a single target or an odd colored target in a search array. Finger trajectories were sampled at 120Hz using a Polhemus device. In the search condition, highly curved trajectories were observed, showing that similar to eye movements, initial pointing was to a distractor and that quick, successively planned arm motion ensured the correct pointing response. In contrast, if the subject waited longer before movement execution, fewer curved trajectories were observed. However, because the latency of such a correct movement was relatively long, the quick strategy, requiring online, possibly concurrent processing was no more costly in overall time. This suggests that in the motor planning of the arm, simple selection followed by execution is not necessarily the optimal strategy. We should thus conceive of visuo motor behavior as an online process, with different multiple goals and plans being implemented concurrently as visual information is processed.

386 Heading toward distant targets: optic flow and the recalibration of visual direction

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Background: The visual direction of an intended heading point has been shown to play an important role in guiding locomotion toward close targets (Rushton et al *Curr. Biol.* 8,1191, 1998, Rogers and Dalton, *Invest. Ophthalmol. Vis. Sci.* 40, s764, 1999). With distant targets, however, the error signals from eye and head position (whenever the observer strays off a direct heading path) are extremely small, making it more likely that optic flow influences locomotion. **Aims:** (i) to investigate whether observers' walking paths show an increased variability of direction when optic flow from the ground plane is occluded compared to unoccluded viewing; (ii) to see whether the veridical optic flow information about heading direction might be used to recalibrate eye and head position (and hence visual direction) when prisms are used to alter visual direction. **Methods:** Observers walked towards a distant visual target (150 m) with small angle displacing prisms (5-7 deg) either present or absent. The prisms were mounted close to the observer's eyes to increase the field of view to at least 60 by 60 deg. The presence or absence of occluders (masking the lower half of the visual field below the distant target) controlled to availability of ground plane optic flow. Observers' walking paths were continuously monitored by video. **Results:** (i) walking paths were typically straight, both with and without occluders, but the average unsigned deviation of the path directions was significantly greater when ground plane optic flow was unavailable; (ii) initial walking paths with prisms over the eyes were significantly deviated (70-90% of the prism angle) for both occluded and unoccluded viewing of the ground plane; (iii) the deviation of subsequent walking paths from the correct heading direction became significantly smaller over time but only when ground plane optic flow was available during those subsequent trails. These results provide convincing evidence for the role of optic flow in recalibrating visual direction.

387 Does Perceptual-Motor Recalibration of Locomotion Depend on Perceived Self Motion or the Magnitude of Optical Flow?

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The perceptual-motor calibration of human locomotion can be manipulated by exposure to an environment in which the visual flow associated with self-motion is altered relative to biomechanical walking speed (Rieser, Pick, Ashmead and Garing 1995, JEP:HPP). An open question remains as to whether this recalibration is based on perception of the speed of movement through the world or on the magnitude of optic flow itself. We addressed this issue using a treadmill-based virtual environment in which we could independently vary actual walking speed and the simulated visual experience of moving down a hallway. The hallway consisted of textured walls and textureless floor and ceiling, so that visual flow information was only available from the walls. Subjects were exposed to one of two conditions. Actual walking speed was 1.2m/s in both cases. In one condition, visual information corresponded to movement down a long hallway at a speed one third less than the biomechanical rate of walking. In the second condition, the visual information corresponded to movement three times faster than in the first condition, down a hallway that was three times larger. Because the scale of the space was increased by the same amount as the increase in velocity through the space, the magnitude of optic flow remained essentially constant, though flow due to the walls moved upward in the visual field. Perceptual-motor calibration was evaluated by having subjects walk blindfolded to previously viewed targets at 6, 8 and 10m before and after 10 minutes of walking on the treadmill. For the visually slower condition, subjects increased the distance they walked by an average of 10% between the pre and post tests. For the visually faster condition, subjects decreased the distance they walked by an average of

3%. These differences demonstrate that the recalibration depended at least in part on visual perception of the speed of self-movement, not just on the magnitude of optic flow.

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388 MSTd Population Responses Account for the Eccentricity Dependence of Heading Discrimination Thresholds

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Psychophysical studies have shown that humans can use optic flow to discriminate differences in heading direction < 1 deg. Maximal heading sensitivity occurs for directions around straight ahead, whereas performance falls off steeply when observers discriminate headings around an eccentric reference. Neurons in area MSTd, which respond selectively to large-field flow patterns, are thought to be a key element of the neural substrate for heading perception. Thus, the population code for heading in MSTd should account for the dependence of psychophysical thresholds on heading eccentricity. It has been suggested that a preponderance of neurons tuned to forward motion (expansion cells) might explain the psychophysics. We examined this issue by recording extracellularly from a large, unbiased sample of MSTd neurons in two fixating macaque monkeys. A 3D heading tuning function was measured for each neuron by presenting large-field optic flow patterns depicting all possible directions of heading separated by 45 deg in both azimuth and elevation. MSTd neurons typically have broad, cosine-like tuning for heading in 3D. Heading preferences are distributed broadly, but neurons preferring fore-aft motion are substantially less common than neurons preferring lateral motion. Thus, a preponderance of expansion cells is not the explanation for better heading discrimination around straight ahead. On the other hand, neurons preferring lateral motion frequently have the steep slopes of their heading tuning functions near forward motion, and this could account for better discrimination. By fitting these 3D tuning functions, along with the variance-mean relationship for each neuron, we computed the performance of a maximum-likelihood estimator of heading over a wide range of heading eccentricities. Heading thresholds for this estimator mimic the psychophysical data, indicating that the MSTd population code can account for increased heading sensitivity around forward motion.

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Poster Session D

May 8, 2005 – Sunday AM

Emotional and Social Influences on Attention (389-399), 3D Cue Integration (400-408), Attention, Learning, and Memory (409-428), Visual Neurons: Properties (429-435), Eye Movements: Cognitive (436-453), Contrast (454-463), Contour and Shape (464-474), Spatial Vision 2, (475-489)

8:30 am - 1:30 pm (Authors present 12:00 - 1:30 pm)

Municipal Auditorium

Emotional and Social Influences on Attention

389 Emotion in visual search: The selection of affective faces for awareness

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During visual search, the time to locate a unique target face is less affected by the number of distractor faces when the target face expresses a negative emotion than when the target is positively valenced. Such preferential guidance by negative content suggests that the emotional valence of the face is processed outside the focus of attention and guides focal attention to the target location. In other words, processing of the emotional content of a face stimulus appears to happen prior to conscious awareness. The current set of experiments investigated further whether performance differences between positive and negative targets are due to a bias in selection of information for awareness rather than a bias in responding to the stimulus after selection for awareness. In Experiment 1, participants identified the emotional valence of a positive or negative target face that was presented among varying numbers of neutral distractor faces. Search slopes for negative faces were shallower relative to search slopes for positive faces, indicating more effective guidance of attention by the negative face. In Experiment 2, the search display was occluded apart from a small search window such that only information presented in the focus of attention could influence performance while eliminating guidance by unattended information. This time, search was much less efficient and the search slopes did not differ for the different emotional expressions. These results support the notion that emotional information is processed prior to awareness and influences allocation of focal attention.

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390 Effects of anxiety on attention and visual memory

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An increasing body of literature suggests that affective processing may influence basic visual processing. For example, Anderson and Phelps (2001) found that, in an attentional blind paradigm, normals detected words with negative content (e.g., murder) more often than did a patient with amygdala damage. Consistent with this result, Gupta (2001) reported that arousal alters flicker fusion thresholds. MacLeod & Mathews (1988) found that anxiety-prone individuals fixate longer on negative words. The tasks used in these studies typically required only focal spatial attention. Less is known about the influence of affect on the perception of complex scenes. Research on visual attention and memory, employing change detection paradigms, provides a means of examining this issue. Studies of change detection show that internal representations of visual scenes are incomplete. Factors such as knowledge (Beck, Angelone, & Levin, in press) and social salience (Simons & Levin, 1998) appear to influence whether an

observer attends to, encodes, and recalls an element of a visual scene. We used this paradigm to examine whether anxiety-proneness and immediate arousal influence the detection of anomalous changes in a complex scene. We constructed a mock promotional video in which we included 8 anomalous changes to objects and people. Participants with high or low anxiety-proneness, as measured by the State-Trait Anxiety Inventory (Spielberger, 1983), viewed the 5-min video and subsequently reported any unusual changes they noticed. Preliminary analyses show that anxiety influences the detection of changes. In particular, regression analyses show a negative linear relationship between levels of anxiety and number of changes detected. Individuals with higher levels of anxiety report seeing fewer changes than do individuals with lower levels of anxiety. Such interactions between affective and visual processing have implications for such domains as eyewitness testimony.

391 Differential adaptation to face identity and emotional expression in the near absence of attention

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Retinal inputs that are perceptually suppressed can still build up to various aftereffects such as linear motion or orientation. However, in a previous study we found that the identity-specific face aftereffect following 4 s of adaptation is effectively cancelled by withdrawing attention from the adapting stimulus. Here, we examined whether 1) attention is necessary for gradual buildup of face-identity aftereffect over many trials, 2) adaptation to emotional expressions is modulated by attention, and 3) attentional manipulation has any effect on conscious face identification. In Exp 1, an anti-face image was displayed for 10s (initial adaptation), and redisplayed for 1 s between trials (readaptation). At the same time, a stream of digits (3Hz) was displayed at fovea. Observers (n=9) were instructed to either attend to the distracting digits and report occurrences of letters, or ignore them. A test image followed and was identified by pressing a key. The identity strength of the test face varied between 0 (average) and 0.4. When the distracting stimuli were ignored, there was significant shift in the identification curve as a function of identity strength ($p < .01$). The aftereffect disappeared completely when subjects monitored the digits. In Exp 2, happy and angry expressions were tested on 5 observers. The paradigm was similar to Exp 1. Although when the distracters were attended, adaptation to emotion was reduced ($p < .05$), some aftereffect specific to the emotional expression still remained ($p < .05$). In Exp 3, observers concurrently performed both digit/letter and face identification tasks. Surprisingly, the shift in the identification curve due to inattention was negligible. We conclude that the implicit processing of face identity and emotion underlying the corresponding aftereffects require different levels of selective attention. Adaptation to emotion is

possible in near absence of attention. Explicit face identification (Exp 3) also seems to be robust to attentional blink.

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392 Spatial attentional cuing effects on emotional evaluation of faces

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Faces seen as distractors in visual search arrays are subsequently rated as less trustworthy than faces previously seen as search targets (Raymond, et al., 2004, VSS). Similarly, task-irrelevant faces associated with no-go cues in a simple reaction time task are seen as less trustworthy than faces not so associated (Fenske, et al. 2003, VSS). A possible mechanism for this attentional control over emotional evaluation may be a persistent effect of attentional inhibition. Here we ask whether brief spatial cues presented to the left or right of a fixation spot just prior to the presentation of a target face (presented to the left or right) would modulate the social-emotional evaluation of the face. After viewing a simple cue, participants categorized the gender of the face as quickly as possible and then rated the face for its trustworthiness. The stimulus onset asynchrony (SOA) between cue and target face was varied; cues were presented at a location that was the same as (valid) or opposite to (invalid) that of the target. For faces presented on the left, gender categorisation response times (RT) were faster with valid v. invalid cues for all SOAs. For faces seen on the right, this cuing benefit was only seen for short SOAs. For long SOAs, RT was faster with invalid cues, indicating inhibition of return (IOR). Trustworthy ratings of faces presented on the left were unaffected by cues for any SOA. Similarly, for faces presented on the right, cues had no effect on ratings for short SOAs. However, for long SOAs (producing IOR), validly cued faces were rated as significantly less trustworthy than invalidly cued faces. These results indicate that the inhibitory processes underlying IOR have consequences for the social-emotional evaluation of stimuli and are therefore consistent with previous accounts that persistent attentional inhibition can modulate affective responses. These data also suggest that attentional facilitation has no impact on affective appraisal.

393 How Persistent is Attentional Modulation of Affective Evaluation?

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Previous research has shown that if a stimulus is evaluated along an emotional dimension immediately after being seen in a simple selective attention task, its evaluation will be more negative if it had been previously viewed as a distractor than if it had been seen as a target (Raymond, et al., 2003, Psych Sci, 14 (6), 537-542). Here, we extended the investigation of this distractor devaluation effect in three ways. First, we asked whether such effects could be produced when target search was slow and effortful, requiring analysis of each distractor. Second, we asked if these effects could be obtained using exemplars of everyday objects, as opposed to the abstract patterns studied previously. Third, we explored whether distractor devaluation would persist even when other information and other evaluative tasks were imposed between exposure to an item in a search task and its subsequent evaluation. Using full colour photographs of objects, we asked participants to categorize as quickly as possible a categorical oddball in a 3-item display. After each search task, participants rated a single object on a 'good' or 'bad' scale. The item evaluated was either from the immediately preceding trial (n); seen about 5 s earlier) or from the n-4 search trial (seen about 66 s earlier). We found that for both n and n-4 conditions, items previously seen as distractors were rated more negatively than items previously seen as targets. The results suggest that distractor devaluation effects can persist over relatively long intervals and can modulate responses to a wide range of

stimuli. Our findings support the idea that attentional modulation of emotional appraisal results from persistent attentional inhibition that becomes associated with an object's representation.

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394 Emotional Valence and the Attentional Blink: The Impact of Meaning on Detection

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The Attentional Blink (AB) is a visual phenomenon demonstrating an apparent limit of the visual system's ability to process individual items in a rapid serial visual presentation (RSVP). The AB occurs when two items, the first (target) to be identified and the second (probe) to be detected, are presented among other stimuli in a RSVP. The AB describes the interval of time in which attention cannot be focused on the probe which thereby proceeds undetected. Previous research has demonstrated that an iconic happy face attenuates the AB (Mack et al, 2002). We chose to explore whether this finding was face specific or emotionally mediated. **Methods:** RSVP streams of face stimuli with similar emotional expressions were presented at a rate of 100/ms each to produce an AB. Ss were instructed to identify one of five blue shapes superimposed over one of the faces in the RSVP and detect a subsequent face probe presenting a different emotional expression. Conditions consisted of: 1) a smiling face probe among neutral expressions; 2) a frowning face probe among neutral expressions and; 3) a neutral expression face probe among smiling faces. **Results:** When Ss were asked solely to detect the probe, performance ranged between 90 & 100%. However when Ss were asked to both identify the target and detect the probe, the results demonstrated a monotonic AB with a lag effect (Awh et al, 2003) rather than the classic U-shaped AB function (Raymond et al, 1992) across all conditions. Notably, significant differences were found between detection rates of the happy face and sad face as compared to the neutral face ($p < .01$). **Conclusions:** The AB has been demonstrated reliably over numerous conditions using various stimuli. Our experiment differs from these studies in that both the distractors and probes comprised similar forms with different meaning. Our results point to the attenuation of the AB by emotion and offer additional support in the late selection processes mediating perception of the attentional blink.

395 Social context influences gaze-following and neuronal activity in macaque area LIP

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People rapidly shift their attention where another person is looking. We recently demonstrated that macaques also shift their attention in the direction of viewed gaze and the similar spatial and temporal dynamics of this gaze-following response in macaques and humans suggests shared neural circuitry (Deaner and Platt, 2003 Current Biology 13: 1609-1613). To assess the flexibility of these mechanisms, we probed whether gaze-following is modulated by social context and whether neuronal activity in area LIP reflects this modulation. Monkeys performed a peripheral target detection task by fixating a central square briefly replaced by an image of a familiar macaque looking left or right (100-800 ms SOA). Upon face offset, a yellow square unpredictably appeared 15 degrees left or right and monkeys were rewarded for shifting gaze to it. High and low social status monkeys served as gaze cues. We predicted gaze-following would be weaker when viewing high-status monkeys because they attracted gaze in a separate target choice task (Deaner and Platt 2004 Journal of Vision Supplement). At 200 ms SOA, reaction times were faster when targets appeared in the direction of viewed gaze. Moreover, gaze-following was suppressed when viewing high-status monkeys. These findings suggest

that gaze-following is not reflexive, but can be modulated by social context. We next probed the effects of viewing faces with averted gaze on neuronal activity in macaque area LIP. The preferred direction of each neuron was first mapped using standard delayed saccade trials. We found that neuronal activity in area LIP reflected spatial bias induced by viewing faces with laterally-deviated gaze. Specifically, firing rate was enhanced by viewing low-status monkeys gazing in the preferred direction of each neuron, but was suppressed by viewing high-status monkeys gazing in the same direction. LIP neurons thus encoded spatial bias derived from social cues and context.

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396 The interaction of body and gaze cues in directing attention

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We pay attention to the direction of eye gaze because it is an important social cue about other people's goals and intentions. There is a tendency to look where other people look, a phenomenon that seem to be automatic and innate. However, would the direction of the eye gaze be given attentional priority in the presence of other cues such as body direction? To answer this question, we measured reaction times to combinations of body and eye gaze cues in a numeral identification task. We found that numeral identification was significantly faster only when both eye gaze and body direction were congruent with the target location. Our results suggest that eye gaze direction does not cue our attentional priority to a location when it competes with body direction cues.

397 Perception of other's action influences performance in Simon task

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Most of our actions are influenced by the social context, in particular, by the presence of others and the actions performed by others. Previous studies have shown that observing others' actions can affect individual performance of the same actions. In order to investigate the effects of the presence of others on an individual's performance of the Simon task, we conducted three experiments in three conditions: individual (only individual presented), joint (two persons performed simultaneously), and nojoint condition (two persons present while only one performed). We developed a new Simon task paradigm, in which each person only responded to on trials designated by special fixation point style. In Experiment 1, two persons performed a Simon task sitting side by side. Simon effect was observed in every condition when the same person made a response in two consecutive trials ('go' trial), whereas Simon effect was observed after another person made a response ('no-go' trial) only in the joint condition. In Experiment 2, we examined whether Simon effect was observed when a person performed with another person whose color-key assignment was reversed. The result showed no Simon effect in the joint no-go condition. In Experiment 3, two persons with the same color-key assignment performed the task sitting face to face or side by side. In face to face condition, there was no Simon effect in joint no-go condition. These results showed that after go trial Simon effect always occurs and that after no-go trial Simon effect occurs in only the joint condition in which two persons with the same color-key assignment performed the Simon task sitting side by side. This suggests that one's own actions and others' actions are represented in a functionally equivalent way in particular situations. We will discuss a possibility that other's existence, perception of other's action, and the sight of others affect our action in terms of sequential analyses of S-R compatibility in the preceding trial.

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398 Action Simulation influences Personality Judgments

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Observing the actions of another person activates similar action representations in the observer. A consequence of this perception-action matching process is that producing actions one simultaneously observes will be easier than producing different actions. For example, when observing another person kick a ball, a foot response to identify a stimulus will be faster than a key-press with the finger. In contrast, observing a person press a key with the finger will facilitate a subsequent finger key-press relative to a foot response. We investigated two issues concerning this action priming effect: First, the effects have typically been obtained when viewing video clips or real actions, but can they be detected when static images implying action are viewed? Second, can visuomotor priming influence other stimulus properties such as personality characteristics of the viewed person? New data providing answers to these two questions will be reported.

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399 Conversation Limits Attention: The Impact of Conversation Complexity

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In two experiments, we assessed the impact of different conversational content on visual attention. Both experiments used the Useful Field of View (UFOV) test to measure attention. In the first experiment, participants performed the UFOV test while responding to cardinal directional terms with their vertical-plane analogues (e.g., responding 'upper left' when hearing 'northwest'). In the second experiment, participants performed the UFOV test while making ending-letter contingent responses to words empirically demonstrated to have positive or negative emotional valence. Results of both experiments indicate a significant increase in the presentation time required to respond to UFOV targets while concurrently conversing relative to responding to UFOV targets without conversing. These effects suggest that some drivers conversing on a cellular phone may be greater than 16 times as likely to be in an injurious accident. These experiments also suggest directional as well as emotional conversations limit visual attention more than conversations using random-word stimuli such as those reported in Atchley and Dressel (2005), indicating conversational type, not simply conversational presence, can further limit visual attention capacity.

3D Cue integration

400 Irrelevant boundaries disrupt the short-term storage of visual information

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Purpose: To analyze the role of irrelevant, visually salient boundaries in the short-term storage of visual information. **Method:** On each trial, the S viewed two briefly flashed, 6-by-6, random checkerboards separated by a 1 sec. ISI and judged (with feedback) whether they were different. In Exp. 1, the S was aware that the difference (if there was one) was always in the contrast polarity of a single square. Performance was observed (in separate blocks) for two task variants: in the homogeneous task, the entire checkerboard was achromatic; in the segmented task, the squares in the lower right quadrant were achromatic, but those in the upper left, upper right, and lower left quadrants were tinted red, green, and blue, respectively. This color scheme remained fixed across all trials in the segmented task, producing irrelevant chromatic boundaries. All dark squares were equiluminant, as were all bright squares. Expt. 2 was analogous to Expt. 1, except that the roles of contrast polarity and color

were reversed: i.e., in both tasks S's tried to detect a change in (equiluminant) color; and in the segmented task, the irrelevant boundaries between quadrants were defined by contrast polarity. Results: In both experiments, performance was significantly worse in the segmented than in the homogeneous task. Although the boundaries (either chromatic or contrast-defined) in the segmented task were both irrelevant and fixed from trial to trial, they nonetheless impaired performance. In addition, changes in four central squares were easier to detect than other changes in the homogeneous task but harder to detect in the segmented task (in which these squares abutted two irrelevant boundaries). Conclusions: these findings suggest that (1) at least some of the statistics used to sense changes recruit information from across multiple squares, and (2) these statistics are impaired if they have to pool information across preattentive boundaries.

401 Early Temporal Dynamics of Cue Combination for Slant from Stereo and Texture

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In natural conditions, a given object property is often specified by multiple sources of visual information, so the sources of information must be integrated during perception. Recent results suggest that the visual system combines information in an optimal manner, with cues being weighted according to their reliability. But the reliability of information from a given source surely changes over time, as sensory measurements accumulate and as computations that use them progress, and there is no reason to believe that the time course would be the same for all cues. Van Ee and Erkelens (1996) found that the influence of stereo on perceived slant continues to accumulate over a period of many seconds. Greenwald, Knill and Saunders (VSS 04) perturbed stereo and texture cues during reaching movements, and observed an early influence of stereo, followed by a later influence of texture. We tested how the contributions of stereo and texture change over time for a slant judgment task, using briefly presented stimuli in order to track changes during the critical first moments of perceptual processing. Stimuli were binocular images of textured planar surfaces displayed for a limited time, followed by a binocular noise mask. The display duration had values between 30 and 4000 ms, tested in separate blocks. On each trial, subjects judged the sign of slant relative to frontal. Stimuli contained a ± 10 deg conflict between the slants indicated by stereo and texture cues, respectively, and we used the differences in observed PSEs for the different conflict conditions to infer the relative weights given to stereo and texture. The weight given to stereo increased with display duration, and some observers gave weight to stereo even at the very briefest durations.

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402 Cue combination: compulsion and the effects of asynchrony

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One issue that has largely been ignored in the cue combination literature is that different visual cues are processed with different latencies. Differences in latency could lead to errors in cue combination if the attribute that is being judged changes over time. Are differences in latency taken into account when combining different cues, or are errors arising from combining information from different moments simply tolerated? Does the brain reduce such errors by integrating cues over extended periods of time?

In order to answer these questions, we examined how varying the relative timing of changes in two slant cues influences the way that people perceive changes in slant. We presented subjects with a ring that jittered in a certain plane. The slant of this plane was evident from both binocular disparity and from the ring's retinal shape. The plane could change its slant as indicated by only one cue, by both cues simultaneously or by both

cues at different times. In separate experiments subjects had to perform a detection task (detect the occurrence of a change in slant) and a discrimination task (indicate the direction of a change in slant).

In the detection task, the performance when both cues changed matched the performance that is predicted by combining the performance for the separate cues on the basis of probability summation, regardless of the timing of asynchrony. In the discrimination task, performance was significantly better than predicted by probability summation as long as the two cues changed within about 200 ms of one another. These findings suggest that rather than compensating for delays, the brain integrates cue estimates over an extended period of time. Our findings also show that cue integration is not completely compulsory; the benefit that we found for bi-cue slant changes in slant discrimination was absent in the detection task.

403 Modeling dynamic re-weighting in visual cue integration

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Much of the existing data on sensory cue combination is consistent with a linear integration model in which cue weights vary in inverse proportion to the uncertainties of the cues. Research has focused on static cue integration problems, in which cue weights are assumed to remain constant over time. In many scenarios, however, information from one cue can accrue over time to help disambiguate the information provided by another cue, a form of cue promotion. In particular, information from one cue can indirectly disambiguate hidden scene variables that determine the values of other cues. Consider the case of cast shadows. Cast shadows provide information about the relative 3D position of an object and a background surface, but this information is only as reliable as the observer's knowledge of the light source direction. In a dynamic scene, other cues such as stereo, by specifying the relative depth of the object and surface, can indirectly disambiguate the light source direction. In general, one would expect the uncertainty about the light source to decrease over time. This dynamic changing of uncertainties will manifest in the apparent changing of the relative weights of the two cues over time. Similar arguments apply to dynamic cues such as changing size, with object size as the hidden variable. We use Dynamic Bayes Networks to model these scenarios and make connections of our model to the weak fusion model and other cue integration phenomenon such as perceptual-explaining-away. We approximate the optimal non-linear cue integration model using Extended Kalman Filters. The results show that, as predicted, the relative influence of an indirect cue like cast shadows increases with increased exposure time in the presence of direct depth cues like stereo. The model makes strong psychophysical predictions about how the apparent weights of different cues should change over time in dynamic scenes.

404 Combining Slant Information from Disparity and Texture: Is Fusion Mandatory?

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The visual system combines slant cues to form a single percept in a fashion that approaches statistical optimality. We asked whether in combining cues the system fuses the cues such that access to the single-cue estimates is lost. Previous work on this issue observed fusion for disparity and texture using a 3-interval oddity task. We wondered whether the 3-interval task made it too difficult for the observer to retain single-cue estimates. To test this, we used a simpler 2-interval task that reduced the memory load. Observers were presented two slanted planar stimuli in succession; one with a conflict between the disparity and texture, and one without. The conflict interval was a two-cue stimulus (disparity inconsistent with texture). The no-conflict interval was one of three types of stimuli: a single-cue stimulus (disparity only or texture only) or a two-cue, no-conflict stimulus (disparity consistent with texture). Disparity-only

stimuli were sparse random-dot stereograms. Texture-only stimuli were monocular Voronoi patterns. Two-cue stimuli were binocular Voronoi patterns. On each trial, observers indicated the interval with greater slant. A staircase procedure adjusted the slant of the no-conflict stimulus until the two stimuli had equal apparent slants. If disparity and texture were fused (such that the individual estimates were lost), the results with the three types of no-conflict stimuli would be the same. If the two cues were not fused, the results with the three types would differ because the observer could use the cue(s) available in the no-conflict interval to do the match with the conflict interval. We observed both partial and full fusion.

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405 Adaptation to the relation between visual cues affects perception of 3D shape

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The visual integration of different cues for perceiving a three-dimensional (3D) shape is currently understood in terms of a two-stage model hypothesizing that (i) a 3D estimate is derived separately from each cue, and (ii) a weighted combination of these estimates is computed through the estimated reliabilities of the cues (Landy, Maloney, Johnston & Young, 1991). Interactions among cues are allowed only for estimating missing parameters necessary for a 3D interpretation of each cue in isolation. Domini and Caudek (2004) hypothesized, conversely, that perception of 3D shape relies on the natural covariance among the retinal signals defining different visual cues, and does not require separate 3D estimates. In the present experiment we investigate the effects of adaptation to a relation between stereo and motion signals violating the constraints of natural optics. The observers participated to 4 sessions in 2 consecutive days. In all phases of the experiment, the stimuli were defined by stereo and motion information. Each session was made up of a pre-test, an adaptation phase, and a post-test. In both the pre- and the post-test, participants were required to discriminate between concave/convex random-dot rigid surfaces. In the adaptation phase, participants were required to discriminate between random-dot volumes with different depth-extents. In the pre- and post-test, the stimuli preserved the natural linear relation between disparity and velocity signals. In the adaptation phase, the relation between disparity and velocity signals was non-linear. We found a shift in the psychometric functions of the post-test, but only in the second day of testing (after a night of sleep). These results (i) cannot be explained in terms of adaptation to 3D shape (e.g., Poom & Borjesson, 1999), (ii) are inconsistent with a modular theory, and (iii) are predicted by the Intrinsic Constraint model (Domini & Caudek, 2004).

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406 Cue use under full cue conditions cannot be inferred from use under controlled conditions

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Height-in-the-visual-field (HVF) is the angle between the line of sight and a horizontal when viewing an object. We tested this classic distance cue when it was isolated as information about distance and showed that observers used it reliably to make distance judgments. We then tested the same stimuli with additional information available and observers failed to use the cue at all. This indicates that an inference from cue use in isolated conditions to cue use in full information conditions is not warranted.

Experiment 1: We investigated the use of HVF when it was isolated from other information. Observers (n=8) on a chinrest viewed targets in the dark with one eye. Targets were black square tiles, with phosphorescent texture, arranged to subtend the same visual angle. Observers verbally indicated whether targets lay in one of three frontoparallel planes at near, middle or far distance (N, M, F = 20, 27, 35 cm). Targets were presented randomly 5

times. Three targets were located at the M distance at three eye heights (40, 30, 22.5 cm) producing 3 gaze angles (348, 428, 508 from horizontal). The responses (N, M, F) correlated predictably with gaze angle. Two other targets were placed at the N and F distances along the middle gaze angle (at small and large eye heights, respectively). The distances of these targets did not affect the judgments. HVF reliably determined observers' estimates of location.

Experiment 2: New observers (n=8) did the same experiment but now a phosphorescent checkerboard surface (0.5 m wide x 1 m long) was placed under the targets in dark and lighted conditions. Observers now gauged veridically the distance at which the targets lay independently of HVF. Expts 1 and 2 were repeated using larger eye heights (~90cm) and distances with identical results.

Conclusions: These results show that inferring how information is used in multi-cue environments from cue use in isolated conditions is not warranted.

407 The effects of color segregation on the recovery of 3-D structure from motion

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[Purpose] The purpose of this study was to investigate whether the recovery of 3-D structure from motion (SFM) was influenced when image features were segregated on the basis of a color difference. **[Methods]** We used two-cylinder SFM stimuli like those used by Ramachandran et al. (1988) in which two cylinders of the same diameter simulated with random dots on their surfaces were superimposed on each other, but rotated at different speeds. The perceived curvature of each cylinder surface was measured with a matching method when the two groups of dots belonging to different cylinders had the same color (unsegregated condition) and when they had different colors (red vs. green, segregated condition). Relative rotating speeds of two cylinders were systematically varied. **[Results]** The results for the unsegregated condition indicated that the observers perceived two distinct cylinders with the faster cylinder appearing more convex than the slower one, which quantitatively confirmed Ramachandran et al.'s demonstration. The results also showed that the difference in perceived curvature increased monotonically with the difference in rotating speed of two cylinders. When two groups of dots on different cylinders were differentiated by a color difference in the segregated condition, the difference in perceived curvature was greatly reduced compared with the unsegregated condition. Thus the surfaces of two rotating cylinders appeared more closely located in 3-D space. Interestingly, the influence of color segregation disappeared when the cylinders were of different diameters and thus two distinct cylinders could be easily recovered. **[Discussion]** The present results imply that color segregation can modulate some aspect of SFM processing, possibly the one assigning depth values to the surfaces according to the differences in speed of image features.

Acknowledgment: Supported by JSPS grant.

408 Depth from shading and disparity in humans and monkeys

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This study compared the effectiveness of binocular disparity and shading cues for the perception of depth in humans and monkeys. Using a novel display, we presented shading and disparity cues conjointly, separately, and in conflict with each other in an oddities depth discrimination task. An example of the figures used in the display can be viewed in the form of an autostereogram at <http://web.mit.edu/bcs/schillerlab/vss05abstract.htm>. The following is a summary of our findings:

1. Both shading and disparity cues are effectively utilized for the perception of depth by humans as well as by monkeys.

2. Depth information can be processed very rapidly when shading and disparity cues are provided conjointly. When presented singly, the processing of disparity cues takes significantly longer than the processing of shading cues.

3. By placing shading and disparity cues in conflict with each other we assessed their relative effectiveness. Processing times were significantly increased under conflict conditions suggesting that normally these cues are co-processed. Similar values were obtained in humans and monkeys.

4. Control conditions for shading included the rotation of the display by 90 degrees thereby reducing the effectiveness of differential luminance values as a depth cue. Performance under these conditions became significantly worse and reaction times were increased.

<http://www.cingulate.com/papers/>; <http://people.bu.edu/takeo/>

Attention, Learning, and Memory

409 Short and Long Term Learning in Visual Search: An Unexpected Interference

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Aim: Visual attention can benefit from both short and long term learning: if we're looking for a cat who has climbed up a tree, and we looked at the tree before he climbed, we'll ignore the tree and find the cat more quickly (as in 'preview search'). However, if Whiskers always climbs up the same five trees, and always goes to the same branch on a given tree, we'll also get better at finding him (as in 'contextual cueing'). Are these two forms of attentional learning additive, or do they interfere with each other?

Methods and Results: We used a hybrid paradigm combining preview search with contextual cueing. Subjects were asked to look for a T among L's. Each trial began with a display of scattered black L-shaped distractors, followed one second later by a display with more distractors and a single black T. On valid preview trials, the distractors on the second display were added to those present on the first, while on invalid preview trials, all of the distractors in the second display were in new positions. In addition, half of all trials benefited from contextual cueing, as the same spatial layouts were repeated over the course of the experiment. As expected, valid preview trials were faster than invalid trials, but there was a contextual cueing benefit only on invalid trials. In a second study, a color cue segregated the old and new items: the first display items were red and the second were blue. In this case, contextual cueing benefits were found on both valid and invalid preview trials. **Conclusion:** Long term learning effects of contextual cueing are reduced in a typical preview paradigm, perhaps because subjects do not search exactly the same set of items on a given valid preview trial. They fail to ignore all of the previewed distractors, and instead search through a different subset of them from trial to trial, changing the attended set on a given layout. Color cues eliminate this variability by allowing consistent segregation of old and new items.

410 Long-term gaze cueing effects: Evidence for retrieval of prior attentional states from memory

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When observing another person shifting their gaze to a particular location, the observer's attention moves to the same location. Such gaze-evoked attention shifts occur rapidly and automatically. The results of initial studies demonstrated that such cueing effects are fairly transient, no longer being observed after about 1000 ms. However, it is possible that cueing effects may be obtained over considerably longer intervals under certain circumstances. For example, research on peripheral cueing has suggested that attention states activated when encoding a distinct object such as a face can be retrieved from memory when the face is encountered again after several minutes (Tipper et al, 2003). In those experiments,

encoding and retrieval of distinct episodes was encouraged by the use of rich and unique stimuli with many intervening trials between matching cue- and target-displays. In contrast, experiments on gaze cueing typically employed uniform gray-scale pictures of a single face and presented cue and target within the same trial. In the current work we utilized the critical features of the Tipper et al study (rich, colourful stimuli and many intervening trials). Under these circumstances, we observed long-term gaze cueing effects over a period of about 3 minutes. We propose that the attentional state associated with the gaze direction of a particular face can be retrieved from memory when the face is re-encountered some minutes later.

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411 Scene-Specific Memory Guides the Allocation of Attention in Natural Scenes

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Two experiments examined whether scene-specific memory guides attention to relevant objects and/or locations within a scene. In both experiments, subjects performed an initial block of flicker change detection trials in which they detected the addition of an object to natural scenes. After a 30 minute filled delay, subjects performed an unanticipated second block of change detection trials. In experiment one, the second block consisted of trials with entirely new scenes and new changes, trials that were identical to the first block, and trials with identical scenes but the item that changed was a different object and it appeared in a different location than the change in the original block. Results: Identical changes were detected quickly, suggesting that memory of the scene guided attention to the change. However, new changes in previously viewed scenes were detected no faster than changes in entirely new scenes, suggesting that the memory was limited to the relevant aspects of the original change location and/or object. In experiment 2, the second block of trials independently varied the location of the change and the identity of the change item to determine the extent to which faster change detection was due to memory of a location and/or the identity of the change object. Results: Changes that occurred in the original location were detected quickly even when a new object changed at that location, suggesting that attention was allocated to the behaviorally relevant location in the scene. However, detection was slow when the original object changed in a new location, suggesting that the identity of the object was not used to allocate attention. Results are consistent with the view that incidental memory is created while viewing a scene and can be used to guide attention to locations, but not specific objects, which were behaviorally relevant during previous experiences with environments.

412 Eye Movements in Episodic Memory

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Previous research has been inconclusive as to the role of eye movements in episodic scene recognition. We investigated this issue by focusing on perceptual reinstatement. In two scene recognition experiments, eye movements were registered during study and test. At test participants indicated their recollective experience as based on explicit recollection and familiarity respectively. In Experiment 1, participants studied scenes under different concurrent tasks. This manipulation produced parallel effects on eye movements and recollection. Furthermore, eye movement consistency across study and test differentiated recollective experience. Specifically, explicit recollection was characterized by a higher consistency than familiarity-based responses. However, number of study fixations was correlated with the consistency measure. In Experiment 2, we obtained control over number of fixations through a gaze contingent paradigm, and corroborated the consistency results. Our findings are in line with general theories of episodic memory such as the transfer appropriate processing

account and the encoding specificity principle. The results indicate that active gaze control is an important component in episodic scene recognition.

413 When We Use the Context in Contextual Cueing: Evidence From Multiple Target Locations

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BACKGROUND: Consider two visual search paradigms: Chun and Jiang's "Contextual Cueing" and Wolfe's "Repeated Search". In contextual cueing experiments, observers are presented with a mixture of repeated and novel visual search displays. The usual finding from these experiments is that, as the number of repetitions increases, RTs to find the targets in repeated displays become markedly faster than RTs for unrepeated displays. In repeated search experiments, repetition is more dramatic. The same display is unchanged for hundreds of trials. Observers are asked about the presence or absence of specific targets in the unchanging display. In contrast to the contextual cueing experiments, search does not become more efficient over time in repeated search nor is search more efficient than in unrepeated displays. **METHODS:** We explore this apparent contradiction by focusing on two critical differences between these designs. First, in a standard contextual cueing experiment, the target location on one trial is never occupied by a distractor item on another trial, whereas in a repeated search task the same items change roles from target to distractor from trial to trial. Second, in a contextual cueing experiment there is only one possible target location, whereas in a repeated search task there are several. Here, we manipulate two aspects of the contextual cueing design: 1) a distractor item could occupy a target location and 2) a target item could appear in up to four unique positions (which were never occupied by distractors). **RESULTS:** When targets and distractors can appear in the same locations on different trials, then we find no evidence for contextual cueing. However, if the targets are restricted to unique locations, we can obtain contextual cueing at multiple locations. Initially, the multiple location effect is weaker than a single location case but is strengthened after extended training.

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414 The repetition of object identities modulates attentional guidance in visual search

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Purpose: The repetition of spatial configurations of search displays implicitly facilitates visual search (contextual cueing effect; Chun & Jiang, 1998). A similar effect was also observed when the object identities were repeated (Chun & Jiang, 1999). However, it is unclear whether the repetition of the object identities facilitates form processing of search items or attentional guidance to a target. In this study, we measured eye movements in order to clarify the mechanism of the object-identities-based contextual cueing effect. **Method:** Participants were asked to a search target among 9 distractors. A target was a novel object whose shape was symmetric around the vertical axis, and a distractor was symmetric around an axis apart from the vertical axis. 12 target objects were paired with 9 distractor objects. These 12 sets were repeatedly presented in the experiment (repeated sets). The other target objects were presented with different distractor objects for each trial (non-repeated set). The locations of the target and the distractors were randomized in each trial. In the half of trials, repeated sets were presented. In the other half of trials, non-repeated sets were presented. Eye movements were recorded with EyeLink2. **Result:** Reaction times were shorter in repeated sets than in non-repeated sets, showing a typical contextual cueing effect. More importantly, fewer saccades were required to find targets in repeated sets than in non-repeated sets, and the difference was greater in later trials than in early trials of the experiment. On the other hand, durations of fixations

did not differ between object-set conditions and were constant throughout the experiment. Although latencies of the first saccades became shorter as the experiment progressed, there was no difference between repeated sets and non-repeated sets. These results indicate that object-identities-based contextual cueing modulates attentional guidance to a learned target, as well as configuration-based contextual cueing.

415 Effects of scene-based contextual guidance on search

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Everyday search tasks are performed in contextually rich environments that offer numerous high-level cues for likely target location. Chun & Jiang (1998) studied such constraints using simple search stimuli, and Henderson, Weeks, & Hollingworth (1999) reported effects of semantic consistency on search. Still, the question of how scene-based constraints affect search behavior remains largely unexplored. We addressed this question by having subjects search for the presence or absence of a blimp, helicopter, or jeep in a pseudorealistic mountainous desert scene. Consistent with pre-existing scene expectations, the blimp appeared only in the sky, the jeep only on the ground, and the helicopter appeared as often in the sky as it did on the ground. Importantly, subjects were not instructed as to these contingencies, but were instead left to devise their own search strategies. There were 6 objects per scene with at least one object of each type present in each scene. Object color was manipulated to avoid duplicate items. Subjects ($n = 11$) were shown a semantically-defined target (e.g., 'Red Blimp') for 1 second followed by a search scene. Analysis of TP trials revealed that scene-constrained (SC) targets (blimp, jeep) were detected 265 ms faster and acquired with 1.04 fewer eye movements compared to the scene-unconstrained (SU) target (helicopter). In the case of SC targets, we also found that ~75% of the initial saccades landed in the target-consistent region and that subjects spent a greater proportion of their total search time in these regions. Interestingly, analysis of the SU target data revealed a high percentage of initial saccades to the sky region, suggesting that eye movements were guided by pre-existing scene-constraints rather than learned probability matching. Smaller effects were found in the TA data. We conclude that subjects can use scene-based contextual constraints to guide their search, and that this information is available to the initial eye movements in a scene.

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416 Implicit and Explicit Memory in Scene Based Contextual Cueing

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Aim: Humans process a visual display more efficiently when they encounter it for a second time. When conducting visual search for a 'T' target presented among 'L' distractors, observers are faster at detecting the target when the same display is occasionally repeated, even when the repeated displays are not explicitly recognized. This study investigates how repeated presentation of natural scenes (rather than meaningless T-L configurations) affects visual search. In particular, we test the role of implicit learning and explicit associative memory in learning of natural scenes.

Method: Subjects searched for a 'T' among 'L's presented in a circular array against natural scenes or scrambled scenes. Each block contained 32 trials, divided randomly and evenly by two factors: background type (scene vs. scrambled image) and condition (repeated vs. nonrepeated). In repeated conditions, both the background image and the target location remain the same for each repetition. In the nonrepeated conditions, the background image was novel. We measured search RT throughout the experiment. At the end of the experiment, we tested explicit recognition of repeated scenes and recall of target locations for repeated scenes.

Results: In explicit recognition, subjects showed better scene recognition

and displayed better target location memory for natural scenes over scrambled scenes. However, in visual search, RT advantage for repeated over nonrepeated displays was comparable between scenes and scrambled scenes. In addition, repeated scenes that were correctly recognized were not searched faster than repeated scenes that were missed in recognition. This suggests that while subjects have explicit memory for repeated natural scenes, visual search is facilitated primarily through implicit learning.

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417 Little is remembered about rejected distractors in visual search

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During visual search, knowledge about previously examined distractors is used to guide attention towards unexamined items (McCarley et al., 2003 Psychol Sci 14 422-426). Last year, we demonstrated that the spatial location of examined items, rather than the identity or surface features of those items, is used to guide attention towards new items (Beck, Peterson, & Vomela, VSS 2003). In the experiments reported here, we investigate whether any identity information is explicitly remembered about rejected distractors. We used two different search tasks: a conventional search task and the oculomotor contingent task of McCarley et al. (2003). In all experiments, on roughly one third of the trials, search was terminated, an examined location was circled (a place holder marked that location), and observers were quizzed about the item that had been at that location (two alternative forced choice). Although observers clearly had a memory for examined items - they avoided revisiting the last 4 items in the oculomotor contingent experiments - performance in the 2AFC recognition tasks was extremely poor. When asked to discriminate a previously seen letter from one that had not appeared in the display (foil), memory performance was near 75%, regardless of lag. However, when the foil was another item that had been fixated on that trial, results from the memory task were near chance (56%). This suggests that people do remember the identity of rejected distractors, but their explicit memory for distractors does not include their locations. Interestingly, memory performance for the penultimate item (lag 1) was contingent upon whether the search display was present when the location was probed. When the display was present (items replaced with placeholders) during the memory probe, accuracy for the last examined item improved. This suggests that scene context can help to improve memory performance.

418 Memory Models of Visual Search - Searching in-the-head vs. in-the-world?

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Visual search takes place whenever we are looking for something. But when a stimulus has been visually encoded on a previous occasion, memory processes can supplement or compete with eye movements during search.

While previous research has mostly focused on the perceptual features that allow us to identify a target among distractors in single shot searches (Wolfe, 1998, Psych. Science), recent findings have highlighted the contributions of visual short-term memory (VSTM) to search processes (Alvarez & Cavanagh, 2004, Psych. Science).

We present a paradigm of repeated serial search that attempts to illuminate the potential roles of working memory (Anderson & Matessa, 1997, Psych. Review) and VSTM in visual search. A series of simple process models exemplifies various ways in which memory for items and/or locations can facilitate or obliterate search. Within a cognitive

engineering approach, we developed multiple computational models that allowed us to explore and explicate the consequences of assumptions about VSTM capacity and organization, and the interaction between long-term memory and VSTM. Each model yielded distinct performance profiles based on the sequential order of target stimuli.

We investigated our model predictions through an experiment that employed a serial search paradigm. Each of 10 targets (showing alphanumeric captions) had to be found on average twice per trial. As some items could be mere distractors and next targets were presented (auditorily) whenever the current target was found, participants could not anticipate the target sequence. Detailed comparisons between search performance, eye data and our computational models show clear evidence for memory processes for both target and distractor information, both within a single search and across multiple searches. Also, a between-subjects manipulation of target visibility shows that the use of knowledge-in-the-head (or memory) increases as the perceptual-motor costs of visual access are increased.

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419 Competing attention vectors can produce the appearance of memory-free visual search

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The role of memory in visual search is under debate. Wolfe et al. reported that RTs to confirm the presence of a target increased with the number of display items even when search displays were repeated multiple times. They took these results to indicate that subjects continued to search through repeated displays as if they had no memory for the display items. In contrast, Chun et al. showed that with repeated presentation, subjects moved their attention to the target location more quickly. These "contextual cueing" effects suggested that memory plays a role in visual search. On the assumption that memory for the target location takes the form of an attention vector, we hypothesized that competing attention vectors might produce the appearance of memory-free search in the Wolfe et al. paradigm. Suppose subjects move their attention to the target location before they affirm its presence; a display with multiple repeated targets will have multiple associated attention vectors. To move attention to the location of one target, competition among attention vectors must be resolved. If resolution time increases with the number of competing attention vectors, these implicit memories may produce Wolfe et al.'s pattern of results. By this account search time should vary with the number of probed targets in repeated displays rather than with the number of display items, factors that were confounded in the original design. Like Wolfe et al. we repeated search displays containing 2, 3, 5, or 8 items multiple times by block. In each block, every display item was probed an equal number of times. We also included a condition in which 8 items were always displayed, but only 2, 3, or 5 items were probed by block (there was also a set of target absent trials in each condition). When the number of probed targets varied from 2 to 5, search slopes were equivalent (34 ms) regardless of the number of items in the display, consistent with the competing attention vectors account.

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420 Vision Leaves Its Fingerprints on Memory: Recognition and Identification Memory for Compound Gratings

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Because vision blends seamlessly into memory, vision's imprint can yield unique insights into memory processes. To exploit this possibility we examined errors in short term episodic recognition and source memory for simple visual stimuli. On each trial of three experiments, subjects saw and had to remember a trio of sequentially-presented compound sinusoidal gratings. The study items were followed quickly by a probe grating. On

some trials, the probe matched one of three study items; on other trials, the probe was novel. Subjects made source memory judgments, identifying the serial position of the study item that matched the probe (Experiments 1 and 2), or made old-new, recognition judgments (Experiment 3). About 25% of correct recognitions were accompanied by incorrect source identifications. Such errors were deterministic: When subjects misidentified serial position, they still retained partial information about the actual memory source, namely its perceptual or serial order characteristics. ROCs for recognition memory were generated from all three experiments, either by aggregating source identification responses (Experiments 1 and 2), or directly from recognition responses (Experiment 3). The three sets of recognition ROCs were very similar to one another, suggesting that memory loses little information in generating recognition judgements from stored exemplars. Slopes of zROCs for old-new judgments were consistently >1 , indicating that distributions on old and new trials had different variances. This result could be easily explained within a summed-similarity model for visual memory (NeMO; Kahana & Sekuler, *Vision Research* 2002).

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421 Is long-term inhibition of return caused by perceptual mismatch processes?

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During visual search, inhibition of the return (IOR) of attention to previously examined items gives attention a momentum towards searching novel information, thus ensuring that the target will be detected. The inhibitory processes underlying IOR have been shown to be associated with both objects and locations. Research using face stimuli has shown that object-based inhibition can be retrieved from memory after relatively long periods (Tipper et al., 2003). However, it is possible that these long-term IOR effects were due to a perceptual mismatch between the cue signal and the target signal. The present study aims to confirm the existence of long-term IOR for faces, and also attempts to demonstrate long-term IOR using objects. In addition, this study examines whether these long-term IOR effects are caused by the retrieval of mismatching stimulus features. Presentation of two faces on the left and right alternated with presentation of two objects above and below fixation, and participants had to ignore a cue signal and make a localisation response to a target signal presented over one of the items. In the mismatch condition the cue signal was red and the target signal was green, whereas in the match condition the cue and target signals were identical. Long-term IOR for faces was observed when the cue and target were separated by 4.8 minutes and 64 displays. This IOR effect remained even when the cue and target signals were the same colour, which shows that the effect cannot be due to retrieval of mismatching stimulus features. Long-term IOR effects for objects were also unaffected by perceptual mismatch, however these IOR effects were less robust and only reached significance in the error analysis. These results suggest that inhibition associated with a cued item can be encoded into memory, such that later retrieval of the cued item reinstates inhibitory processing and encourages examination of new information.

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422 Visual statistical learning through intervening noise

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A primary goal of visual processing is to extract statistical regularities from the environment in both space and time, and recent research on visual statistical learning (VSL) has demonstrated that this extraction can occur rapidly for even subtle correlations in homogenous streams of stimuli. In the real world, however, most regularities do not exist in isolation, but rather are embedded in noisy and heterogeneous input

streams. To explore VSL in such contexts, we measured subjects' ability to extract statistical regularities in time through intervening distractors, in a stream of shapes appearing one at a time. Novel shapes were randomly assigned to one of two color groups and within each group they were clustered into temporal 'triplets' -- three shapes that always appeared in the same order. Shapes from both color groups were then randomly interleaved, maintaining triplet order (e.g. triplets abc in red, and XYZ in green, presented in stream aXbcYZ). Subjects were instructed to perform a repetition detection task for shapes in just one color for 20 min, and were then given an unexpected forced-choice recognition task (without color cues) pitting triplets against random sequences of 3 shapes (from that same color group). This test revealed robust VSL for triplets despite the pervasive interruption by shapes from the other color. This VSL was replicated even with more tightly constrained interleaving, such that no triplet ever occurred without at least one interruption. Additional experiments report (1) whether 'interrupted' VSL of triplets can occur even in the absence of any uninterrupted pairs (aXbYcZ), and (2) whether interrupted VSL occurs even when there are no extrinsic cues (such as color) to distinguish the relevant and irrelevant items. Overall, these demonstrations of VSL through intervening noise suggest that statistical learning may 'scale up' to more real-world contexts wherein we encounter a constantly shifting array of objects, only some of which are related.

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423 Interactions between long-term visual working memory and attention

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The current study explores two issues about the relationship between working memory (WM) and attention. First is whether information retrieved from long-term memory (LTM) into WM guides attention. The second issue concerns the level of abstraction at which WM representations guide attention. The method is adapted from Downing (2000, *Psychological Science*, 11:6, 467-473). At the start of each trial subjects are given an item to hold in WM. Then two cue objects are simultaneously flashed on the screen, one of which matches the memory item. A square is then presented at the location of one of the flashed items and subjects respond as to whether it has a gap at the top or the bottom. After response to the square, a test item is presented and subjects indicate if it is the same as the memory item. If WM guides spatial attention, then RTs to the probe should be faster when they occur in the same location as a cue matching the memory item. In short-term memory (STM) conditions a memory item itself was presented at the start of each trial. In LTM conditions the basic-level name of a memory item was presented and subjects had to retrieve the item from LTM from a set of 6 objects they memorized earlier. For both STM and LTM conditions, subjects completed one block of trials where the two cue items flashed on the screen were different exemplars from the same category and another in which they were from different categories. Results from the STM/Different category condition replicate Downing (2000) in that most subjects were faster to respond to the probe when it appeared at the location where a cue matching the memory item was flashed, indicative of an attentional shift to that location. In all other conditions there was no evidence that the contents of WM guided attention in this way. The results suggest 1) items recalled from LTM do not guide attention in the same way as items held in short-term WM and 2) WM does not guide attention at a fine level of detail.

424 The effects of familiarity on encoding efficiency in visual search

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In a number of variations on an experiment by Treisman and Souther (1985, Expt. 1), Rauschenberger and Yantis (1999, 2004) found that a particular circle-line combination (oriented to resemble a 'Q') enjoyed

significantly greater search efficiency than other, similar circle-line combinations, even though subjects were not instructed to interpret the stimulus in any meaningful way. At the same time, although control experiments made it unlikely that featural differences were responsible for the observed benefit, there was no direct evidence that this benefit was attributable to the 'Q-ness' of the stimulus. In the present study, a subset of Rauschenberger and Yantis' experiments was repeated in a remote region of China, using 21 Chinese participants who had never been exposed to the letters of the Latin alphabet. For these participants, there was no difference in search efficiency between the different variants of the circle-line stimulus. That is, in contrast to Rauschenberger and Yantis' results, there was no benefit for the 'Q'-like stimulus. These results corroborate Rauschenberger and Yantis' conjecture that the familiarity of the 'Q'-like stimulus was responsible for the relatively efficient search afforded by this stimulus. To demonstrate that familiarity is only a secondary factor, however, that influences search efficiency by modulating the redundancy (in the sense of Garner, 1962, 1974), or perceptual 'goodness,' of the stimulus, we will review a number of findings from Rauschenberger and Yantis' original study.

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425 Brief stimuli that evoke false memories seem to last longer

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It is known that when a previously-presented stimulus is presented again, its duration is estimated to be longer than in the initial presentation (Witherspoon & Allan, 1985). Such a prior presentation effect has been attributed to enhanced perceptual processing due to perceptual priming. We used the DRM procedure (Deese, 1959; Roediger & McDermott, 1995) to examine whether this effect can be mediated by strictly conceptual processes without any perceptual repetition. Specifically, we asked whether the duration of a word that has never been presented but that elicits false memory (recall/recognition) is judged to be longer than a control word that does not elicit false memory. If the prior presentation effect can be mediated by conceptual rather than perceptual processes, then the estimated duration of a falsely recognized word should be longer than that of a control word. The present experiment consisted of three phases. In the learning phase, subjects memorized several lists of sequentially presented words. The words in each list were all converging associates of a lure word that was not presented. In the temporal production phase, subjects saw a word and pressed a key as soon as they judged that the word had been on display for 2.5s. The words were a) old words that had been presented in the learning phase, b) lure words, or c) control words that had never been presented. In the recognition phase, subjects judged whether or not they had seen these three types of words in the learning phase. As expected, prior presentation increased the estimated duration: the temporal production of the words that had been presented was shorter than that of the control words (Temporal production bears an inverse relationship to the estimated duration). More importantly, the estimated duration of falsely recognized words was longer than that of a control word. The results suggest that the prior presentation effect on temporal estimation can be mediated by conceptual process without any perceptual repetition.

426 Visual Working Memory as the Substrate for Mental Rotation

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Classic studies of mental imagery showed that the time required to mentally rotate a visual object depends on the amount of rotation, just like the physical rotation of a real object. The goal of our present study is to show that visual working memory serves as the buffer in which an object representation is held while the rotation occurs. We asked subjects to perform a mental rotation task during the delay interval of a change-

detection task to determine whether mental rotation interferes with working memory storage and vice versa. The mental rotation task required subjects to determine whether a letter character--presented at 0, 72, or 144 degrees from upright--was presented in its canonical form or in a mirror-image form. In Experiment 1, this task was presented during the delay interval of a color change-detection task that was designed to selectively load visual object memory. The mental rotation and change-detection tasks were also presented individually as single-task control conditions. Compared to the single-task conditions, accuracy in both the change-detection and mental rotation tasks was impaired when both tasks were performed together, and the degree of impairment increased as the amount of rotation increased. Thus, it is difficult to mentally rotate a continuously visible object while simultaneously holding other objects in memory. In Experiment 2, a spatial change-detection task was used instead of a color change-detection task, and no systematic interference was observed between the rotation and memory tasks. Together, these results indicate that mental rotation requires the buffering of the to-be-rotated object in the object working memory subsystem, not in the spatial working memory subsystem.

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427 The Role of Attention in Binding Features in Visual Working Memory

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Attention plays a key role in binding features during perception. Is attention also necessary to maintain bindings in visual working memory? Luck & Vogel (1997) proposed that visual working memory stores features in integrated object representations, with no additional effort required to maintain feature bindings. In contrast, Wheeler and Treisman (2002) proposed that attention is necessary to maintain bindings but not individual features in working memory. The present study was designed to distinguish between these alternative hypotheses.

Experiment 1 used a color-orientation change detection task and investigated whether memory for bindings would be worse than memory for features when attention was divided among multiple items in the test array. Memory for bindings was found to be statistically indistinguishable from memory for features despite the presence of multiple test-array items, suggesting that focused attention is no more important for bindings than for individual features.

In Experiment 2, subjects performed an attention-demanding visual search task during the delay interval of the change-detection task. If the maintenance of bindings is uniquely dependent on the continued engagement of attention, then performance of the search task during the delay interval should greatly impair memory for feature bindings but should not impair memory for the individual features. The interposed search task produced a small but significant decrement in change-detection performance, but the decrement was nearly equivalent for feature memory and binding memory. Thus, the maintenance of bindings in visual working memory does not depend on the continued engagement of attention, consistent with the integrated object hypothesis.

428 Attention and Memory in Air Traffic Control Tasks

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Air traffic control tasks include visual and auditory monitoring, maintaining aircraft separation, and making decisions. Attention and memory are critical for such tasks. Even experienced controllers can find themselves in circumstances where their inattention, memory failures, or miscommunications lead to the situations in which one aircraft passes too closely to another aircraft (operational error - OE). Many OEs occur as a result of vulnerabilities in visual and cognitive processes. In particular,

visual attention and memory are capacity limited. If a controller performs tasks at the capacity limits, the brain may fail to process certain pieces of information. This study examined the associations between OEs and visual mechanisms. We generalized an attention-memory model and applied the model to OE analysis. The model consists of two memory buffers: a working-memory buffer and a short-term memory buffer. The operations of the model can be described as follows: 1) The working-memory buffer associates pieces of information needed simultaneously for a given task. It also swaps information back and forth with the short-term memory buffer; 2) The short-term memory buffer maintains information for a period of time without being attended; 3) Attention selects items of information needed for a given task and puts them in the working-memory buffer. The two memory buffers and attention are all capacity limited. We analyzed 58 OEs with this model and found that about 60% of OEs were related to exceeding the capacity limits of attention and memory. The following phenomena were among the top factors contributing to the OEs: 1) inattentive blindness. 2) attentional blink 3) working-memory overload; and 4) disruption of memory consolidation. The results indicate a critical role of attention and memory in air traffic control tasks. The challenge for future work is how to apply the results of basic visual research to air traffic control to prevent certain types of OEs.

Visual Neurons: Properties

429 Dynamics of Spatial Frequency Tuning in Lateral Geniculate Nucleus

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Neurons in primary visual cortex (V1) exhibit changes in spatial frequency tuning through time [1, 2]: a neuron's preference shifts from low frequencies early in the response to higher frequencies later in the response. This shift is accompanied by a narrowing of tuning bandwidth [1]. It has been proposed [3] that such phenomena might originate in Lateral Geniculate Nucleus (LGN). LGN neurons have center-surround receptive fields with the response of the surround delayed relative to that of the center. If neurons respond linearly, spatial frequency tuning is expected to be low-pass early on in the response, and become band-pass only later. We tested this hypothesis by measuring spatial frequency tuning dynamics in 147 LGN neurons in anesthetized, paralyzed cats using reverse correlation in the spatial frequency domain [1]. We found that the preferred spatial frequency typically shifts from lower to higher frequencies through time. The median shift is ~0.75 octaves over a time period of 40 ms, slightly smaller than the ~1 octave over 30 ms observed in V1 [2]. Furthermore, the tuning bandwidth of the neurons typically narrows over this same period: the median narrowing of tuning is ~0.2 octaves. In many cases, the preferred tuning shifts back towards lower spatial frequencies even later in the response, because the receptive field surround alone is contributing to the response. Thus, the dynamics of spatial frequency tuning observed in LGN may contribute to those seen in V1 but alone may be insufficient to explain them.

[1] Bredfeldt & Ringach, *J Neurosci.*, 2002

[2] Frazor, Albrecht, Geisler & Crane, *J Neurophysiol.*, 2004

[3] Allen, Peterson & Freeman, *Soc Neurosci Abs* 2004

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430 Characterizing V1 Population Responses to Superimposed Gratings

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Previous studies have shown that the responses of V1 neurons to an optimally oriented grating are usually suppressed by superimposition of a

second grating at a non-preferred orientation. However, these single unit studies leave open the question of how two orientations are simultaneously represented in the distribution of population activity. To explore this question, we acquired intrinsic signal optical images of tree shrew V1 during presentation of a stationary full-field grating presented alone and in combination with a second grating at a range of orientations. Consistent with single-unit results, regions of cortex that are activated by each of the gratings presented singly are less activated by the combined stimulus. To quantify activity patterns we constructed a population response profile (PRP), a distribution which represents, for each orientation value, the summed activity of all pixels with that preferred orientation. We find that the height, width, and position of the PRP for the combined stimulus is well predicted by the mean of PRPs derived from the component gratings. This holds true for orientation differences between components ranging from 20 to 90° and over a range of contrasts. Thus the peak of activation for the combined stimulus is shifted away from the peaks for the components, and for gratings separated by 20° or less, the pattern of activity is often indistinguishable from that produced by a single lower-contrast grating at an intermediate orientation. As with gratings, responses to isolated line intersections are predicted by the mean of responses to the component lines, but only within 1mm of the cortical representation of their crossing point. Overall, we find that population responses to multiple orientations are governed by a simple scaling rule consistent with a local circuit-based mechanism of divisive cortical gain control.

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431 Response-contrast functions for multifocal visual evoked potentials (mfVEP): A test of a model relating V1 activity to mfVEP activity

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The multifocal visual evoked potential (mfVEP) is largely generated in V1 [1-4]. To better understand the neural substrate of the mfVEP, response-contrast functions were compared to predictions from a model based upon single cell recordings from monkey V1 [5,6]. Monocular mfVEPs were obtained from three normal subjects with a pattern reversing dartboard pattern (VERIS, EDI). The display contained 16 sectors each with 64 checks and both the sectors and the checks were scaled approximately for cortical magnification. The conditions included six contrast levels and three viewing distances (check sizes varied by a factor of 8). The records from 3 channels of recording were analyzed with custom software [4]. Two measures of response amplitude, the RMS and the first principle component [3], gave similar results. Even though the check size varied by a factor of 8, the overall response-contrast functions (RvsC) were similar in shape, saturating by 35 to 50%. These functions were well fitted up to 40 to 50% contrast by the theoretical population curve for V1 neurons developed by Albrecht & Geisler (see [6]); there was a systematic deviation for higher contrasts. However, when the results for the central 108 were analyzed separately, the larger checks saturated at higher contrasts than did the relatively smaller checks. These results deviate from the predictions of the model. However, in general the results are consistent with a model of V1 neuron population, which predicts no change in the RvsC function with spatial frequency of display. The systematic deviation from the theoretical RvsC function for higher contrasts and for central vision may be due to a weakness in the model and/or a mixture of components with different waveforms in the mfVEP response [1]. 1. Baseler & Sutter, (1997) 2. Slotnick et al (1999) 3. Zhang & Hood (2004) 4. Hood & Greenstein (2003) 5. Albrecht & Hamilton (1982); 6. Heeger et al (2000).

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432 Delayed maturation of receptive-field center and surround in macaque V2 neurons

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The perceptual ability of infant monkeys to integrate local stimulus features over a large area (e.g., contour integration) does not emerge until relatively late in development (Kiorpes and Bassin, 2003). The neural basis of this subnormal perceptual binding in infants is not well understood. In mature monkeys cortical neurons are capable of integrating signals over a large area that surrounds their 'classic receptive fields' (CRFs), and this ability to integrate signals over distance is thought to be intimately involved in perceptual 'binding'. In this study, we investigated the postnatal development of the cortical circuits underlying long-range signal interactions. Microelectrode recording experiments were conducted in V1 and V2 of 2-, 4- and 8-week-old infant monkeys. To obtain area summation functions of individual neurons, we varied the diameter of drifting circular sine-wave gratings (TF=3.0 Hz; contrast = 80%) that were optimized for the orientation and spatial frequency for each neuron. We found that adult-like center/surround organization was largely present in V1 neurons as early as 2 weeks of age. However, in V2, RF surrounds did not appear until 4 weeks of age and the center/surround organization was still quantitatively immature at 8 weeks of age. These results indicate that the cortical circuitry responsible for the RF center-surround organization matures considerably later in V2 than in V1 and give evidence for the hypothesis that the functional maturation of the primate visual brain proceeds in a hierarchical order.

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433 Disynaptic connections from the superior colliculus to cortical area MT revealed through transynaptic labeling with rabies virus

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Previous studies have shown that MT neurons continue to respond selectively to the direction of moving visual stimuli following the elimination of their primary source of input, V1. A proposed substrate for this preserved function is through the superior colliculus (SC) relay of retinal inputs to visual cortex via the pulvinar nucleus. The inferior portion of the pulvinar (PI) is subdivided into several nuclei that provide distinct projections to extrastriate visual cortex. The medial subdivision, PIm, provides the main projections to MT and its 'satellite' areas, while a second, lateral subdivision, PIL, projects almost exclusively to MT. However, it remains to be shown whether MT projection zones in the pulvinar receive direct SC input. Previous studies using anterograde tracer injections in the SC and retrograde tracer injections in MT showed no evidence of overlap in PIm. Here we use rabies virus as a transynaptic tracer to directly examine disynaptic connections from SC to MT in macaque monkeys. Three days (required time for disynaptic transport) following injections in MT, retrogradely labeled cells were found in superficial layers of SC. These results show that MT and SC are disynaptically connected. Whether these colliculocortical connections are relayed through, as yet, undetected SC inputs to PIm or PIL remains to be determined.

434 Nonlinear Dynamical Characterization of Magnocellular Neural Population Response Variability

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Purpose: To apply the methods of non-linear dynamical systems analysis (chaos analysis) to neuronal population response variability, using the Visual Evoked Potential (VEP) in glaucoma as a test case for magnocellular function. **Methods:** 30 s single sweep VEPs in response to 30.3 Hz full field

luminance flicker were recorded from 18 volunteers. The volunteers were normal controls, confirmed glaucoma patients, or patients clinically deemed at risk for glaucoma. Power spectral densities (PSD) and fractal dimensions (e.g. D_2 via the Grassberger-Procaccia algorithm) were calculated from the data. Results: Normal subjects demonstrated $1/f^\alpha$ ($1.4 < \alpha < 2.1$) EEG PSD spectra and constrained fractal dimensionality ($D_2 < 4.6$) while glaucoma patients showed more noise-like spectra ($\alpha = 1.4$) and unconstrained dimensionality. Extracted response magnitude data showed similar trends in the PSD and more obvious separation in D_2 . Ocular hypertensive patients were partitioned by the results and are being followed for progression. Conclusions: Glaucomatous damage seems to remove the informational content of fast luminance flicker VEP amplitude variability resulting in random amplitude variations rather than well defined, albeit nonlinear chaotic patterns. This may allow an additional diagnostic index more sensitive than the current triumvirate of fields, cups and pressures as well as pointing the way to more sensitive measures for other neural populations.

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435 Multifocal VEP recordings can be used to identify the onset of cortical activity after visual stimulation for different parts of the visual field

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Purpose. We present a method to identify the onset of cortical activity after visual stimulation using multifocal VEP (mfVEP) recordings. The aim of the study was to compare this latency measure with peak latencies of averaged mfVEP traces.

Methods. 30 visually normal subjects participated in the study. Binocular mfVEPs were recorded between two electrodes placed 4 cm above and below theinion. Dartboard patterns with 60 fields were presented within a stimulus field with a diameter of 41 deg. Within the dartboard fields checkerboard patterns with a mean luminance of 86.1 cd/m² and a contrast of 99.8% were counterphased following m-sequence stimulation. Either mfVEP traces or their squares were averaged across different subsets of the 60 fields (upper and lower hemifield, 5 rings). For the average of the mfVEP traces (mVEP) latency was derived from the peak implicit time around 90ms. For the average of the squared mfVEP traces (sqVEP) latency was defined by the onset of a sudden rise above the noise pedestal.

Results. (1) When averaged across all subjects the sqVEP for the upper and lower hemifields showed a similar onset of cortical activity (48.5ms vs. 48.0ms) while their peak mVEP latencies differed significantly (100.8ms vs. 91.7ms). (2) We found a continuous shortening of sqVEP latencies from the central ring (55.0ms) to the most peripheral ring (46.3ms) while the mVEP latencies did not show any significant differences (around 85ms).

Conclusions. The mVEP latencies for the different parts of the visual field can not be derived from the sqVEP latencies by adding a constant time delay. This discrepancy may be due to the fact that sqVEP latencies reflect pre-cortical processing of retina and optic nerve, while mVEP latencies involve intracortical processing over a timer interval of about 50 ms. The data suggest that sqVEP latency can be used as temporal reference point to distinguish between pre-cortical and intracortical processing in basic research and in the clinical routine.

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Eye Movements: Cognitive

436 The influence of retinal smear on discrimination of single and surrounded moving letters

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Purpose: When the velocity of a moving retinal image exceeds about 3deg/s discrimination declines. Recently we showed that a single moving letter is discriminated better than a moving letter surrounded by other letters. This experiment was to determine what role retinal smear plays in reducing discrimination with the surrounding letters. Methods: 10 subjects participated. Subjects sat 4m from a black target plane. The projected target was a single white Landolt C or a Landolt C in the center of 8 Cs. In the latter case the 9 Cs were arranged in 3 columns. In each trial subjects fixated a dim spot that was extinguished just prior to target presentation. Subjects identified the orientation (up, down, left, right) of the (central) Landolt C as it moved across fixation. The target was revealed by opening a shutter. Thus, when the Landolt C gap was horizontal, the gap was not smeared either at the beginning or end of the presentation. The orientation of the gap, target velocity (1-5deg/s), direction of target motion (left, right), and target appearance (single (SI), surrounded (SU)) were all randomized. Targets were presented for 113ms to prevent eye motion. Each subject completed 144 trials. Results: At all velocities the mean number of targets whose orientation was correctly identified was greater in the SI condition. The mean incorrect (out of 36) was 14±5 SU for horizontal gaps, 20±6 SU for vertical gaps, 4±3 SI for horizontal gaps, and 16±5 SI for vertical gaps. Discussion: Discrimination was better for horizontal gaps than for vertical gaps in SI and SU because the horizontal gaps could not be smeared at either the beginning or end of target motion. Thus, retinal smear reduced discrimination for vertical gaps. Performance for horizontal and vertical gaps was more similar for SU than SI, suggesting that poorer letter discrimination for SU is at least partially the result of retinal smear and is not explained entirely by a shift in attention away from the central letter.

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437 Hand pointing is accurate following adaptation of saccadic gain

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The visual system uses two major sources of information to determine the direction of an object in space: extra-retinal signals from ocular muscles and retinal cues. The influence of extra-retinal signals on estimates of perceived space is unclear. Saccade amplitude can be adapted quickly using a double-step paradigm. Extra-retinal factors are thought to be responsible for the resulting change in saccade size and its influence on perceived direction. An alternative hypothesis is that retinal signals undergo adaptation. In order to determine which of these accounts is correct, we asked subjects to point with the unseen hand to brief visual targets at eccentricities of 5, 10, 12, 15 and 20 degrees. There were two conditions: (1) the subject made a saccade toward the intended target and then pointed towards the remembered target location, and (2) the subject pointed at the flashed target without making a saccade. Subjects performed this task before and after saccade adaptation. Although saccades were adapted to 1/3 of their original size, subjects still pointed towards the correct location of the flashed target under both conditions. This suggests that the assumption of extra-retinal adaptation is correct, and that retinal signals are not altered by double-step saccade adaptation.

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438 Center Blocks the Square: Eye Movements to Absent Objects Are Under Cognitive Control

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Are eye movements to the former locations of objects in space reflective of memory retrieval processes that index space during memory encoding? While refixations to the former locations of objects have been found in previous studies using semantic verification tasks (e.g., Spivey & Richardson, Cognition, 2000), we hypothesized that the visuospatial disruption that eye movements cause might reduce refixations to the former locations of objects in visuospatial memory tasks. To test this, subjects were visually presented 4 numbers arrayed in the corners of a 3x3 grid. The numbers were presented serially and the subject fixated each one and then returned their gaze to the center of the empty grid at which point their memory for the numbers was assessed in one of several ways (varied across experiments). In experiment 1, subjects were presented an audio number probe and they responded whether the number had been present or absent in the grid. No eye movements to the former location of the number were found. In experiment 2, subjects verified the spatial position of the audio number probe. A small number of saccades were made to the former location of the number, but substantially fewer than reported in previous studies. In the third experiment subjects reported the three locations of the numbers that would add up to the audio number probe. A slight increase in saccades to the relevant locations was observed, but again not at the levels reported by Richardson and Spivey (2000). In all three experiments subjects preferred to keep their eyes still while performing the memory task. Furthermore, most saccades to relevant locations were made after the memory response, suggesting that they reflect post-response verification rather than memory retrieval. These results suggest that oculomotor spatial indices are not necessarily encoded and activated during memory retrieval, especially under conditions in which eye movements might interfere with cognitive processing.

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439 Rapid goal-directed exploration of a scene: the choice between a Direct and a Pragmatic scan path

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When searching for a target at a cued location in a limited amount of time, an obvious search strategy is to direct your first saccade to that location. Even when the probability of the target being at that location drops between 100% and 50%, sending your eyes there before you look elsewhere still sounds like a good idea. Araujo, Kowler, and Pavel (2001, Vis. Res.) found that, counterintuitively, most participants (Ps) routinely made initial saccades to low-probability locations despite a resulting accuracy cost. Why would this indirect scan path be a good idea at all? When information about target location is given prior to a brief (~500 ms) presentation of the search display, Ps can set attentional weights for each spatial location and plan saccades accordingly. If a two-saccade path is anticipated, it may actually be cheaper in terms of planning and enacting saccades to look from the low- to the high-probability location: the eyes would be more automatically drawn to the high probability location from the low probability side than in the converse situation. The present experiments explore the conditions under which the indirect (Pragmatic) path is chosen over the Direct path. Ps viewed 2 clusters of items for a brief time (250, 500 ms) and reported if the target was normal or reversed. Their eye movements were recorded with an ISCAN eyetracker. Before each trial Ps were told target identity, the locations of the 2 clusters, and each cluster's probability of containing the target (Definite, Equal, or Weighted). We varied the complexity of items (digital numbers, objects) and background (blank, indoor scene). Under these conditions, contrary to those used by Araujo et al., very few Ps used the Pragmatic path and error rates were low. Further variations of display complexity and task constraints will be presented to examine the modulation of the choice

between a Direct and a Pragmatic scan path in the rapid goal-directed exploration of a visual scene.

440 Do pursuit eye movements improve discrimination of object speed?

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The speed of an object in the world is the sum of speed on the retina and speed of the eye: $S = R + E$. Thus, the precision of speed estimation depends on the precision of retinal and extra-retinal signals and how their precisions vary with speed. People usually pursue an object when estimating its speed in everyday tasks; they do not choose to hold the eye steady. Compared to the non-pursuit strategy, pursuing the object minimizes retinal speed while increasing eye speed. How does this affect the precision of object-speed estimates? To examine this, we had observers judge the relative speeds of Gabor patches in a 2-IFC task in two conditions: 1) non-pursuit in which they held the eye steady as the stimuli moved across the retina, and 2) pursuit in which they pursued the stimuli. To make the stimulus information equivalent during pursuit and non-pursuit, we could not present a fixation aid. Thus the stimuli were pairs of Gabor patches moving rigidly together, with one patch above the place where the observer fixated and one below. Before each stimulus presentation, a lead dot appeared moving at a speed close to (but not indicative of) the speed of the upcoming target. The dot then disappeared and the Gabor patches appeared. In the pursuit condition, observers pursued the lead dot, so their eyes were already moving when the target appeared. In the non-pursuit condition, observers kept their eyes stationary for the whole trial, including the presentation of the lead dot. Observers were trained under these conditions to make smooth pursuits in the pursuit condition and to hold the eye steady in the non-pursuit condition. Eye movements were measured to determine accuracy on each trial. Speed-discrimination thresholds were lower in the pursuit than in the non-pursuit condition for most observers, but the differences were small. The difference depended on target speed, which means that the noises in the retinal and extra-retinal signals are affected differently by speed.

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441 The Effect of Plaid Orientation on Pursuit of Partially-Predictable Motion

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Goodwin & Fender (1973a,b) studied smooth pursuit of trajectories composed of a predictable sinusoid and an unpredictable noise signal. When these signals are applied in orthogonal directions, the sinusoidal component of the motion is pursued with a latency approaching 0 (perfect prediction). Here we examine how this decomposition of the trajectory is influenced by the spatial content of the supporting pattern, to provide insights into low-level motion computations. Square-wave plaid patterns (1 cpd, 50% contrast) were viewed through a dual-Purkinje eye-tracker. The eye-tracker's stimulus deflectors were used to apply a sine/noise trajectory to the pattern, which moved behind a stationary circular aperture (diam. = 10 degrees). Subjects attempted to track the pattern, and pursuit latency was computed by correlogram analysis (50 trials per condition). Eight conditions were run, consisting of 4 trajectory orientations (0,45,90,135) crossed with 2 plaid orientations (0,45). We replicated the results of Goodwin & Fender, finding predictive pursuit of the sinusoidal component (latency 10-40 msec), with longer latencies for the unpredictable component (110 msec). Some subjects reported that in the aligned condition the components were less likely to "cohere," often

appearing to slide over one another. No effect of plaid/trajectory alignment or motion direction was observed in the latencies to the noise component, but predictive latency for an aligned plaid was approximately 10 msec faster than that for either an unaligned plaid or a simple spot. A larger effect was found for direction of motion, with predictive pursuit in the vertical direction having a latency about 20 msec shorter than the horizontal or oblique directions. The results suggest that pursuit is driven by pure "pattern" motion with little or no influence from "component" motion signals. The shorter predictive latencies for vertical motion may be related to the relatively weak reflexive pursuit in the vertical direction.

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<http://mysite.verizon.net/vzeejf0b/index.html>

442 Version and vergence eye movements in mobile observers

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The bulk of published data on eye movements have been gathered in laboratory settings. One eye of a seated observer is often tracked while s/he views static objects or images constrained to a single depth plane. By contrast, eye movements in natural environments are often made while the observer and/or target are in motion, to objects that vary in both direction and depth. We monitored monocular and binocular eye movements of mobile observers as they performed a number of tasks, from scanning a 3D array of targets while seated in the laboratory, to navigating footpaths in natural, wooded environments. A custom-built wearable eyetracker was used to monitor version and vergence eye movements of observers performing the tasks under a range of conditions. Monocular and binocular eye movements were studied within a 3-dimensional array of calibration points surrounding observers indoors, free viewing outdoor scenes, a visual search task, and while walking indoors and out.

In the free-view task observers were instructed to simply familiarize themselves with a region defined as the hemisphere forward from their fixed viewpoint. In the visual search task, observers searched for a small target within a hemisphere. Free to move their heads and bodies, large gaze changes (> 30 deg) were common. Fixations durations in the search task ranged from < 50 msec fixations in large area search sequences to > 1000 msec fixations while inspecting high-density regions. While it is possible to extract individual version and vergence 'components' of gaze shifts between targets in 3D space, the right and left eye movements each exhibit main-sequence saccadic characteristics; the dynamics of each determined by the relative location of the two eyes and the sequence of targets.

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443 The effect of retinal jitter on referenced and un-referenced motion discrimination thresholds

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Referenced motion thresholds are significantly lower than un-referenced motion thresholds. To account for this, previous studies have postulated the existence of compensatory mechanisms, driven by the presence of a surround, that cancel the effects of eye movements. In the present study we used an Adaptive Optics Scanning Laser Ophthalmoscope (AOSLO) to investigate the effects of retinal jitter due to fixation eye movements on referenced and un-referenced motion thresholds in addition to the effect of external jitter on un-referenced motion thresholds. Methods: The stimuli were produced by modulation of the AOSLO imaging beam. In Experiment 1 subjects made up/down motion judgments of a dark horizontal bar presented against a stationary 1-degree bright background.

In Experiment 2 un-referenced motion thresholds were measured with isolated bright horizontal bars in otherwise complete darkness. Experiment 3 was identical to Experiment 2, except that the eye was externally perturbed through the lower lid with a 2HZ square wave by a cotton tip applicator attached to a galvanometer. In all three experiments, AOSLO images for each trial were analyzed offline to extract retinal jitter. Results: For referenced motion, the results were consistent with complete compensation for eye movements by the visual system. In the un-referenced motion case eye movements adversely affected motion judgments however there was evidence of partial compensation for such eye movements. The results for the external jitter condition were also with consistent partial compensation for the external jitter. Conclusions: Compensatory processes completely cancel the effect of fixation jitter for referenced motion but such compensation is partial for un-referenced motion. The external jitter experiment suggests that proprioception may be a possible signal that could drive compensatory processes.

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444 Attending to Original Object Location Facilitates Visual Memory Retrieval

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It has long been known that attention plays a critical role in the transfer of perceptual information into memory. The present study examined whether attention plays a complementary role in the retrieval of visual information from memory. Specifically, we tested the hypothesis that visual object representations in scenes are bound to scene locations, and that attending to an object's location facilitates the retrieval of object information bound to that location (Hollingworth & Henderson, 2002).

On each trial, participants viewed a 3-D rendered scene for 12 seconds, followed by a mask and a test scene in which a single target object had been moved from its original position in the scene to the center of the scene. The target object was either the same as the original object or mirror reversed. The task was change detection. Eye movements were monitored during study and test.

In the first experiment, when attempting to perform the change detection task, participants fixated the (now empty) original location where the target had appeared on approximately 30% of trials. To examine if this behavior is functional in visual memory retrieval, in the second experiment we controlled participants' ability to fixate the original location. In the eye-movement condition, participants were free to look around the scenes while making their change judgment. In the no eye-movement condition, participants were only allowed to fixate the central target object during test, which ensured that they could not fixate the object's original location. Change detection was significantly more accurate in the eye-movement condition (89%) than in the no eye movement condition (76%). These data support the hypothesis that object representations are bound to scene locations and that object retrieval is facilitated by attending to object location.

445 Ocular Tracking Of Transiently Occluded Targets

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Purpose: When individuals pursue an object moving horizontally that disappears for a short time and then reappears, they continue to move the eyes during target occlusion but at a lower velocity than the target. This study had 2 purposes. (1) To compare horizontal and vertical tracking of a transiently occluded two-dimensional (2D) target. (2) To determine whether subjects could learn to more accurately track this 2D target after repeated exposures.

Methods: 3 subjects tracked a letter 'E' (0.3?) monocularly (distance=1.6m). The target started 11? above the eyes and then moved down (14?/s). At

random angles of 3? above to 3? below the eyes, a horizontal ramp (14?/s, random direction) was added to the vertical motion (2D target). At random intervals (0.7-0.8s) after the 2D motion began a shutter occluded the target for 0.3-0.4s. The target continued to move at the same velocity. The shutter then reopened and the target continued moving for < 0.14s. Subjects were to always pursue the target as if it were visible. 15 consecutive trials were recorded. Eye movements were recorded with a search coil.

Results: After occlusion subjects continued to track the target with pursuit and saccades. However, mean retinal position errors (PE) increased throughout the occlusion period in most trials. The PE prior to occlusion (after 2D motion onset) were 0.8?±0.5? horizontal (H) and 1?±0.5? vertical (V). The PE during occlusion were 2?±1? H and 4?±1? V. The PE after occlusion were 3?±2? H and 7?±1? V.

Discussion: The increase in tracking errors during occlusion and the lack of improvement in tracking during occlusion over 15 trials shows that the memory store that allows for tracking during occlusion is short lived. Thus an efferent copy of the eye movements in a trial cannot be modified for use in subsequent trials by the visual feedback provided when the target reappears. Finally, the short-term memory store for tracking is more effective for horizontal than for vertical tracking.

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446 Do complex motor sets have the same effect on express saccades as simple ones?

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Previously, we demonstrated that instructions to make a saccade to one end of a horiz bar that appeared suddenly in a random location can affect saccade vector with no sacrifice in RT (Soc for Neuro 2002). Subsequently, we have shown the effect of such an object-centered motor set holds true even for express saccades (SfN 2004). Here we test for similar effects of an instruction to make a saccade to the upper or lower end of a vertical target array, as well as effects of a more complex instruction to make saccades to one of 4 targets arranged in the shape of a square. RTs and spatial effect of instruction were measured in 4 tasks: 1) Horiz - 2 targets were spaced horizontally (68) and subjects were instructed to make a saccade to the left or right target 2) Vert - 2 targets were spaced vertically (68) and subjects were instructed to go to the top or bottom target 3) 4 target/ 2 instruction; 4 targets were arranged as corners of a square (68x68) and Ss were instructed to go to the top right, bottom right, top left or bottom left target. 4) like 3), but Ss were instructed to go to either to the top, bottom, left or right pair of targets. All instructions were indicated by an arrow that served as the fixation point prior to target appearance. In all tasks, targets appeared a random location on the screen. A 150ms gap was used to facilitate express saccade generation. The eye movements of two Ss were recorded at 500Hz using a video eyetracker (Eyelink II). As in the case for previous studies using horiz instructions, both vert instructions and simultaneous vert and horiz instructions influenced saccade endpoint with no increase in RT. In addition, comparing the results of conditions 3 and 4, we found only a slight interference of following the horiz instructions with the simultaneous following of vert instructions. These results beg the question: at what level of motor set complexity does its implementation cause an increase in saccade latency?

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447 Orienting contributes to preference even in the absence of visual stimuli

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We previously demonstrated the active contribution of orienting to preference decision making (Shimojo et al, 2003) in the "gaze cascade

effect", a continually increasing likelihood that subjects' gaze was directed to the stimulus eventually chosen. The effect was robust across a wide range of stimuli and conditions (VSS 04), thus we suspected that whenever a preference decision needs to be made the gaze cascade accompanies it. We here show an extreme case where gaze cascade effect was observed even when the stimuli were no longer visually present. Unlike our previous studies, the observation duration was controlled and randomized by the experimenter while subjects were trying to decide the preferred one. In roughly half of the trials the presentation time was long enough for a decision, mimicking our previous experiments. However, in the other half, a decision had to be made after the stimuli were taken off the screen. Testing whether visual input is required for the cascade effect was one of the motivations of this study. We used eye-tracking and our gaze likelihood analysis (VSS 02).

First, as expected, we show the gaze cascade effect before decision in the trials in which observers had enough time to choose the preferred stimulus. Moreover, the bias slowly decreases in the next second after decision, when the stimuli were still presented on the screen, confirming that the cascade is linked to the decision process and not to observers' already-made preference. Second and intriguingly, in the trials where a decision came after the stimuli were removed from the screen, the cascade was still present. Thus, gaze is participating in the decision process even when the decision is made purely in memory. Observers made fixations in the approximate regions previously occupied by faces, and their gaze pattern was still correlated with their decision. Thus our claim that gaze cascade is intrinsically involved in the decision making process is extended beyond perceptual domain.

448 Visual persistence of saccade-induced image smear

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Visual persistence has been studied mainly in normal viewing, which indicates eyes are fixed. Recently, some reports have demonstrated that the result of temporal judgment tasks in perisaccadic periods have different tendencies than in normal viewing (e.g., Yarrow et al., 2001). The reports indicate that a person's subjective sense of time, or internal clock, ticks more slowly in perisaccadic periods. Few studies, however, have investigated the mechanism of time perception around the time of a saccade. We, therefore, measured the visual persistence of a perisaccadic light stimulus, which is fundamental for studying perisaccadic time perception. Based on Di Lollo's sequential method (1977), we specifically determined the duration of a saccade-induced image smear, which is painted by a stationary light stimulus when an eye movement is performed. In our experiment, a flickering light stimulus was presented through the duration of a saccade (34 ms) in a dark environment, and a dot array (saccade-induced image smear by a flickering light stimulus) was observed due to retinal afterimages. After the presentation of the dot array, another light point was presented with one of six inter-stimulus intervals (0, 40, 80, 120, 160, 200 ms). The observers were asked to answer whether the image smear and the light point were perceived as one image or they were sequentially presented. We defined PSE of the inter-stimulus interval as the duration of saccade-induced image smear. We compared the duration for saccade-induced image smear with the duration when a physically spreading light array was observed in normal viewing. Although the results of temporal judgment tasks in previous studies indicated a slowing of the internal clock in perisaccadic periods, our results show that the duration of the saccade-induced image smear lasts as long as the duration of afterimages induced by a physically moving illuminant.

449 Is Gaze Selection Diagnostically Tuned for Spatial Frequency During Face Recognition?

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University Department of Psychology and Cognitive Science Program; Previous work with high- and low-spatial frequency hybrid images has demonstrated a bias for extracting information at the spatial frequency scale diagnostic of the viewing task. Specifically, the visual system can be influenced by top-down information to flexibly select the appropriate task-dependent (diagnostic) spatial frequency channel. These results have been interpreted to suggest cognitive penetrability of early perceptual processes (Oliva & Schyns, 1997; Schyns & Oliva, 1999). The current study sought to determine whether gaze selection is similarly flexible. High- and low-spatial frequency hybrid images were constructed from two superimposed faces (one at each scale) such that regions of interest (eyes, nose, mouth) did not overlap. In the first experiment, subjects were instructed to identify (by name) either the high or low spatial frequency (HSF or LSF) face in the hybrid. Results suggest that the gaze control system is most effective at targeting HSF information for selection regardless of which spatial frequency is most task relevant. Based on these results, we reject the strong hypothesis that the gaze control system is maximally flexible in selecting only information in the task-dependent spatial frequency channel. However, it is possible that these results may reflect either a specific tuning to the scale most likely to contain diagnostic information (i.e., HSF information for face recognition), or alternatively, a general bias to select HSF information. In the second experiment, we tested these alternative explanations. Participants were asked to categorize the mood expression of each face at one of two spatial frequency scales in a task that has been previously shown to rely heavily on cues from LSF scales. We discuss the implications of our results in relation to the cognitive penetrability of gaze selection.

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<http://www.augen.uniklinik-freiburg.de/edg/ambi/index.html>

450 Top-down and bottom-up influences on saccades in a visual search task

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We measured top-down and bottom-up influences on human saccadic eye movements by having observers perform a visual search for an oriented target in the presence of an orthogonally oriented distractor. Bottom-up, salience-based mechanisms predict the frequency of saccades both to the target (correct) and to the distractor (incorrect) will increase similarly as their contrasts increase, with correct saccades favored as the distractor contrast decreases. Top down, template-based mechanisms predict that the proportion of correct saccades will increase as target contrast increases and incorrect saccades will decrease as distractor contrast increases. Our experiment measured the relative contribution of these two mechanisms to saccadic targeting.

Two observers performed a 6 AFC (6 locations equally spaced at 6.0 deg eccentricity) search task to find the target (vertical Gabor) and disregard a distractor (horizontal Gabor). The Gabors were both odd-phase (SF: 3.3 c/d, σ : 0.23 deg) and added to white noise (RMS 26%). All combinations of 4 target contrasts (6% - 24%) and 5 distractor contrasts (0% - 24%) were used. The target and distractor locations were independently and randomly chosen. Observers searched the display and at the end of each trial indicated the target location with a mouse. We defined the 1st saccadic 6AFC decision as the element location nearest to the 1st saccade's endpoint.

Despite prior knowledge of the orientation of the target and distractor, observers were unable to fully use the orientation information. The mean (over distractor contrasts) slope of the proportion of saccades to the target vs. target contrast was 2.2. The mean (over target contrasts) slope of the proportion of saccades to the distractor vs. distractor contrast was 2.3. The positive distractor slope and its similarity to the target slope show that, in

this task, bottom-up factors dominated with performance largely determined by the contrast difference between target and distractor.

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451 Contrast dependence of smooth eye movements using superimposed transparent surfaces

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We sought to use eye movements as a readout of selection of one of two spatially superimposed surfaces. We trained a monkey to saccade to a 2.75 deg. radius circular aperture within which one or two superimposed patterns of dots, which appeared as transparent surfaces, translated to the left or right. On each trial, the monkey maintained gaze on a central fixation spot and the aperture appeared in the periphery (7 deg eccentricity). After a variable period of time, the fixation spot disappeared, and the monkey made a saccade to the aperture. Reward was delivered if gaze remained within the aperture for 200 ms. We examined how smooth eye movements during this 200 ms period varied as a function of the luminance contrast of the surfaces. With a single low contrast surface, eyes moved slowly in the direction of the surface. Gain increased with contrast, saturating at 70-90% of surface velocity. The function relating gain to contrast shifted to the right when a second, lower contrast, surface was added moving in the opposite direction. Equating the contrast of the two surfaces nulled pursuit. We consider these results in the context of three models: a vector averaging model, a winner-take all model, and a weighted vector averaging model in which the motion-selective neurons that drive the pursuit system are highly sensitive to contrast, and motion in a neuron's null direction results in a rightward shift in its contrast response function.

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452 Poor saccade control in a simple search task

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Background: A large number of studies have investigated observers' ability to make targeted saccades in the absence of other stimuli. In these studies the observers' task is to saccade quickly and accurately to the target, usually presented in one of a limited number of locations. Here we investigated observers' ability to make accurate saccades when they first must select the target on the basis of its color, and when the target was presented alone and in the presence of other stimuli. **Methods:** Observers made saccades to an oriented-c of a specified color when it was presented alone or flanked on both sides by one or two c's of other colors. The spacing between the target and the flanks was either near or far. The target was randomly presented to the left or right of fixation. The display on the other side of fixation was the same, except that it did not contain the target color. Targets and flanks were about 0.33 deg in diameter. Eye movements were tracked with a dual-Purkinje-image eye tracker sampled at 1000Hz. Trials were judged correct if the eye landed within a window centered on the target of $\pm 1.5^\circ$ its size. **Results:** Observers performed poorly on this task. In the absence of flanks they landed on the target only 54% of the time. The addition of one flank reduced performance to 43%; two flanks further reduced performance to 30%. There was little effect of spacing; 38% for the near spacing and 34% for the far spacing. Reaction times parallel these data. **Conclusions:** We were surprised by the poor performance of the observers in this study. It is possible that the choice component of the task or the displays we chose interfere with one's ability to program accurate saccades. Experiments are under to test these possibilities.

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453 Infants' Motion Sensitivity Predicts Smooth Pursuit Performance but Fails to Predict Perceptual Completion

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A longstanding debate in developmental psychology concerns the mechanisms of development which allow infants to perceive partially occluded objects as complete. One candidate explanation involves the role of motion. It has long been known that young infants achieve perceptual completion only when the visible portions of a partly occluded surface undergo common motion, implying that failure to perceive connectedness may be rooted in an insensitivity to visible motion.

Perceptual completion, motion sensitivity, and smooth pursuit emerge at about the same age in human infants (2 months), leading to the hypothesis that smooth pursuit and perceptual completion arise from developments in motion sensitivity. We observed 11 infants, 52-99 days of age, in three tasks on the same day. In the first, infants viewed small moving targets as their eye movements were recorded with a corneal-reflection eye tracker. We isolated segments of smooth pursuit and compared its speed with object speed to obtain individual infants' gain. In the second, we tested object unity perception by habituating infants to a partially occluded moving rod and recorded looking times at unoccluded rods, either broken or complete. A novelty preference for the broken rod was interpreted as evidence of perceptual completion. In the third, infants observed side-by-side random-dot kinematograms in which dots moved either uni- or bi-directionally.

Infants who showed a preference for bi-directional motion displays were better able to smoothly pursue a moving target ($p < .03$). In contrast, neither performance in the motion task nor the smooth pursuit task predicted perceptual completion. Smooth pursuit and motion sensitivity performance were correlated with infant age ($r = .75$, $p < .01$ and $r = .50$, $p = .11$), but unity perception was not ($r = -.06$, ns). We conclude that motion sensitivity is more strongly involved in smooth pursuit than it is in the development of the perception of object unity.

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Contrast

454 A New Psychophysical Test for the Rapid Measurement of Spatial Contrast Sensitivity in Infants and Young Children

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Purpose. A challenging objective in the field of developmental psychophysics is to produce tests that are rigorous scientifically, but for practical application, are also simple, time-efficient, and portable. Based on the Teller visual acuity cards, we have developed a non-verbal test of contrast sensitivity (CS) for infants and young children. Although successful methodologically, the sine waves in our prototype test were difficult to reproduce and were susceptible to light damage and chemical leaching. Here, we report on a new, more precise version of the test.

Methods. Using new custom software and an advanced photo quality printer, sine wave gratings were printed on high resolution photographic paper. To produce a stimulus 'card', each test grating (16 deg at 60 cm) was mounted on acid-free foam core, adjacent to a second 'control' grating with 0% contrast. There were 5 sets of 56 x 28 cm cards, each with gratings of either 0.75, 1.5, 3, 6, & 12 c/deg, and contrast ranging from 57% to 3.6%. FPL thresholds were obtained at each spatial frequency for 30 infants ($M = 12$ mo) and preschoolers ($M = 3.5$ yr).

Results. All preschoolers and most infants completed the test in less than 10 min, and all generated a CSF with the typical inverted U-shape. Mean CSFs for both groups were well within the range of previous FPL studies. Moreover, we produced two other new sets of cards which continue to replicate contrast levels to almost exact specifications. There has been no evidence of light damage or chemical leaching.

Conclusions. We have been able to develop a new set of CS cards with sine-wave gratings reproducible with greater reliability and durability. Moreover, these cards yield interpretable data from young children in a relatively short period of time. These are important steps in the goal of developing a universal, time-efficient psychophysical tool for assessing this critical aspect of vision in the pre-verbal child.

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455 Summation Processes in Contrast-Contrast.

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We have previously shown that the apparent contrast of a grating patch first increases and then decreases as a function of the size of the patch. This can be explained by assuming two antagonist mechanisms. A center part sums the contrast energy over some small area and a larger surround part inhibits the center. The summing center mechanism prevails in the rising portion of apparent contrast curve and the inhibiting surround mechanism dominates after the peak apparent contrast has been reached. To further test the idea of contrast-summing antagonistic mechanisms, we measured the apparent contrast of a center grating surrounded by a similar annular grating under two spatial arrangements. The size of the stimulus (center+surround) was either within the size of the measured summation area or the center of the stimulus was matched to the summation area, with the surround falling outside, on the inhibition-dominating area. The annulus either had higher or low contrast than the center. When the whole stimulus fell within the summation field, the apparent contrast of the center was roughly the average of center and surround contrasts. When the center was the size of the summation area and the surround fell outside the summation area, the apparent contrast of the center was reduced in all surround contrasts. These results support the idea of a center mechanisms integrating contrast information over limited range of space, opposed by a spatially wider mechanism inhibiting the center one.

456 Singularities in the inverse modeling of contrast discrimination and ways to avoid them

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A basic problem in psychophysics is estimating the mean internal response and noise amplitude from sensory discrimination data. However, these components cannot be measured independently and therefore several indirect methods were suggested to resolve this issue. Here we analyze the two-alternative forced-choice method (2AFC), using a signal detection theory approach, and show analytically that some combinations of internal parameters exhibit singularities in the sensitivity to sampling errors, which results in a large range of estimated parameters with a finite number of experimental trials. Four types of singularities were identified. It was found that performances, measured as percent correct discriminations in 2AFC contrast discrimination experiments, are well described by a model with the noise amplitude that is independent of the stimulus intensity (one of the singular models). Thus, the 2AFC contrast discrimination experiment is not suitable for characterization of the contrast perception model. We show that this problem can be avoided using a visual category rating task, with Gabor signals at nine contrast levels as targets. Assuming stable category boundaries, the model

parameters, namely, mean internal responses, noise amplitudes and category boundaries were found using a best least square fit to the data. Our findings show that at low contrasts noise amplitude decreases as a function of contrast level, while at higher contrasts the amplitude is independent of the contrast level. The internal responses were found to be best described by a saturating function of contrast. The confidence intervals were estimated using Monte-Carlo simulations of the identification task. The results show that the well-known increase of contrast discrimination thresholds with contrast is due to reduced sensory gain and not due to increasing internal noise.

457 Spatial but no spectral limits on contrast conservation

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There is a dissociation between the orientation of contours and their contrast: suddenly changing the orientation of a grating during brief presentations has no effect on its apparent contrast at suprathreshold levels even though its threshold contrast increases (Fiser et al, Vis. Res. 2003). We call this supra-threshold phenomenon contrast conservation. Here we ask whether there is any limit on the differences between stimuli over which contrast is conserved. Two naïve subjects matched the apparent contrast of a succession of 2 images that were spatially coextensive but different in Fourier spectra (a plaid, a natural scene, or a random noise pattern) to a composite formed by superimposing the two images; or they matched a succession of spectrally similar stimuli that differed orientation or spatial position (a ring of 8 evenly spaced Gabor patches whose elements were either rotated by 90 deg in place or moved 22.5 deg along the ring). All stimuli were presented for 53 msec at 25% RMS contrast, 2 deg from fixation. The spectral change had no effect: the curve describing the growth of apparent contrast was the same whether the stimulus was a simple plaid, a natural scene, a random noise pattern, or one of these followed by a different one. The same was true when the orientation but not the position of the ring of Gabor elements was switched. However, when the positions of the Gabor elements changed, but not their orientation, contrast conservation was abolished. As the spectra of a plaid and random noise are as different as possible (maximally concentrated and evenly distributed), we find that the shape of the Fourier spectra of images places no limit on contrast conservation. However, conservation occurs only over a limited area, even for stimuli that are spectrally similar. Natural scenes are no different from either of these artificial stimuli in this respect.

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458 Neural Circuitry Revealed by Near-Threshold Transducer Nonlinearities

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Rationale. The accelerating nonlinearity revealed in contrast detection tasks must combine nonlinearities of all processing stages involved. If there were some means to disable these nonlinearities selectively, one could reveal the stages by linking them with the component nonlinearities. To exploit such an opportunity, the nonlinearities were probed by 1) presenting a contrast pedestal dichoptically and 2) introducing a luminance pedestal. We argue that in the first manipulation eliminates the nonlinearity at the binocular summation site and the second manipulation eliminates any nonlinearity in the luminance adaptation stage. Methods. The contrast target was a monocular Gaussian blob with $\sigma = 3$ arc min. The matching pedestal in the other eye had a contrast of 10%; the luminance pedestal was a disk with 1 deg diameter presented upon a dark field. Results. We found that 1) monocular contrast detection upon a uniform field produces a quadratic (accelerating) nonlinearity; 2) dichoptic presentation of the contrast pedestal did not affect the quadratic nonlinearity; 3) presenting the test with the luminance pedestal eliminated

the quadratic nonlinearity, revealing a hard threshold nonlinearity instead; 4) presentation of the dichoptic contrast pedestal with luminance pedestal in both eyes did not eliminate the threshold nonlinearity but halved its value. Conclusions. From results 1) and 2) we conclude that the quadratic nonlinearity is a property of the luminance adaptation mechanism in the retina. From results 3) and 4) we conclude that the threshold nonlinearity is located in the cortex and has two components: monocular and binocular, indicating that the monocular receptive fields of the binocular neurons are provided by the monocular cortical neurons, which, in turn, collect signals from the LGN. The stage where the critical noise is infused in the contrast signal must be located right after binocular summation.

459 Bayesian Adaptive Estimation of Threshold versus External Noise Contrast Functions.

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Purpose. Contrast threshold as a function of external noise contrast (the TvC function), measured at multiple performance criterion levels, provides a fundamental description of the observer system that distinguishes mechanisms of adaptation, spatial attention, and perceptual learning. Previously, measuring TvC functions at three criterion levels, required for model inference, has been demanding (often >2000 trials). We develop and test a Bayesian adaptive procedure to estimate multiple TvCs with 240-480 trials. **Method.** Based on Kontsevich and Tyler's ψ method, the quick TvC ($qTvC$) procedure estimates three parameters: c_0 and N determine a bilinear approximation to the TvC at 79% correct-- c_0 determines the constant threshold level observed in low noise and N determines the noise level at which thresholds begin increasing with slope=1.0. The third parameter, γ , determines the constant threshold ratio between criterion levels across noise conditions. This slope invariance assumption (validated by dozens of data sets) allows us to estimate TvCs at other criterion levels (e.g., .65, .92%). On each trial, stimuli are placed at signal and noise contrast levels minimizing the entropy of the three-dimensional posterior probability distribution, $p(c_0, N, \gamma)$ in a one-step ahead search. The procedure was tested in Monte Carlo simulations and a psychophysical task comparing $qTvC$ estimates (240-480 trials) with those obtained using constant stimuli (1920 trials). **Results.** Simulations showed that after 240 and 480 trials, the rms error of $qTvC$ estimates at three criterion levels is 1.3 and .9 dB. Further, $qTvC$ and constant stimulus estimates were very similar: the rms difference was 9 ± 1.1 dB. **Conclusions.** The $qTvC$ method holds considerable practical value: it measures the observer system's functional properties (equivalent internal noises corresponding to absolute threshold and Weber fraction), within a plausible data collection regime for special populations or testing applications.

460 Spatial and Temporal Determinants of Contrast Facilitation and Suppression

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Lateral masking experiments indicate greater sensitivity to a foveal Gabor target when presented with flanking Gabors whose local carrier orientations match the target orientation. We examined the spatial and temporal determinants of this surround facilitation by measuring target contrast detection thresholds at multiple exposure durations, target-flanker SOAs and separations. Consistent with previous findings, we found maximum facilitation with synchronous collinear target-flanker

onsets and offsets. Critically, the minimum exposure required to elicit facilitation increased with target-flanker separation. Transforming the visual field to human striate co-ordinates, rates of increase in facilitative delay across cortical space corresponded with the conduction velocities of long-range intra-striate connections (0.1 m/s). Contrary to previous findings (Polat & Sagi, 2004), robust suppression occurred when flanker offsets preceded target onsets, but not when the target preceded flankers. This temporally contingent suppression was evident 20ms following flanker offset at all target-flanker separations (0.6 - 1.7 degrees of visual angle), implying very fast suppressive transmission velocities, possibly due to striate-extrastriate interaction. Using circular Gaussian targets, facilitation was also maximal for synchronous presentation, but with no evidence of suppression at any SOA. These data suggest temporally dependent suppressive effects may be contingent upon local carrier information.

461 Characterizing contrast response functions measured with rapid event-related fMRI

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Rapid event-related designs are an increasingly popular method in fMRI studies of perception. These designs typically produce smaller fMRI response amplitudes than spaced and blocked designs, but whether they preserve the relative amplitudes of responses is unknown. It is also unclear whether the signal reductions arise from nonlinearities in the hemodynamics or in the neural responses. To address these issues, we compared contrast response functions in visual cortex measured with spaced and rapid event-related designs. During scanning, subjects viewed 18 degree contrast reversing checkerboard patterns presented for 500 msec on a gray mean field. Condition ordering was counterbalanced using an m-sequence to optimize efficiency. To control attention, subjects performed a demanding RSVP task at fixation throughout all scans. fMRI signal (BOLD, 3T) was averaged from early visual areas, and linear response kernels were estimated for each condition from the average timeseries. Estimated conditional response amplitudes were then averaged across subjects. In Experiment 1, patterns at three different contrast levels were displayed every 16 seconds (spaced scans), or 3 seconds (rapid scans). For all contrast levels, average responses measured in the 3-second design fell close to those measured in the 16-second design. In Experiment 2, seven patterns of different contrast were displayed every three seconds, or every one second. For all contrasts, average responses measured with the one-second design were smaller than those measured with the three-second design. The difference between the one- and three-second contrast response functions was best characterized by a horizontal shift along the log contrast axis. This result suggests that reducing the time between stimulus presentations from three to one second reduces the contrast gain of those neurons producing the fMRI response, perhaps due to increased masking or contrast adaptation.

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462 A Comparison of Behavioral Contrast Sensitivity with the Contrast Sensitivities of X and Y Geniculate Cells in the Awake Cat

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To determine if individual LGN cells are sensitive enough to account for cat dim-light vision, the contrast sensitivity of single cells and behavioral contrast sensitivity were measured at adaptation levels from the lowest scotopic to the mid-mesopic. Cats were trained to fixate a centrally-presented laser spot, to make saccades to Gabor functions appearing 8 deg to the right or left, and to ignore patches of uniform sine gratings.

Temporal frequency was 4 Hz for both Gabor functions (SD = 1.5 deg) and extended sine gratings (15x15 deg), and both were upward drifting. Behavioral contrast sensitivity was determined with a staircase procedure, and psychometric functions derived for 0, 1/8, 1/4, 1/2, 1, 2 and 4 cyc/deg at adaptation levels spanning 8 log units above absolute luminance threshold. Single cells were isolated at mesopic levels, and characterized as X or Y with counterphasing gratings. The cats were dark adapted, and spikes evoked by drifting sine gratings of spatial frequency 1/8, 2 and 4 cyc/deg were recorded at increasing levels of adaptation. Signal detection theory was used to estimate thresholds from the mean firing rate (F0) and first harmonic (F1). We find that the most sensitive LGN cells can account for the observed behavior under all conditions tested - i.e., there is no need to invoke post-thalamic averaging across a large population of cells at these adaptation levels or spatial frequencies. For F1 responses, behavioral sensitivity for 1/8 cyc/deg closely matched the most sensitive Y cells, whereas for 2 cyc/deg, the most sensitive X cells were as sensitive as the cat. For 1/8 cyc/deg in the scotopic range, Y cells were approximately 1 log unit more sensitive than X cells over a wide range of contrasts. Cats performed above chance at 4 cyc/deg, with contrast thresholds of about 75% for luminance levels above 1 cat troland. Surprisingly, this behavior appears to be supported not by X cells, but by the F0 response of Y cells. Supported by NIH EY02695.

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463 Laser Induced Fluorescence in the Human Lens

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Purpose: When the human eye is exposed to a short-wavelength light in the near-ultra violet region, the light causes the lens to fluoresce, which produces a widespread glare effect on the retina. This glare may interfere with normal vision, especially at lower ambient illumination conditions. The aim of this study was to characterize the spatial extent of veiling glare caused by laser induced lens fluorescence.

Methods: The elevation in contrast threshold induced by eye-safe laser exposures from an ultraviolet laser operating at 364 nm was determined in human observers. The laser exposures were 8 mW/cm² at the cornea, and were 5 s in duration. The angle between the laser beam axis and the visual task was varied between at 2.5° and 30°. Contrast thresholds were determined by the method of adjustment for a Landolt ring target with a critical detail of 0.5' against a dim background (5 cd.m⁻²).

Results: The studies showed that a significant elevation in visual increment thresholds could be produced through ultraviolet laser induced lens fluorescence. Thresholds were increased by 50-100%, over a large part of the visual field. Thresholds for the target as far away as 30° from the laser beam axis were elevated by 50%. Equivalent background techniques estimated the luminance on the retina from the laser exposure to be around 5-10 cd/m².

Conclusions: This study characterized the spatial extent of veiling glare caused by laser induced lens fluorescence and showed that exposure to a near-ultra violet laser at 'safe' exposure levels (with respect to existing laser safety standards) can induce a veiling glare intense enough to impair visual performance.

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Contour and Shape

464 Different mechanisms encode the shapes of contours and contour-textures

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Aim. It is often assumed that curved contours, and textures made from parallel curved contours, are processed by the same mechanism. However, recent evidence from primate neurophysiology and brain-imaging studies suggests that contours and textures might be processed by different mechanisms. We used an adaptation paradigm to test whether the shapes of contours and contour-textures were encoded by the same or by different mechanisms. **Method.** Subjects adapted to pairs of sinusoidally-shaped contours or contour-textures. The two stimuli from each pair were an octave apart in shape frequency and presented above and below fixation. During the test phase, subjects indicated which of two test contours/contour-textures had the highest shape frequency, and an adaptive procedure found their PSE. **Results.** Adaptation to contours produced significant shifts in the perceived shape frequency of contours, but relatively little shift in the perceived shape frequency of contour-textures. Adaptation to contour-textures produced significant shifts in the perceived shape frequency of textures, but relatively little shift in the perceived shape frequency of contours. **Conclusion.** The shapes of contours and contour-textures are encoded by different mechanisms.

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465 Detecting Curvature in First and Second-order Periodic Line Stimuli

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It has been suggested that second-order processes may have coarser orientation tuning functions than first-order mechanisms. The purpose of the present study was to determine if differences between these two classes of stimuli are evident when processing periodic line stimuli of different frequencies and to further determine whether periodic line discriminations solicit oriented receptors. The stimuli were composed of D4 luminance or contrast defined lines that were distorted with sinusoidal curvature modulations. The curvature modulations varied in frequencies between 1/8 and 1 cycle per deg and the total image size was 8x8 deg. The lowest spatial frequency was such that a minimum of one full cycle was visible. Five young healthy observers participated in the study. Individual contrast thresholds were obtained for the first and second-order stimuli to adjust for stimulus visibility. The thresholds were obtained with a temporal forced choice paradigm where the subject had to indicate whether the stimulus was present in the first or second presentation for contrast detection, or whether curvature was present in the first or second stimulus for the curvature amplitude measurements. The results show that, when the visibility is individually adjusted, there is no difference between first and second-order class stimuli for this type of task. This suggests that the mechanisms involved in detecting curvature in periodic line stimuli are common for both first and second-order processing mechanisms and probably minimally solicit oriented receptive fields which would make this processing analogous to a Vernier alignment hyperacuity type task.

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466 Neural Curvature Mechanisms for Shape Perception

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Introduction. Curvature encoding serves as an intermediate step towards the neural representation of shapes and object parts (Loffler, Wilson & Wilkinson, 2003, Vision Research; Wilkinson, Wilson & Habak, 1998, Vision Research). We compared the performance of several curvature-encoding schemes (inspired by computational, physiological, and

psychophysical considerations) with respect to natural constraints imposed by shape perception tasks.

Methods. Using an image filtering approach, we evaluate the response properties of different curvature encoding schemes, with respect to (1) object size variability for size constancy, (2) curvature amplitude, (3) response noise away from regions of stimulus curvature, and (4) 1st order to 2nd order contour alignment for application to texture edges or 2nd order contours.

Results. Results indicate that: (1) to combine successive edge elements, an 'AND' operator is preferable to a linear sum filter to reduce neural noise away from loci of maximum curvature, (2) filter properties need to be adjusted to object size otherwise systematic distortions in the locations of response maxima may occur, (3) introducing orientation-selectivity to the inputs to the curvature mechanism only modestly sharpens curvature responses in well-defined isolated contours, and (4) opponent-curvature mechanisms have greater spatial- and curvature-selectivity.

Discussion. By developing an understanding of success and failures of different mechanisms, we isolated the requirements of neural curvature mechanisms. We provide important constraints on the design of biologically plausible curvature filters for use in object processing models. We also discuss a fast method of implementing position-dependent curvature mechanisms that can be used to recover curvature responses independent of object size.

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467 The Role of Local Position in the Detection of Contour Curvature

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Aim. Several models of curvature detection assume that curvature is detected by mechanisms that compare local luminance-defined orientations along the contour. Here, we tested the alternative notion that the inputs to curvature detection mechanisms are local contour positions.

Method. Contours consisted of strings of oriented Gabor elements with various curvature frequencies. The curvature of the contour could be defined in terms of Gabor position, Gabor orientation, or both. In the position-only condition Gabor orientation was constant, and in the orientation-only condition the Gabor positions formed a straight line. In a 2-IFC procedure subjects were to determine which of two contours was curved. Threshold curvature amplitudes were determined for each of the three conditions. **Results.** Curvature amplitude thresholds were similar for the position-only and position-and-orientation conditions. However, thresholds were elevated for the orientation-only condition, especially at low curvature frequencies. **Conclusion.** Our results suggest that the inputs to contour curvature mechanisms are the positions of local contrast-energy along the contour, with little or no input from luminance-defined orientations, particularly at low curvature frequencies.

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468 Changes in orientation and position do not affect angle discrimination: shape does

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Introduction: We have previously provided evidence that angles are encoded as part of a global shape and not simply as a difference of local line orientations: discrimination thresholds for angles embedded in isosceles triangles are 2.5 times lower than for those in scalene triangles. Since the shape of the object affects performance, we aimed to ascertain if angle discrimination in the fronto-parallel plane shows the same pattern as

'mental rotation' matching tasks, where performance is impaired when the shapes to be matched differ in orientation.

Methods: We measured angle discrimination in a 2AFC paradigm using triangles in four different configurations: 1) No transformation: both stimuli presented at the same location (38 eccentricity) and with the same orientation. 2) Rotation: same location but 90° difference in orientations. 3) Translation: same orientation but different (68 difference) locations. 4) Rotation and translation combined. The triangles (isosceles or scalene) were outlined or defined by a dot at the location of each corner.

Results: 1) Parafoveal angle discrimination thresholds are 30% higher than foveal. 2) Thresholds are 20% lower for isosceles triangles than scalene, compared with 2.5 times lower at zero eccentricity. 3) Thresholds are 70% lower for outlined triangles than for those defined by 3 dots. 4) Most importantly, for all four types of triangle (isosceles and scalene, outlined or dots), discrimination is unaffected whether angles are presented at the same or different location and with the same or different orientation.

Conclusions: The results show no cost to angle discrimination when shapes are rotated or translated. This is consistent with mechanisms that encode angles depending on the shape of the object, but independently of the orientation and position of the object. Our data provide no evidence for the use of 'mental transformations' in this task.

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469 Contour Shape Effects on Search Performance: Evidence for Constant Curvature Coding

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In natural scenes, physical contours are not always visible along their entire extent. Often, spatially disparate parts of the contour must be linked to establish shape. Field, Hayes, & Hess (1993) studied path-linking among separated Gabor elements and found that detection of the path depended on the spacing, orientation, and alignment of the constituent elements. Later, Yen & Finkel (1998) modeled contour integration using a grouping mechanism that considered interactions among pairs of oriented units. Effects of higher-order relations, such as curvature polarity, have also been found (Pettet, 1999).

We hypothesized that neural circuits involved with shape representation might facilitate detection, via reduction of target uncertainty. Specifically, we conjectured that oriented segments related by constant curvature play a role in shape representation and thereby produce certain efficiencies in detection.

We report three experiments using a modified version of the paradigm developed by Field, et al. (1993). The results show that detection of a path defined by four oriented elements was enhanced if the orientations of the elements were constrained to lie along a path of constant curvature. This result cannot be explained by pairwise interactions among oriented units and suggests sensitivity to properties more specific than that demonstrated for consistent curvature polarity reported earlier (Pettet, 1999). We also found performance differences between constant curvature as compared to varying turn-angle targets in a priming / detection paradigm.

Taken together, these experiments suggest an interaction between neural shape representation mechanisms utilizing constant curvature, contour interpolation, and search and detection performance. We simulated these results using a modified version of the model developed by Yen & Finkel (1998) that incorporates higher-order interactions among oriented units, providing added salience to constant curvature contours.

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470 Manipulating contour smoothness: Evidence that the association-field model underlies contour integration in the periphery

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Field et al. (1993) proposed that an association field model underlies performance in path-paradigm tasks. The association field integrates dynamically the outputs of filters with different orientation preferences. In the current study, simulations examined whether path-paradigm tasks could be solved by a simple-filter model (SFM) which posits that 2AFC decisions are based upon the maximum length of zero-bounded regions after convolution of stimuli with elongated filters. For the SFM, integration only occurs between the outputs of co-oriented filters. In contrast to Hess and Dakin (1999), initial simulations found that manipulations of Gabor patch phase were an inadequate control for the contribution of the SFM towards path-paradigm performance. In a further simulation, the angular difference between neighbouring elements was held constant, while the global smoothness of contours was varied. The SFM favoured jagged contours and was relatively impaired in the detection of smoother contours. Conversely, human observers favoured smoother contours in the fovea and parafovea (13?). Whilst the SFM could account for the detection of jagged and randomly structured contours, it is inadequate as an account of the detection of smooth contours. Consequently, the association field may provide a parsimonious account of contour integration across the whole visual field.

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471 Testing the limits of good continuation: does human vision extrapolate rate of change of curvature?

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In recent work, we showed that (1) the visual system systematically takes into account the curvature of an inducing contour when extrapolating its shape behind an occluder, and (2) extrapolation shape is characterized by a systematic decay in curvature with increasing distance from the point of occlusion (Singh & Fulvio, PNAS 2005).

The current study investigated whether the visual system also extrapolates rate of change of curvature. We used arcs of Euler spirals as inducing contours -- defined by a linear dependence of curvature on arc length: $\kappa(s) = \kappa + \gamma s$. Five values of γ were used: 2 negative (decreasing curvature), zero (constant curvature), and 2 positive (increasing curvature). The inducing contour disappeared behind a half-disk occluder, at the center of its straight edge. Observers adjusted both the position and orientation of a short line probe around the curved portion of the half disk in order to extrapolate the inducing contour's shape. Measurements were taken at 6 distances from the point of occlusion.

For each inducer's extrapolation data, we computed the best-fitting parameters of an Euler-spiral model. The maximum-likelihood estimates for extrapolation γ exhibited no systematic dependence on inducer γ . Moreover, the γ estimates were consistently negative, i.e., extrapolated contours had decreasing curvature irrespective of whether the inducer curvature was increasing or decreasing. These results indicate that the visual system does not extrapolate rate of change of curvature. In addition, estimated extrapolation κ was inversely related to inducer γ : Extrapolation curvature was higher for inducing contours with negative γ (hence higher mean curvature). The results provide further support for a Bayesian model in which extrapolation shape derives from an interaction between (a) a likelihood tendency to continue estimated curvature, and (b) a prior tendency to minimize total curvature (Singh & Fulvio, 2005). Rate of change of curvature does not play a role.

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472 Closed-contour shapes encoded through deviations from circularity in lateral-occipital complex (loc): an fmri study

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PURPOSE: Exceptional human sensitivity to small deviations from circularity in closed contours has been well demonstrated psychophysically. Here we used fMRI to test whether circularity holds a special status in the neural coding of closed-contour shapes. **METHODS:** BOLD signals were recorded from 5 participants in 13 6-mm coronal slices with the most posterior slice anchored on the occipital pole. A region-of-interest analysis isolated the lateral-occipital complex (LOC) by contrasting BOLD signals from images of intact vs. scrambled tools. In key experiments, observers viewed closed contours that varied in basic shape (i.e. radial frequency) and deviation from circularity (i.e. radial amplitude). Experiments followed a block design where deviation from circularity was varied across blocks, and basic shape was either varied within block (multi-shape blocks) or held fixed (single-shape blocks). Observers performed size judgments to maintain attention. **RESULTS:** BOLD response in LOC for multi-shape blocks was lowest for pure circles and increased monotonically with deviation from circularity. Single-shape blocks showed similar results. Response in striate and extrastriate areas remained approximately constant across all conditions. **CONCLUSIONS:** Results are consistent with neural representations of closed-contour shapes that are centered on circular prototypes, and data suggest that prototype deviations constitute the basis of increased neural activity. Lack of circle-selective responses in striate and extrastriate areas suggests that LOC activity reflects active shape integration rather than passive inheritance from lower-level areas. Encoding prototype deviations is an efficient strategy and is likely a recurring theme throughout the visual hierarchy.

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473 Contour Integration and Hyperacuity in Children with Dyslexia

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Children with dyslexia have reading deficits that may have a phonological, auditory or visual basis. Most studies of vision in dyslexia have examined disturbances in eye movements, in the latency of visual responses, or tasks that emphasize pattern detection, such as contrast sensitivity. We hypothesized that tests of visual discrimination and perceptual organization may identify visual deficits in dyslexia, since these tests tap the abilities needed to identify letters and words. We measured hyperacuity and contour integration in 92 children aged 6.5 to 16.5 years, 38 of whom were identified as dyslexic. Each child was administered two standardized tests designed to identify children at risk for dyslexia: the Dyslexia Screening Test and the Word Attack subtest of the Woodcock Johnson Reading Mastery Test. We then used visual evoked potentials (VEPs) to measure vernier acuity and contour integration thresholds. Vernier acuity was measured by sweeping the size of offsets embedded in square wave vertical gratings. Offsets appeared and disappeared at a fixed rate of 5 Hz. Contour thresholds were measured by sweeping the spacing of randomly oriented background Gabor elements that surrounded a closed circular contour formed by collinear Gabor elements. The contour appeared and disappeared as the target Gabor elements changed orientation (from noncollinear to collinear) at a rate of 3.6 Hz while the background Gabor elements modulated at rate of 3.2 Hz. Vernier acuity and contour integration both undergo some development in the age range that we tested. We did not find mean threshold differences between dyslexics and non-dyslexics when the dyslexics were considered as one group. However, a subgroup of older dyslexics (age 12-16), ironically those who were relatively faster readers according to one standardized test, had significantly poorer vernier acuity, compared to

other dyslexics and to controls. This subgroup was not distinguished in the contour threshold data.

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474 Can 6-Month-Old Infants Integrate Individual Elements to Discriminate Contours?

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Purpose. Research has suggested that children's ability to perform contour integration of individual elements in the presence of stimulus noise develops slowly (K ldy & Kov cs, 2003; Kov cs, 2000). A recent study with 3-month-old infants has demonstrated an immaturity in their contour integration mechanisms (Gerhardstein et al., 2004). The goal of this study was to further investigate the developmental trend in infants' ability to integrate individual elements into whole contours. **Method.** Six-month-olds' discrimination of differently shaped contours was tested via a cueing paradigm in which a circle or square contour, defined by the alignment of oriented Gabor patches, embedded in background noise of randomly oriented Gabor patches, served as a cue for the subsequent presentation of a target on either the right or left. The relation of the contour to background noise called the noise density and defined as the ratio of average noise spacing over contour spacing was set to 1.0. Eye movements were analyzed for correct anticipatory eye movements to the targets in response to which face cue had been presented. **Results.** Preliminary data indicated that the infants anticipated on 40.1% of trials and 58.1% of those were to the correct target. This percent correct approached but was not significant ($p = .0823$). Thus, infants were anticipating the targets at chance level, suggesting that they were unable to discriminate the circle and square contours. **Conclusions.** These data suggest that 6-month-olds' ability for contour integration is not yet mature enough to support discrimination of different shaped contours. Additional data will be collected to examine the effect of noise density level and whether discrimination is possible when no background noise is present. Regardless, the current findings are consistent with the relatively slow maturation of contour integration ability and the underlying neural mechanisms.

Spatial Vision 2

475 A theoretical framework for texture parameterization

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It is well known that textures with sufficiently distinct power spectra are perceptually distinct, and that some higher-order spatial correlations also support texture discrimination and segmentation. However, a concise parameterization of the correlation structure relevant to perception is as yet elusive. We attempt to bring together a range of psychophysical and analytical results to suggest a minimal structure for the perceptual space of textures.

The motivation for the present approach is that the visual system is likely to represent image statistics in a manner that is efficient, but perhaps not comprehensive. We hypothesize that any texture is perceptually equivalent to a texture for which all statistics of all orders can be reconstructed from a small subset of image statistics. A natural formalization of this reconstruction is maximum entropy extension (Zhu et al., 1998).

Filtered Gaussian noises can always be set in this framework, consistent with the notion that second-order statistics typically support texture discrimination. For textures defined by high-order correlations extended

along one dimension, discriminability appears to be based on induced differences in the luminance histogram of multichannel blocks, or induced long-range second-order statistics. In two dimensions, the simplest scenario is that of binary textures in 2x2 blocks. Only a small subset of assignments of block probabilities allows for maximum entropy extension. Two of these correspond to previously-recognized families of binary isodipole textures, but other components of this subset correspond to as-yet unrecognized isodipole textures that are highly discriminable. These observations suggest that perceptual texture space is usefully parameterized by maximum-entropy extension of pixel histogram and second-order statistics at many scales, and fourth-order statistics restricted to two-dimensional nearest-neighbor cliques. Predictions and shortcomings of this view will be discussed.

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476 Modelling texture discrimination asymmetries using quadratic forms of random variables

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Purpose: Rubenstein and Sagi (1990, JOSA) argued that local variability within textures makes an important contribution to texture discrimination asymmetries and modelled their results using Signal Detection Theory (SDT). We asked whether differences in orientation variability alone would produce discrimination asymmetries, and modelled our results using distributions of quadratic forms of random variables.

Method: The stimulus comprised four quadrants of 8x8 lines (256 items per display). Each quadrant contained lines drawn from one or two distributions. Both distributions had a mean of 0 deg. (vertical). One distribution (fixed) had a standard deviation of 2 deg. and the other (variable) had a standard deviation varying from two to six deg. in seven equal logarithmic steps. In one condition the target quadrant comprised 32 lines drawn from the fixed distribution and 32 drawn from the variable distribution. The lines in the remaining three quadrants were drawn from the fixed distribution. In the second condition the reverse was true (one fixed quadrant in three variable quadrants). Three participants performed a 4AFC in which they were to indicate the different quadrant. Accuracy was measured as a function of the variability difference between target and background textures in the two conditions.

Results: Threshold was defined as the standard deviation that elicited 72% correct responses. All subjects showed a lower threshold for the quadrant with two distributions, i.e. a higher variability signal in a low variability background was more salient than a low variability signal in a high variability background. An SDT model constructed from distributions of quadratic forms was found to be in qualitative agreement with the empirical data.

Conclusion: Differences in orientation variability alone are sufficient to produce a texture discrimination asymmetry. Quadratic forms in random variables provide a useful representational tool for modelling decision processes.

477 Modeling lateral interaction in fine spatial discriminations: The plot thickens

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A patterned annulus that fails to activate a cell on its own may reduce activity when the cell is excited by a center patterned disc. Most models assume lateral interactions among low-level mechanisms (pooled gain control) are responsible, and psychophysical models further assume that the interactions are reciprocal between center and surround. To complicate these simple models, there is some physiological evidence that the apparent size of a cell's excitatory zone is not fixed; it appears to decrease with increasing contrast. Here, we a) tested the reciprocity assumption for

fine spatial discriminations and b) psychophysically measured summation areas at three contrast levels. In both experiments, observers discriminated between two highly similar grating patches (4 cpd) in each block of eighty trials. Half discriminated on the basis of orientation; half on spatial frequency. Each condition of each experiment was run in a separate session, using a signal detection rating paradigm, and was replicated five times following extensive practice and individual determination of 'threshold' ($d' = 1.5$). In the reciprocity experiments, observers made decisions either on a center circular patch of grating with and without an annular masking surround or on an annular surround ring with and without a center masking disk. Four test/mask size ratios and six contrasts were used. In the summation experiment, discrimination performance was measured for center discs alone as a function of size (5 levels) and contrast (3 levels). We confirmed that summation areas decreased with increasing contrast when measured psychophysically. Furthermore, interactions were not reciprocal. Surrounds masked centers, but centers had no effect on surrounds. These results imply that current psychophysical models of lateral interactions are too simple, and that mechanisms of figure-ground organization may play in role in mediating these lateral interactions.

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478 Noise does not shrink the summation region for grating detection

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Detection of low-contrast luminance-defined stimuli can involve spatial summation over a large portion of the visual field. For example, contrast thresholds for grating detection decrease as a function of the width of the grating, up to a width of about 8-10 cycles. There is evidence, however, that high levels of stimulus noise may shut down long-range spatial pooling. Kersten (1984), for example, found that contrast thresholds for grating detection in noise bottomed out for gratings only one cycle in width. Here we use a classification image technique to directly test for variations in the extent of spatial summation as a function of noise contrast. Stimuli were large (26 deg) vertical gratings. Classification images for grating detection were estimated at grating frequencies of 0.5 and 1.7 cpd and noise contrasts ranging from 4%-50%. Classification images were fit with a 4-parameter Gabor model tuned to the frequency and phase of the signal. In all conditions, the estimated summation fields extended over many cycles of the stimulus. No systematic variation in the extent of summation as a function of noise contrast was observed. Linear and nonlinear pooling models were evaluated in terms of trial-by-trial consistency with the human data. In general, probability summation over localized responses of broadband (1.7 octave) detectors was found to better predict human judgements than a purely linear model. Our results suggest that the extent of spatial summation for grating detection is relatively unaffected by high contrast stimulus noise. We speculate that Kersten's previous results may be explained by an increase in spatial uncertainty with stimulus size.

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479 Paradoxical, Quasi-Ideal, Spatial Summation in the Modelfest Data

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The Spatial-Modelfest dataset consists of detection thresholds (defined at $d' = 1.4$) and standard errors for 43 diverse static stimuli on 16 observers. 22 of the stimuli were single Gabor patches of diverse spatial frequencies, sizes and aspect ratios. The variability across the 16 observers was surprisingly small. The rms Weber fraction SE for the 16 stimuli between 1 and 15 c/deg was less than 5.5%, placing strong constraints on models of

spatial vision. Here we present two of the surprises revealed by fitting the Modelfest data with a simple area summation model.

1) The seven 4 c/deg Gabor thresholds (with rms Weber SE=4.6% across observers) were well fit (chi square=7.9, df=5) by a straight line (log threshold vs log stimulus area) with a Minkowski pooling exponent of $p = 2.24 \pm 0.12$. This relatively low exponent is close to 2, the ideal observer prediction. The low value of p is not compatible with the measured d' function exponent of $b > 1.5$ (where $d' = c^b$), since Pythagorean d' summation would predict $p = 2b > 3$. The strong spatial summation may be due to a combination of defining threshold at a high level ($d' = 1.4$) plus a two-limbed d' function with an exponent of $b = 2$ near zero contrast dropping to a unity log-log slope ($b = 1$) above threshold (as is characteristic of a Weibull function). Our high d' would have an effective d' exponent close to 1, accounting for the strong spatial summation.

2) When the fitted data is expanded to the full set of Gabor stimuli a different picture emerges. The 22 Gabor thresholds were fit with 7 parameters: a 5 parameter full-field CSF, a Minkowski spatial pooling exponent, and an aspect ratio parameter (tiger tail Gabors being slightly less visible than baguette Gabors). The fit is remarkably good (chi square = 13.9, df=15) considering that the SEs are so small. The Minkowski pooling exponent is $p = 2.61 \pm 0.07$. The discrepancy with the value of $p = 2.24$ for the 4 c/deg data may indicate a limit to the efficiency of spatial summation as the number of cycles gets large.

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480 Psychophysical Inferences About the Interactions Within and Between Sub-Populations of Striate Neurons

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Typical psychophysical methods for evaluating human visual processing of spatial scale and orientation (at the striate cortex level) involve measuring threshold sensitivity for single sinusoidal gratings of different spatial frequencies (SFs) and/or orientations (Os). However, in the natural environment, the visual system typically processes spatial content that is broadband (energy at many SFs and Os) and is well above threshold. Thus, while such methods provide useful inferences regarding the sensitivity of small sub-populations of striate cortical cells at threshold, they do not provide information about how those sub-populations interact when presented high-contrast, broadband content. We therefore sought to investigate human visual processing of high-contrast broadband spatial structure at different Os with two 16-condition suprathreshold matching experiments. The tasks required participants to match the perceived strength of different amounts of oriented structure alone, or embedded in $1/f$ visual noise, to that of a standard stimulus. Stimuli were generated from broadband isotropic $1/f$ noise patterns by filtering their amplitude spectra to contain a test increment across a specified range of Os and SFs. The test increment's O and SF bandwidth was systematically varied from a single SF (16cpd) to a broadband (many Os and SFs) increment. Results showed the traditional oblique effect (worse sensitivity at the obliques) when a small range of Os and high SFs were incremented. A horizontal effect (worst sensitivity at horizontal and best at the obliques) was observed for broadband increments of $\sim 20^\circ$ in orientation and 1-octave in frequency and larger. The current results are the first of a series of experiments designed to assess the extent of the interactions within and between different sub-populations of neurons in striate cortex in order to devise a striate normalization model to provide insight into visual processing of naturalistic content.

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481 A Statistics Toolbox for Classification Images

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Despite an obvious demand for a statistical test adapted to classification images, none has been proposed yet. The Stat4Ci Matlab toolbox (<http://mapageweb.umontreal.ca/gosselif/Stat4Ci.html>) performs all the computations necessary for the application, to classification images, of the Pixel and Cluster tests, both based on Random Field Theory (Adler, 1981; Worsley, 1994, 1995, 1996). These tests are easy to apply, requiring a mere three pieces of information. Furthermore, they are sensitive, producing *p*-values and thresholds usually much lower than those produced by the standard Bonferroni correction. The Stat4Ci toolbox comprises ReadCi.m that reads Classification Image Data at the individual trial level (in CID format); BuildCi.m that performs least-square multiple linear regression on this data; hrCi2clm.m that transforms a 24 bits classification image into a color image, for storage; clm2hrCi.m that does the opposite; SmoothCi.m that convolves a classification image with a Gaussian filter; ZTransCi.m that Z-transforms a smoothed classification image; CiVol that calculates a vector of spherical intrinsic volumes for the search region in the classification image; HalfMax.m that computes the FWHM of the Gaussian filter used to smooth the classification image; stat_threshold.m that applies the Pixel and Cluster tests on a Z-transformed and smoothed classification image; and DisplayCi.m that displays the statistically thresholded classification image and outputs a summary table. We illustrate the workings of the Stat4Ci toolbox on a set of representative classification images from Gosselin and Schyns (2001), Sekuler, Gaspar, Gold and Bennett (2004), and Adolphs, Gosselin, Buchanan, Tranel, Schyns and Damasio (2004).

482 Spatiotemporal templates for detecting 1st- and 2nd-order orientation- and luminance-defined targets

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Using the classification image technique, the present experiments revealed several characteristics of human observers' spatiotemporal templates for the detection of texture-defined targets. The stimulus consisted of a five frame (each frame: 80 ms) movie of a five by five spatial array of elements (whole size: 1.6 x 1.6 deg). The target was defined by the first-and the second-order characteristics of orientation- and luminance-defined textures and observers were required to respond whether a target or non-target was presented on each trial. When a target signal was presented across all five frames, human observers typically relied on the most reasonable cues in all five frames for detecting targets. In other words, they used the first-order cue for detecting the first-order target and used the second-order cue for detecting the second-order target. When the target signal was presented just during the third temporal frame, the temporal profile of the observers' spatiotemporal templates changed, so that only information presented near the third temporal frame was used. In addition, the type of spatial cue utilized also changed, so that for first-order target detection observers used second-order cues as well as first-order cues. This strategy was sensible, because both first- and second-order cues were available in this condition. There also was a trend toward increasing the extent of spatial information used when the temporal information was restricted, perhaps indicating that there is a space-time tradeoff in the information that can be used in these tasks.

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483 Noise detection: summation of high spatial frequency information

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Previous work (Kersten, 1987; Taylor et al., 2003) has shown that the summation of spatial frequency information in one-dimensional noise patterns is well described by an ideal observer, suggesting that human observers may sum spatial frequency information optimally over a six-octave wide band. This result is surprising, given that many models of vision contain independent channels that only sum probabilistically (Graham, 1989). However, the previous studies used a restricted set of conditions; specifically, the center frequency was at or near the peak of the CSF. To further test the idea of optimal summation, we had observers perform a detection task with band-pass Gaussian white noise centered at 15 cycles/degree. Spatial frequency bandwidth varied from one-half to four octaves. Stimuli were presented for 200ms in a two interval forced-choice task. Unlike what was found for noises centered at 5 cycles/degree, we found that detection thresholds were not consistent with ideal frequency summation. Hence, the ideal frequency summation reported previously does not generalize to other bands of spatial frequency. Currently we are using the response classification technique to reveal the perceptual template for the detection of these patterns. We will discuss how the frequency summation data can be explained using a standard multiple-channel model (Wilson & Gelb, 1984).

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484 Different Internal Noise but same Calculation Efficiency for Processing Luminance-modulated (LM) and Contrast-modulated (CM) Stimuli

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Introduction: We are generally less sensitive to CM than LM stimuli. Therefore, CM stimuli are typically considered more complex than LM stimuli. Why are we less sensitive to CM stimuli when an ideal observer is not? Based on known theoretical formulations, measuring the sensitivity of a stimulus in different noise conditions permits to indirectly evaluate the subject's internal equivalent noise and calculation efficiency for perceptual processing of that stimulus. The purpose of the study was to compare internal equivalent noise and calculation efficiency for LM and CM stimuli processing in order to identify the level where the perceptual processing differs. Methods: Both LM and CM stimuli were composed of a 1 cycle/deg sinusoidal signal and a plaids (two perpendicular 8 cycles/deg sinusoidal gratings). The luminance profiles of the LM and CM stimuli were given by the sum and multiplication, respectively, of these two components. The detection thresholds of five young subjects were evaluated for both types of stimulus in three different noise conditions. A regression analysis was performed on the data to derive each subject's internal equivalent noise and calculation efficiency for LM and CM stimuli perception. Results: The internal equivalent noise was greater for CM than LM perceptual processing. However, the calculation efficiencies were not significantly different. Conclusion: The present study suggests that a relatively low-level processing difference between the detection of LM and CM stimuli explains the lower CM sensitivity. A model was proposed where a second-order rectification process would be sub-optimal and where higher-level perceptual mechanisms would be common for both LM and CM stimuli processing.

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485 Modeling the detection of blurred visual targets in non-homogeneous backgrounds

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Detection models work well for targets on uniform or homogeneous backgrounds. How well do they work for the detection of airframe cracks in their natural setting by actual inspectors? How well do they predict the performance when the images are blurred? We measured crack detection performance for 7 experienced inspectors and 2 non-inspectors. Signal images were formed by subtracting a crack-removed image from the original image. An attenuated-crack image at a desired contrast level was generated by attenuating the difference image and adding it back to the crack-removed image. The visual resolution was 30 pixels per deg. The display background screen had a luminance of 40 cd/m². The images were Gaussian blurred with spreads of 0, 1.1, 1.7, and 2.3 arc min. Contrast attenuation thresholds were obtained using a 2IFC staircase. The crack-removed image remained on for the duration of a block of trials. At least 3 replications were obtained. Attenuation thresholds for 75% correct were estimated by probit analysis. Two measures of contrast energy were computed, the visible contrast energy in the signal and that energy attenuated by local visible contrast energy (gain-control masking). Local contrast was computed from a local luminance image computed by blurring the luminance image with the surround of a DoG CSF. The same 8 min spread was used to compute an average local masking energy image. The visible energy of the un-blurred signals correlated well with the average contrast thresholds over the 15 cracks ($r=-0.89$), and including masking raised the correlation ($r=-0.95$). Blur raised the thresholds much more than the loss in visible contrast energy. For the images with the greatest loss in visible contrast energy (4.7 dB) at the 1.7 min blur, the average threshold loss was 10 dB. This 5.3 dB discrepancy may result from a lack of experience with blur, or the blur may affect higher order processes such as edge extraction.

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<http://cogsci.bme.hu/>

486 Modulation of the decision criterion by collinear lateral facilitation

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The increased contrast sensitivity for targets placed between collinear flankers is modeled as target's excitation mediated by lateral interactions. The interactions are thought to underlie filling in along contours. Here we probe the filling in process by measuring false-alarm (FA) rates in such a detection task, taking advantage of results showing observers inability to adjust FA to a particular, identifiable, stimulus in experimental conditions where the different stimuli are mixed (Sagi & Gorea, VSS 2004). We measured d' and zFA for a Gabor target (9 cpd) using YES-NO paradigm and compared FA rates across target-flankers separations of 3,4,6,9 and 12' (wavelength). The target contrast was fixed. Two sets of experiments were used; in the first, each separation was measured in a fixed block (Fix) of 50 trials for each separation; in the second experiment all separations were randomly mixed in a single block of trials (Mix). At least 400 trials per datum point were measured with 7 observers. In the Mix condition the criteria were found to vary according to the separation, the probability of reporting target present (FA and Hit) was very high at the shorter separations (3,4') and decreased with increasing separation. With larger separations (9,12') there was a bias toward No response (Miss and Correct Rejection). On the average, across the different separations, the Yes and No reports were balanced, showing no significant response bias. d' behaved as expected from previous 2AFC measurements. The results show that subjects can not optimize their performance in the Mix condition despite having exact knowledge of the stimulus parameters

(separation), rather they seem to equate the global FA and Miss rates by reducing the FA at large separations to compensate for the high FA at the small separations. The high FA rate with small target-mask separations in the Mix condition, suggests that the target location is being 'filled in' by lateral excitation from the flankers.

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487 Adaptation to astigmatic lens: effects on lateral interactions

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The visual system is capable of adapting to optical distortions caused by the eyes optics or by added lenses. Astigmatism is an optical error that distorts the visual input along one axis of the visual image due to the cylindrical shape of the lens (which is spherical in the standard eye). Here we ask if adaptation to cylindrically distorted visual inputs given to one eye affects spatial interactions. Subjects wore on one eye a cylindrical lens of +1.00 D, to create an optical distortion which changed the perceived sharpness along one direction and thus the directionality of the perceived pattern. The other eye was covered with translucent lens. Adaptation was tested using two sets of experiments: 1) A 10x10 dot matrix served as a target for testing grouping by proximity. Observers were asked to distinguish between horizontal and vertical groupings without feedback. Perceived grouping before, after, and throughout the adaptation period was measured. 2) Lateral interactions between a target Gabor Patch (GP) and two collinear GPs that improve detection at target-flankers separations of 2,3,4 and 6' (wavelength). Initially, perceived proximity with the lens (N=6 Obs) showed a bias in accordance with the distortion axes. After 4 hours, observers' bias was reduced (adaptation). These results carried over to the next day when the lens was re-applied. A persisting opposite bias was observed without the lens after adaptation. Lateral facilitation at 2,3' was observed with the lens when initially applied, but disappeared after 4 hours, with and without the lens, an effect that persisted to the next day. The results suggest that visual adaptation to astigmatic lens involves long term plasticity in the visual system. Both the geometrical recalibration, that corrects for spatial distortions, and the change in spatial interactions seem to involve obligatory processing stages, most likely at early stages of visual processing.

488 Symmetry perception: a high-density ERP approach

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Symmetry is a salient characteristic of visual stimuli that may be used to detect and recognize many natural and manufactured objects. Psychophysical studies have demonstrated that we are extremely fast and efficient at extracting symmetry, but the neural mechanisms underlying symmetry processing remain largely unknown. In one of very few ERP studies, Norcia et al. (JOV 2002) examined the time course of symmetry processing. In their experiment, observers were presented with symmetric and random dot patterns alternating every 500 ms. ERPs measured with symmetric-random sequences diverged from control random-random sequences between 130 and 220 ms after stimulus onset. However, it is not clear whether this response difference was due to symmetry per se or to the presence of structure in the symmetric dot patterns. We tested this possible confound by adding textured dot patterns (Glass patterns), which were asymmetric yet clearly distinguishable from random dot patterns, to the same experimental design. EEG was recorded from 256 electrodes while observers passively viewed alternating random-texture, random-symmetric, and random-random stimuli. Our preliminary results replicate and extend the findings of Norcia et al.: ERPs to structured dot textures

were very similar to those evoked by random dots, and both begin to differ from ERPs to symmetric dots at about 160-170 ms after stimulus onset. We note that the onset of the symmetry effect is relatively late compared to the time course of object processing as described in the ERP literature. To further investigate this issue we will conduct another experiment in which observers actively discriminate between symmetric and non-symmetric patterns. This will allow us to relate the behavioral RTs with the onset of the symmetry ERP effects. Source analyses on individual subjects will also be conducted.

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489 Identification of Luminance and Contrast Modulation Signatures in the Steady-State Visual Evoked Potential

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Shapiro and colleagues (2004; <http://www.journalofvision.org/4/6/5/>) recently reported a class of visual effects that demonstrate a perceptual separation between a luminance response (1st order) and a contrast response (2nd order). The basic version of the effect consists of two identical patches whose luminances are modulated sinusoidally in time. One patch is surrounded by a dark annulus, and the other by a light annulus. Thus, the 1st-order luminance information in the two patches modulates in phase while the 2nd-order contrast information modulates in antiphase. At 1 Hz, observers track both the 1st- and 2nd-order information, creating the paradoxical impression that the disks modulate in antiphase but become light and dark at the same time. At 3 Hz, the 2nd-order information dominates, so that the patches appear to modulate in antiphase. In addition, a disk surrounded by mid-gray appears to modulate faster than a disk surrounded by black or white, indicating the presence of a rectified 2nd-order visual response. In the present study, we used steady-state visual evoked potentials (SSVEPs) to explore the electrophysiological correlates of an analogous effect. We presented observers with a circular patch (6 degrees in diameter, centered at the point of fixation) that modulated in luminance at 3.2 Hz. The patch was surrounded by an annulus (12 degrees in diameter) that did not modulate. When the annulus was light or dark, the 1st- and 2nd-order information modulated at 3.2 Hz, but when the patch was mid-luminance (gray), the rectified 2nd-order information modulated at 6.4 Hz. SSVEPs recorded from occipital electrodes revealed a strong signal at 3.2 Hz - corresponding to the 1st-order modulation signal - for all three conditions. The SSVEP power at the second harmonic (6.4 Hz) was higher for the mid-luminance annulus than for the light or dark annulus. These results indicate that visual response to 1st- and 2nd-order information can be identified in the VEP.

Talk Sessions

May 8, 2005 – Sunday PM

Motion: Cortical Mechanisms (490-496), Perceptual Organization (497-503)

Motion: Cortical Mechanisms

3:45 - 5:30 pm

Hyatt North Hall

Moderator: J. Anthony Movshon

490 Retinotopic mapping of motion stimuli in human visual cortex

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When a stationary window is filled with a moving texture, the whole window may appear to be displaced in the motion direction (DeValois & DeValois, Vision Res 1991). Curiously, Whitney et al. (Science 2003) found that activation in the visual cortex measured by fMRI shows an opposite shift. But their claim that the retinotopic organization itself is flexible remains controversial because they did not directly compare the spatial activation profiles for motion in the two directions. We presented an annular window with hard edges, in which a concentric sinusoidal grating drifted inward or outward, and measured the fMRI BOLD responses in the occipital lobe of human participants at 3T. A block design was used: inward and outward blocks were interspersed with blocks in which there was no stimulus. For each direction of motion, the difference in activation between motion and blank blocks was mapped onto a cortical flat-map. The representation of stimulus polar angle and eccentricity within each of the first three visual areas was also mapped, using conventional retinotopic mapping procedures conducted in separate scans. The magnitude of cortical activation was then plotted as a function of eccentricity, separately for V1, V2 and V3. Although we replicated the result that activation is stronger near the trailing edge of the moving stimulus than the leading edge, the difference was small and significant shift of the overall spatial distribution was not observed. Instead, the spatial profile of the activation pattern was skewed by motion such that the activation near the trailing edge was enhanced. There was no substantial difference among the visual areas assessed. Gabor stimuli with smooth edges, as used by Whitney et al, yielded very similar results. We confirm that activity in the early visual areas does not explain the perceived shift of stimulus location, but show that retinotopic organization does not change with direction of visual motion.

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491 Global Form and Global Motion: Which Develops First in Infancy? VERP Evidence

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Sensitivity to global form and to global motion are dissociable measures of processing in the ventral and dorsal cortical streams, in adults and in developmental disorders. How do these two forms of processing develop in infancy? Changes in contour orientation elicit visual event-related potentials (VERP) earlier in development than do reversals of motion direction (Atkinson, ARVO 2002); however, both these responses may arise from purely local mechanisms. Here we tested infants aged 8-16 weeks, and adults, for VERPs dependent on global processing. In both form and motion stimuli, a display containing a region of concentrically organized elements alternated at 1-2 Hz with a display of similar, randomly oriented, elements. For the global form test, the elements were short arc segments; for global motion they were dots moving along short trajectories forming similar arcs. In each case, a signal at the stimulus frequency (F1) indicates differential responses to globally coherent and incoherent displays, while a second-harmonic signal (F2) could arise from responses to local changes in orientation or direction. A large proportion of the infants show a statistically reliable F1 response to coherent motion, while few do for coherent form. Infants show a larger F1 for motion than form; this ratio declines with age and averages about 1 in adults. The ratio shows the opposite behaviour for F2, so the motion advantage is specific to global processing. This suggests a developmental advantage for global motion processing over form processing in infancy, even though local processing develops earlier for form. This result will be discussed in relation to the apparently opposite effect in middle childhood whereby dorsal stream function tends to lag behind ventral and show more vulnerability to neurodevelopmental disorders (Atkinson et al, NeuroReport, 1997; Gunn et al, NeuroReport, 2002; Braddick et al, Neuropsychologia, 2003).

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492 Common mechanisms for processing of perceived, inferred, and imagined visual motion

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Does mental imagery of motion recruit populations of direction-selective neurons that also respond to perceptual motion? We show first that imagining a moving pattern while fixating a stationary target yielded a motion aftereffect (MAE), as measured by the response to directionally ambiguous perceptual test stimuli (dynamic dot displays). In a second experiment we replicated the effect and also observed the MAE when subjects' eyes were closed during imagery. In a further set of experiments, we asked whether

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photographs of objects frozen in motion (animals, people and vehicles) could also lead to motion adaptation. When a series of unrelated photographs was viewed, all with implied motion in the same direction, an MAE in the opposite direction was induced, again measured with dynamic dot test stimuli. The MAE was found both for right / left implied motion and for in / out implied motion, the latter created by using mirror-reversed pairs of identical implied motion images either facing towards or away from each other. Similar to the perceptual MAE, the MAE to implied motion significantly declined if a delay (3 s) was introduced between adaptation and test. The MAEs to imagined and implied motion ranged from 20 - 35 % of the size of the MAE from perceived motion. The transfer of adaptation from imagined and implied motion to perception of real motion demonstrates that at least some of the same direction-selective neurons are involved in imagination and actual perception.

493 Retinotopy and its modulation by attention in higher cortical areas studied with structured motion stimuli

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Using action videos as stimuli in fMRI experiments, we have recently found retinotopic responses in parietal, temporal and even frontal cortex in the human brain. We are now interested in the nature of these responses -- e.g., whether the activity is driven primarily by the stimuli, and whether attention is necessary. We developed novel stimuli which are complex enough to drive maps in these high-level areas, but are manipulable in terms of low-level visual features and are amenable to attentional manipulation. We use moving objects defined by point-lights (primarily point-light biological motion, but also non-biologically moving, translating objects composed of point-lights) in phase-encoded polar angle mapping paradigms. These stimuli are almost as effective as video stimuli in activating multiple maps outside of visual cortex. Here we ran an experiment in which the stimuli rotated in a polar angle wedge and the background was filled either with control stimuli (scrambled motion) or identical stimuli, such that the whole visual field was stimulated at all times. Subjects either attended to the stimuli (performed a task on the polar angle stimuli) or ignored the stimuli (performed an unrelated attentionally demanding task at fovea). With control stimuli in the background, well-defined maps were found in parietal, lateral and ventral temporal cortex, and in some subjects in frontal cortex under the attend condition. Attention appears necessary for the activation of these maps, except in the vicinity of area MT/MST, where attention increased the response but strong retinotopy was seen even when the stimuli were completely ignored. Finally, even when the background contained identical stimuli as the wedge, significant retinotopy was observed in temporal, parietal and frontal cortex in the attend condition. Thus retinotopic responses are affected both by the complexity of stimuli and by attention, with attention seemingly as important as visual stimuli in evoking activity in some areas.

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494 Relative timing of center and surround signals in motion revealed by temporal reverse correlation

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Center-surround interactions are a hallmark of neural motion processing. Different neural circuitry underlies center and surround responses, thus changes in their relative latencies (e.g., by varying contrast) may affect their interactions. We approached this question using temporal reverse correlation.

A random-dot surround ($r=6\text{deg}$) moved up-down randomly (20deg/s) for 500ms. A new surround direction was chosen every 5ms (200Hz). Observers perceived this as fast jitter. Surround contrast, in different conditions, ranged from 92% to 1.7%. In the center of the surround was a small

hole ($r=0.7\text{deg}$) where, at a randomly chosen time, high-contrast center motion (20deg/s) was briefly presented. The observer's task was only to report the direction of center motion. Performance was kept near 70% by adjusting center duration (duration thresholds were low, effectively restricting center motion to ~ 3 5ms frames). 3 observers completed 10000 trials each. Temporal patterns of surround motions were classified for correct and incorrect trials, yielding curves depicting the effect of the surround on the center motion for each 5ms frame.

For all surround contrasts, surround motion impulses matching the direction of the center motion increased the probability of making a mistake, indicating surround suppression. This suppressive influence of the surround spanned about 50ms and its timing depended on surround contrast: decreasing surround contrast from 92% to 7%, shifted the peak of the surround influence 11ms backwards (decrease to 1.7% contrast resulted in a 36ms shift). That is, a low-contrast surround signal must be initiated well before the center signal in order to arrive on time to suppress center motion - a finding consistent with longer latency of low-contrast stimuli. Repeating the same study with low-contrast center motion yielded analogous results but with surround facilitation, indicating that the 'sign' of center-surround interactions depends on center contrast.

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495 Visual Motion Processing in a Direction Discrimination Task

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Discrimination of the direction of motion depends on (1) the difference in direction between the discriminanda, (2) the signal to noise ratio of the motion signal, and (3) the viewing time. An increase in any of these factors should improve performance. Here, we examined the dependence of subjects' performance on these factors by asking them to judge the direction of motion of a peripherally-located dynamic random dot field in a single-interval two-alternative forced choice experiment. The signal strength was controlled by the fraction of dots that moved coherently in the target direction; the remaining dots changed position randomly and served as an external source of noise. We tested 5 different angular differences (θ : 12, 22.5, 45, 90 and 180 degrees) and 5 different viewing times (T: 100, 200, 400, 600 and 800 ms). In a single block, we measured coherence threshold for all 5 viewing times for a given θ . For the range of values tested, coherence threshold is a monotonically decreasing function of both θ and T. The drop in performance at shorter viewing times is not compensated by a proportional increase in the signal strength, suggesting imperfect temporal integration at all values of θ . The decrease in threshold with angular difference is most pronounced for short viewing times, and suggests a loss of signal for smaller angular differences, presumably because of the overlap of the tuning curves of relevant channels. We interpret our results in the framework of a computational model of direction selective neurons, with which we account quantitatively for the roles of tuning bandwidth, spontaneous firing rate and inter-neuronal correlations in determining perceptual performance.

496 Direction selective activity in prefrontal cortex during a working memory for motion task

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While it is known that many neurons in prefrontal cortex (PFC) respond to stimulus shapes and have activity related to working memory, responses of these neurons during tasks involving visual motion has not been explored. We recorded from a region in PFC that is interconnected with motion processing area MT, during a task in which monkeys compared the direction of motion in two sequential stimuli, sample and test, separated by a memory delay. Most neurons with task-related activity clearly responded to the visual stimuli, and more than 70% did so with some degree of direction selectivity. Responses were also modulated by the coherence level of the motion stimuli. The nature of these signals suggests

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that they may arrive from area MT. Activity during the memory delay was highly dynamic and task dependent. At all times during the delay, at least 20% of neurons had activity selective for the remembered direction, and this number increased to 40% just prior to test onset. Selective delay activity was behaviorally relevant since on error trials these signals were substantially weaker, especially late in the delay. Directional signals carried by individual neurons were relatively transient and occurred at different times for different neurons, suggesting a temporally dynamic mechanism for maintaining information through time. The presence of behaviorally relevant motion signals throughout the task supports the idea of an active role for PFC neurons in working memory for visual motion.

Acknowledgment: Supported by EY11749, T32 EY07125, P30 EY01319

Perceptual Organization

3:45 - 5:30 pm

Hyatt South Hall

Moderator: Stephen Palmer

497 Non-Bayesian Contour Synthesis

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Vision science has experienced a recent surge in theories that model perceptual organization as a form of Bayesian inference. Following Helmholtz's principle of unconscious inference, an underlying assumption of such approaches is that perceptual organization is treated as the output of processes that derive the most plausible interpretation of the image data given a set of constraints (or priors). An alternative view, articulated most forcefully by the Gestalt psychologists, emphasizes the role of dynamical principles of organization to explain processes of perceptual organization. Here, I present a class of illusory contours that defy explanation in Bayesian frameworks. A class of robust illusory contours are reported which reveal that contours will form even when they play no necessary part in explaining image data. In one set of displays, a moving outline figure is occluded by a visible surface. Although the pattern of occlusion and disocclusion is fully explained by the visible surfaces in the scene, additional vivid illusory contours are formed that appear to move and deform. A series of experiments reveal that the strength of these contours is completely determined by the relative contrasts of the occluding contour terminator, and the occluding surface relative to the background. This contrast dependence demonstrates that such contours emerge from relatively low level processes that arise early in the visual processing stream. I show that these illusory contours form either in the presence of visible occluding surfaces (i.e., those generating suprathreshold values of image contrast), or when the occluding surface is specified by another illusory contour (i.e., two independent illusory contours can form simultaneously, even when either one alone would fully explain the image data). It is argued that these phenomena challenge the explanatory power of Bayesian models of contour synthesis, and perception more generally.

498 Local and global features in Glass patterns are processed in different brain areas

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Purpose. A Glass pattern consists of randomly distributed dot pairs (dipoles) whose orientations are determined by a geometric transform. To perceive the structure in a Glass pattern, an observer needs to perform local grouping to find dipoles and global grouping across dipoles to get an overall shape. We investigated cortical mechanisms for local and global grouping by observing BOLD activation to Glass or texture patterns.

Method. Each dipole contained two 5.4' square dots separated by 27'. The Glass patterns contained randomly distributed dipoles covering 2% of image. The coherence of a Glass pattern was defined as the proportion of

dipoles oriented tangent to a concentric global form. To eliminate grouping at the dipole level, we also used line element textures which had bars (5.4'x27') in place of dipoles. The BOLD activation (N=6) was collected on a Bruker 3T magnet (EPI, TR=3s, TE=60ms, flip angle=90o). Each 252s block design run had two test conditions alternating with each other in a 36s period.

Result. Compared with a zero coherent pattern, the 100% coherent Glass patterns activated the lateral occipital complex (LOC) and the inferior temporal (IT). The Glass and the texture pattern of the same global structure showed differential activation in V2 and V3 which was posterior to the areas responding to Glass patterns. A rotating wedge of coherent dipoles showed that the dorsal LOC had a retinotopic property for Glass patterns. A rotating concentric pattern produced only weak retinotopic activation at the ventral LOC.

Conclusion. The contrast between line texture and Glass patterns suggests that local grouping occurred in V2 and V3. The rotating wedge suggests the dorsal LOC is for analyzing curvatures while the rotating circle hints that the ventral LOC is responsible for global forms. The weak activation for rotating circles may suggest that the global form processing is less retinotopic mapping than local features.

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499 Perceptual Grouping Induces Real-Time Remapping of Retinotopy

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By using a Ternus-Pikler display, we show that features presented at one spatial location can be perceived at another one in violation of retinotopic relations but in accordance with perceptual grouping. The stimulus consisted of a first frame (70ms) containing three vertical lines, an ISI, and a second frame (70ms) containing three lines shifted to the right. The second and third line of the first frame overlapped spatially with the first and second line of the second frame, respectively. When the ISI was 0ms, observers perceived a single line in motion (element motion); when the ISI was 100ms, the three lines were perceived to move as a group (group motion). We inserted a vernier offset at the second element of the first frame only. Observers' task was to report the perceived direction of vernier offset for a pre-designated line in the second frame. Naïve observers had no knowledge that the lines in the second frame were not offset.

In the case of element motion, performance was high if observers attended to the first element of the second frame and close to chance for the other lines. This result is in good agreement with retinotopic relations: the vernier offset is perceived at the spatial position it was displayed. Surprisingly, when group motion was perceived, performance was high for the second element of the second frame - even though there was no vernier information at this retinotopic location neither in the first nor the second frame! This mislocalization of vernier offset is in accordance with element correspondences in group motion:

the second element of the first frame corresponds to the second element of the second frame. Hence, the attribution of the vernier offset depends on perceptual grouping rather than on retinotopic relations. Our results suggest that motion and form systems interact in real-time to remap the retinotopic projection of the physical space to maintain object identities in the perceptual space.

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500 The hole paradox: Perceiving and remembering the shapes of intrinsic vs. accidental holes

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Holes present an intriguing paradox for figure-ground organization. Although the outside of a hole is seen as the closer figure and the inside as the farther ground, the shape of the interior region appears to be well perceived and remembered, contrary to the usual claim that border assignment is unidirectional and linked for depth and shape. Recent evidence has questioned the claim that the interior shapes of holes are perceived (e.g., Bertamini & Croucher, 2003). We present four experiments that demonstrate circumstances under which the shapes of visual holes are perceived and remembered -- or not. In Experiment 1, subjects saw a series of novel shapes presented as real, physical models of 2D surfaces with and without holes. A later shape recognition test showed that they remembered the interior shapes of the holes as well as the shapes of the solid objects. A second study with stereoscopically viewed depth displays demonstrated that memory for the interior shape of holes is limited to intrinsic holes, whose contours are continuous in depth within a single object. Memory for accidental visual holes, arising from the coincidental alignment of discontinuous contours of two or more objects separated in depth, was no better than chance. A control experiment ruled out explanations based on artifacts due to differential size or shape. Further studies used instructional manipulations to investigate the influence of differential attention to intrinsic versus accidental holes to determine whether the observed differences in shape memory are obligatory or strategic. The findings are discussed as supporting an account of hole perception in which the shape of a hole is attended and encoded as an immaterial (or virtual) surface where matter is missing from the otherwise solid surface, perhaps with a 'missing sign' (analogous to a minus sign in mathematics) to represent its status as a hole rather than as a material part.

501 Dissociation of Color and Figure-Ground Effects in the Watercolor Illusion

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The watercolor illusion occurs when figures are defined by a double contour consisting of lines of different colors and contrasts. Two phenomena are observed, illusory color spreading (Pinna et al., *Vision Res.* 41:2669-76, 2001) and figure-ground organization (Pinna et al., *Vision Res.* 43:43-52, 2003). The purpose of the present study was to distinguish whether the figure-ground effect is a consequence of the color illusion or due to an independent mechanism. Subjects were tested with displays consisting of six adjacent stripes outlined by dark purple lines in which alternating stripes were lined orange inside to produce the watercolor illusion. In experiment 1, the illusory color was measured by finding the matching physical color in the alternate stripes. Figureness (probability of 'figure' responses, 2AFC) of the watercolor stripes was then determined with and without the matching color in the alternate stripes. The color match reduced figureness by 46%, but did not abolish it. There was a range of colors in which the watercolor stripes dominated as figures over the alternate stripes although the latter appeared more saturated in color. In experiment 2, the effect of tinting alternate stripes was measured in displays without watercolor illusion (no orange lining). Figureness increased with color contrast, but its value at the corresponding contrast fell short of the figureness value obtained for the watercolor pattern. Thus, both experiments indicate that figureness produced by the watercolor pattern is stronger than expected from the color effect, suggesting independent mechanisms. We conjecture that part of the figure-ground effect of the watercolor pattern results from the double lines stimulating neurons that are selective for asymmetric edge profiles. Such neurons may signal border ownership and thus contribute to figure-ground segregation (Zhou et al., *J. Neurosci.* 20:6594-6611, 2000).

502 Combining Cues for Boundary Detection Using the "Mixture of Specialists" Model

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Biological visual systems are highly adept at combining cues to improve the sensitivity and selectivity of target detection. For example, depth, motion, intensity, color, and texture cues can together increase the reliability of boundary detection in natural scenes where camouflage abounds. But given a set of single-cue boundary detectors, how should their outputs be combined to arrive at overall boundary probability? Previous work has often assumed that cues are gaussian and class-conditionally (CC) independent; this leads to a linear cue combination rule with weights depending on individual cue reliabilities (Jacobs, 1995). However, the physical processes underlying edge formation in natural images may lead to exponential rather than gaussian distributions (Balboa and Grzywacz, 2003), and higher-order dependencies between edge detectors abound (Schwartz & Simoncelli, 2003). We studied cue combination using co-localized oriented edge detectors operating on red-green and blue-yellow opponent channels. Using the Martin-Fowlkes-Malik (2004) human-segmented database as ground truth, we found that the CC joint distributions of co-localized color edge detectors showed strong statistical dependencies, as expected. The dependencies were well explained by a generative model in which two independent, exponentially distributed raw edge values were multiplied by a third exponentially distributed common factor due to local lighting conditions. The modulated edge values were then passed through a saturating nonlinearity reflecting the range compression seen at all levels of the visual system. We derived a softmax-like divisive normalization scheme from the generative model, leading to a cue-combination rule that ranged from linear to MAX-like depending on joint cue values. We discuss the extensibility of the "mixture of specialists" framework to high-dimensional cue-combination problems, and the possible neural substrate for the scheme's underlying computations. This work was supported by ONR, NSF, ARO, and NIH.

503 Transporting Features

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One of the major questions in the cognitive and neurosciences is how features of an object are bound together to create a unique percept. Usually, it is assumed that features are perceived at the spatial location where they were displayed. Here, we present a new illusion - repetitive-metacontrast - which demonstrates that features can be transported across space.

A single vernier, offset either to the left or right, is shortly presented and followed by two straight flanking lines. This renders the vernier invisible (classical metacontrast). However, subjects report an illusory offset at the flanking lines which are in fact straight. This feature mislocalization can be carried on if an additional pair of lines follows. Each of these two lines flanks one of the previously displayed lines being one step further away in space. For repetitive sequences of lines, a motion percept is elicited with the individual lines being invisible. We called this masking effect repetitive metacontrast. Surprisingly, the vernier offset is perceived even up to the lines displayed last. If these lines are offset itself, this offset is integrated with the vernier offset. Hence, features presented at different positions can be integrated. This integration does not occur when the continuous motion is disrupted.

We conclude that in repetitive metacontrast features can be freed from their physical carriers and 'transported' to other positions in space.

Poster Session E

May 8, 2005 – Sunday PM

Attentional Cuing and Capture (504-516), 3D Visual Processing (517-529), Faces: Cognition and Brain (530-545), Inattentional Blindness (546-558), Lightness and Surfaces (559-570), Modal and Amodal Completion (571-578), Eye Movements: Physiology and Mechanisms (579-596), Natural Images (597-609), Visual Working Memory (610-625)

2:00 - 7:00 pm (Authors present 5:30 - 7:00 pm)

Municipal Auditorium

Attentional Cuing and Capture

504 Attentional capture by color and onset singletons in search tasks

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The purpose of this study was to investigate attentional capture by onset and color singletons in a search task. The contingent involuntary orienting hypothesis (Folk, Remington, & Johnson, 1992) states that attentional capture by a unique singleton is not entirely stimulus-driven, but is contingent on the relationship between the search goal and the properties of the singleton. In this study, we investigated whether a singleton defined by color or onset captured attention when the observer searched for a reddish target defined by an increment in L chromaticity on the cardinal color axis. The singleton's validity to the task was varied in different conditions: valid (singleton always target), invalid (singleton never target), and informative (singleton was target on 50% of trials). Four observers attempted to detect the reddish target in a display of 10 stimuli. Thresholds corresponding to 75% correct were estimated with a yes-no task. Experiment 1 consisted of 3 types of singletons (onset, blue, and bright) assumed to be signaled by a neural mechanism independent of the neural mechanism coding the target increment. Experiment 2 consisted of 2 types of singleton (red and green) assumed to be signaled by the same neural mechanism that signaled the target increment. Results in invalid conditions showed no evidence of attentional capture by color singletons, while results from the valid conditions suggested that these same color singletons could be used to guide attention to the relevant stimulus. Results in the informative condition suggested that attention was directed initially to the red and green color singletons when there was an incentive to attend to both the singleton and the distractors. An abrupt onset of a stimulus captured attention regardless of its validity to the task. Results provide little support for the contingent involuntary attentional capture by color.

Folk, C.L., Remington, R.W., and Johnson, J.C. (1992) JEP:HPP 18, 1030-1044

505 Attentional Capture by Unique Temporal Change

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The time course of attentional capture was measured in the preview search paradigm (Yantis & Joinides, 1984). Participants were first presented a circular preview display of figure eights. After one second two to four line segments of each figure eight were deleted to reveal a search display of letters, with two letters arbitrarily designated as targets. The participant's task was to press one of two keys as rapidly as possible to report target identity. Attentional capture was indexed by the relative ratio of RT

slopes, taken over the display size, for targets that appear in unchanged versus unique display item locations. This is based on the assumption that when a unique item draws attention to itself, it will slow search if it happens to be one of the distractor letters.

The current study points to a temporal factor, over and above the importance of new objects and relative signal speed, which is critical for attentional capture. Attention is captured by temporally unique events. The results of three experiments show that feature changes capture attention as effectively as new objects provided they occur during a period in which the display is static. Conversely, these same feature changes do not capture attention when they occur simultaneously with other display changes, such as the sudden onset of all items or the deletion of some line segments in all items. Importantly, the results show that this unique event hypothesis applies to changes in color (Experiment 1), in motion (Experiment 2) and even to the sudden appearance of new objects (Experiment 3). These findings highlight the importance of considering both space and time in studies of attentional capture.

Yantis, S., & Jonides, J. (1984). Abrupt visual onsets and selective attention: Evidence from visual search. *Journal of Experimental Psychology: Human Perception & Performance*, 10, 601-621.

Acknowledgment: SNF NSERC

506 Attention capture alters motion discrimination

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Purpose: The effects of competition between exogenous and endogenous allocation of attention on motion discrimination are not well known. We examined how the capture of attention by abrupt onsets can improve or degrade performance in a motion-pulse variant of the coherent motion discrimination task.

Methods: The authors (N=3) performed a 2AFC motion discrimination task during fixation. Subjects were cued to the location (75% valid) of an upcoming motion pulse (160 ms duration) by the onset of an incoherent motion patch (68 diameter) that appeared 48 above or below fixation. On 'no capture' trials (25% of total), the cued patch appeared alone and switched briefly (160 ms) to coherent motion at a random time during the trial. On 'capture' trials (50%), the motion pulse in the cued patch appeared cotemporaneously with a second incoherent motion patch in the opposite field. On 'capture+motion' trials (25%), the pulse of coherent motion was presented in the second patch rather than in the cued patch. The motion coherence was any of 8 values. Subjects reported the perceived direction of motion with a button press. We computed coherence thresholds for each condition.

Results: We found large coherence threshold differences between the three conditions. The threshold for 'capture' trials was on average 56% higher than the threshold for 'no capture' trials, and the threshold for 'capture+motion' trials was 202% lower than the threshold for 'no capture' trials.

Conclusions: Attention capture by the second patch overrode the endogenous allocation of attention to the first patch and enhanced discrimination performance. Our task design highlights the competition between endogenous and exogenous control of attention and suggests an approach for physiological investigations of the neural mechanisms underlying both types of attentional control.

507 What kind of attention is controlled by irrelevant symbolic cues?

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Twenty years ago, Jonides (1981) concluded that irrelevant symbolic cues (arrows presented at fixation) do not elicit involuntary shifts of attention within the context of the spatial cuing paradigm; however, this view has recently begun to change. Over the past few years, a wealth of evidence has been interpreted to suggest that symbolic cues can elicit involuntary shifts of attention under a wide range of different stimulus and task conditions (Eimer, 1997; Gibson & Bryant, in press; Hommel, Pratt, Colzato, & Godijn, 2001; Pratt & Hommel, 2004; Ristic, Friesen, & Kingstone, 2002; Tipples, 2002). However, the conclusion that irrelevant symbolic cues can elicit shifts of spatial attention has been founded primarily on the presence of a 'cue validity effect,' indicating faster response times when the target happens to appear at a spatially-cued location than when it appears at an uncued location. In several experiments, we challenge this standard interpretation by employing a display size manipulation. In each experiment, irrelevant symbolic arrow cues were presented briefly just before visual search displays that contained either 4 or 8 visually-similar letters. Consistent with previous studies, the results showed a significant cue validity effect; however, of critical importance was the finding that the magnitude of this effect remained constant across display size, suggesting that the orientation of attention was not influenced by the presence of the irrelevant symbolic cue. Instead these results appear to reflect the operation of a conflict resolution process that becomes sensitive to the correspondence between the initially cued location and target's actual location after the search for the target has been completed. Altogether, the present findings suggest that irrelevant symbolic cues may influence the anterior attention system more than the posterior attention system.

508 The modulation of attentional capture by behavioral relevance

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It is well known that the appearance of a new object in the visual field can capture attention, allowing it to be perceptually processed faster than objects that have been visible for some time. However, there are countless situations, such as walking down a busy Manhattan sidewalk, when new objects (people) appear continuously, but are almost completely ignored. Here, we assess whether the ability of a new object to capture attention depends upon its behavioral significance. We hypothesize that the potency of attentional capture decreases as the odds that a new visual object requires visual processing decreases. 4 Ss performed a modified version of the traditional attentional capture task of Yantis et al (1984). Ss searched for then discriminated a target object amongst 3 distractors. The target could have either just appeared (new object) or had been present for some time, initially masked (old object). In the traditional task, the odds of any object being the target are the same whether old or new. In our task, Ss viewed 4 letters, 3 old and 1 new, in 3 different conditions that differed in the probability of the target being the new object (50%, 25%, or 7.7%).

Participants were informed of these odds prior to testing. In one version of the task, the location of the new object was predictable as soon as the 3 original objects appeared. The attentional capture effect decreased as the probability of the new object being the target decreased (50%: 43ms, 7.7%: 11ms). In the second version of the task, the location of the new object was not predictable. Here, the attention capture effect was reduced from 122ms to 72ms. These results support the hypothesis that the potency of attentional capture is modulated by the behavioral relevance of the suddenly appearing object. Manipulating the importance of a new object in a laboratory attention task may model the visual filtering processes brought to bear when navigating a Manhattan sidewalk.

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509 The Necessity of a Spatial Cue for the Capture of Attention by Abrupt Onsets

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The abrupt appearance of new object in a display, an abrupt onset, has long been shown to capture attention in visual search tasks. Onsets are believed to capture attention involuntarily, regardless of the goals or intentions of the observer. In a series of experiments, we repeatedly fail to replicate this phenomenon with only minor changes to the standard paradigm. We then show that capture only occurs when prior to the start of the search, a spatial cue orients attention to the center of the display. Specifically, onsets do not capture attention in a visual search task unless the fixation circle in the center of the display appears at the start of each trial. If the fixation circle is always present (i.e., during the inter-trial interval), onsets may be prioritized in the search task but response times on trials where the onset appears as the target do not produce a shallow slope for response latency as a function of increasing set size, the standard measure used to infer capture. Further studies show that this effect is not limited to the appearance of the fixation circle; color changes and auditory beeps also provide the necessary impetus for capture. Capture is also eliminated when the fixation circle does not cue attention to the center of the search array. These results reveal a surprising limitation to the robustness of attention capture by onsets. Attention must be cued to the center of the display prior to the appearance of the search array for capture to occur, potentially weakening the strong claim that onsets capture attention involuntarily.

510 Active Suppression of Salient Visual Distractors for Unimodal and Cross-modal Cues in Dual RSVP Tasks.

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The effect of attention on detection/discrimination of basic stimulus features such as motion and disparity can be demonstrated using a dual RSVP paradigm. Participants are asked to await the onset of a cue embedded in a RSVP stream before detecting the presence of a stimulus in a second RSVP. We have previously shown that normal observers are impaired in detecting salient stimuli such as first order motion or detecting a large change in disparity of a surface if it occurs within a 300ms time interval after the cue onset (VSS 2004). The recovery functions for detection of both features (motion & disparity) following the cue onset and their relationship with the frequency of distractor events are similar for both features

We have now demonstrated that the cue, embedded in an RSVP stream, can be either visual (a unique red fixation colour) or auditory (a specific tone). We have proposed that the impairment is due to the active suppression of the distractor events by top-down mechanisms. The cue simply acts as a temporal marker, signalling the release of suppression and therefore, it is independent of its modality. The time-course of the recovery, therefore, would reflect the gating of information to higher-order

stimulus evaluation (or controlled stimulus processing) and not the interference of cue processing within a modality. The findings have also been supported by our recent electrophysiological studies (Niedeggen et al. J. Cogn. Neuro, 2004).

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511 It takes attention to capture attention

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We intuitively believe that a sudden movement or change outside the focus of attention will attract our attention. Indeed, numerous studies of stimulus-driven attention show that sudden changes to a display capture attention, even when subjects know that they are irrelevant to the primary task. This mechanism may exist to automatically allocate visual attention to potentially important changes in the world, even when attention is focused elsewhere. In contrast, we present evidence that a sudden change to the stimulus (the abrupt onset of a new search item) attracts attention in easy search tasks, but not in difficult search tasks, suggesting that important changes to the world are more likely to be missed when we are focused on a difficult task.

In three experiments, we systematically manipulated the difficulty of a letter search task. In Experiments 1 & 2 we varied the set of distractor letters, and in Experiment 3 we rotated all stimuli by 90 degrees. In each experiment, the size of the transient created by the abrupt onset was identical - only the difficulty of the search varied. Across these three experiments, and a meta analysis of several published experiments, the degree of search priority for an abrupt onset letter decreased systematically with task difficulty ($r_2 = .94$); the more difficult the search, the weaker the capture effect.

Past evidence suggests that more difficult identification tasks require a 'smaller spotlight' of attention (e.g., Castiello & Umiltà 1990). Thus, transients may only capture attention in easy search tasks, where subjects use a wide spotlight over large portions of a display, but not in difficult search tasks, where target identification might require a tighter spotlight around smaller sets of search items. Surprisingly, sudden changes to the world may only attract attention if they occur within the spotlight of attention.

512 Invisible interesting pictures can attract spatial attention

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A salient cue in a scene can attract visual attention to its location and subsequently enhance information processing at that location. We investigated whether visual information that is rendered invisible through interocular suppression can still guide the distribution of spatial attention. Using a modified version of the classical Posner's attentional cuing paradigm, we presented two images, one intact and one scrambled, to the left and the right side of the fixation point. However, this pair of images was only presented to the observers' non-dominant eye while high contrast dynamic noises were presented to their dominant eye at the same spatial locations. Observers perceived identical noise patches on both side of the fixation point and were unaware of which side received the intact image. These invisible 'cuing' stimuli were followed by a brief test probe of a small Gabor patch presented either at the location of the intact image or the scrambled image. Observers judged the orientation of the test probe which could be tilted slightly either CW or CCW. Even though observers were not aware of which side the intact image was located, results show that their performance was better for probes presented at the side where the intact image was presented. Pictures with high arousal value, though invisible, were particularly effective in attracting spatial attention. This result suggests that visual spatial attention can be guided by invisible information, possibly through subcortical pathways.

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513 What Drives Visual Saliency in Young Infants?

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HYPOTHESIS: Basic visual functions develop rapidly during the first year of life. Since infants' endogenous attention system is not yet quite matured, visual saliency has an almost exclusive role in controlling their visual attention. However, no previous research has attempted to systematically study the relationship between detectability and saliency in infants and to compare the saliency of different visual features.

METHODS: We measured detection thresholds and saliency relations between iso-detectable stimuli using the forced-choice preferential looking technique in 5- and 6-month-old infants. **Detection:** Stimuli consisted of a dense 20x20 array of randomly oriented Gabor patches, where a 4x4 region that differed from the background elements in either color (red saturation: 6-31%, background: 0%) or spatial frequency (1.5-4.5 cpd, background: 1 cpd) appeared either on the left or the right side of the field. **Saliency:** Two equally detectable (65% preference for color vs. SF) stimuli were pitted against each other on the same background as in the detection task. Gaze directions were coded in both experiments. A total of thirteen 5-month-old and twelve 6-month-old infants participated.

RESULTS: The detection thresholds measured were very similar in the two age groups for color and somewhat lower for the older infants for SF. In our preliminary results detectability nearly always predicted saliency.

CONCLUSION: Saliency preference seems to parallel the underlying maturation of the developing visual system. Our conclusions confirm and extend the predictions of an early model of infants' visual preference by Banks and Salapatek (1981). In our future studies we plan to explore other regions of the feature space.

514 Commonalities and differences between attentional cueing and iconic memory

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Two largely separate lines of research suggest that detection performance can be improved by cueing the location of a target either shortly before (attentional cueing) or shortly after target presentation (iconic memory). Here we attempted to directly compare these two mechanisms. In a behavioral experiment, we investigated performance on an auditorially cued discrimination task, where observers had to determine for bilateral displays (presented for 80 ms) how many of three circles on the cued target side (right or left) contained a gap. Cues were administered in four different temporal conditions (cue-target SOA-s of -400, -200, 200, and 400 ms), allowing us to contrast performance on trials with pre-cues versus post-cues. Performance improved following both pre-cues and the shorter SOA post-cue, while there was a significant decrease in performance with the longer SOA post-cue, consistent with previous results on iconic storage. In order to identify common and distinct neuronal processes underlying the pre- and post-cueing conditions, we subsequently performed an fMRI experiment using the same task, but only 200 ms pre-cues and -200 ms post-cues. Initial analyses show that in comparison with a 'passive' baseline, both pre-cue and post-cue trials resulted in increased activations in bilateral superior parietal cortex and frontal eye-fields. These common activations may reflect attentional control processes involved in retrieval from iconic storage as well as attentional cueing. However, irrespective of cued side, pre-cue trials yielded larger target-related activations in bilateral occipital cortex than post-cue trials. These different activations possibly reflect that attentional cueing, in contrast to iconic retrieval, enhances the receptivity of occipital cortices for sensory input.

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* Student Travel Fellowship Recipient

515 An ideal observer approach to unifying set size and cueing effects for perceptual and saccadic decisions

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Introduction: Two predominant attention tasks, visual search and cueing, often have been treated separately with different attentional theories for the effects found in each task (visual search-set size, cueing-validity). An ideal observer/SDT approach suggests that these two effects may be modeled with a purely selective attentional mechanism with equal discriminability at all locations (e.g., Palmer, et al., VR, 2000; Eckstein, et al., JOV, 2002). In this study we show that an ideal observer model with one selective attention mechanism (weighting information by cue validity) can appropriately predict both set size and cueing effects in the same task. Method: 2 observers participated in a cued visual search of a Gaussian blob (sd=11', contrast = +6.25% on a +7.81% contrast pedestal) in image noise (Gaussian, sd=2.73 cd/m²). The signal appeared on ? the trials in 1 of 8 locations (eccentricity=6?), with observers making a yes/no judgment on signal presence. Effective set size (N) was set at 2, 3, 5, or 8 by precues (500ms) at the possible signal locations. There were 1 primary cue and N-1 secondary cues. On signal present trials, the primary cue always had 50% validity across set size; otherwise, the signal appeared randomly in one of the secondary cue locations. Thus, each single secondary cue had less validity (5/(N-1)) with increasing set size. There were 2 stimulus durations: long (1s), with eye movements, and short, with durations roughly matched to the 1st saccade processing time in the other (long) duration condition (1st saccade latency - 80ms dead time). Results: The ideal observer predicted both cueing and set size effects for this task; also, the predicted effects fit well with the human observers' with the long duration. Observers' performance for the shorter duration and for 1st saccade localization (long duration only) were predicted less well, suggesting that shorter stimulus durations hampered optimal decisions for both perceptual judgments and saccades in this task.

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516 'Your first organization influences your second': Does attention stick to location, color, or both? Evidence from a priming paradigm

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Koffka (1935) first suggested that an initial figure-ground (FG) perception could influence a second perception. The mechanisms that produce this FG carry-over effect remain unclear. We hypothesized that this effect is caused by our attention to the color and location of the figural region. In the present study, we introduce a figural priming paradigm to examine whether an initial percept affects a second percept based on either the color or location of the perceived figures. In Experiment 1, observers viewed displays with three shapes. In prime displays, a red/green FG display appeared above a single shape; observers determined if the single shape was the same or different as the shape of corresponding color in the FG display. 100ms after the prime trial, the probe trial followed. Observers performed the identical task with the prime trial. The critical comparison was between two probe trial conditions: when the target color of the shape-matching task was identical between prime and probe trials (no color change), and different between prime and probe displays (color change). If the first FG organization affected the second, observers' responses would be slower in color change than in no color change. If the first FG organization was independent of the second FG organization, observers response latency would be the approximately the same between these two conditions. We found that observers responded significantly slower in color change than in no color change. In Experiment 2, we examined if location of the perceived figure could influence the perception of a second figure. We switched sides of the figures across prime and probe displays. The results of these experiments suggest that FG assignment can be 'primed' by the color and location of previously

perceived figures. These results are consistent with findings from visual search (e.g., Maljkovic & Nakayama, 1994, 1996) and suggest that FG processes and visual attention may rely on shared mechanisms.

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3D Visual Processing

517 On the anisotropy in the perception of stereoscopic slant

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Many visual processes computationally amount to estimation problems. It has been shown that noise in the image data causes consistent errors in the estimation, that is statistical bias

[1]. Here we analyze the effects of bias on 3D shape estimation, and we found that it predicts the perceived underestimation of slant for many settings found in experiments.

In particular, we concentrate on the problem of shape estimation from stereo using orientation disparity. We found that bias predicts the anisotropy in the perception of stereoscopic slant, an effect that has not been explained before.

It has been found that a surface slanted about the horizontal axis is estimated much easier and more accurately than a surface slanted about the vertical axis [2,3]. In both cases there is an underestimation of slant, but it is much larger for slant about the vertical. Cagnello and Rogers [2] argued that this effect is due to orientation disparity, which when the texture on the plane is made up of mostly horizontal and vertical lines, is smaller for surfaces slanting about the vertical. However as shown in [3], the effect also exists, even though in weaker form, when the texture is made up of lines oriented at 45 degrees. For such a configuration the orientation disparity in the two configurations is about the same. Thus orientation disparity by itself cannot be the cause. But errors in the estimated position and orientation of edgels cause bias, which predicts all the above findings and other parametric studies that we performed.

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518 Local surface slant determines perceived shape in pictures

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A picture viewed from its center of projection (CoP) generates the same retinal image as the original scene. When a picture is viewed from other locations, the retinal image specifies a different layout and shapes, but we normally do not notice these changes. On the other hand, distortions in shape are sometimes perceived when a picture is viewed from its CoP and the retinal image specifies an undistorted object. The visual mechanisms underlying such effects are unknown. We have demonstrated that perceived invariance depends on the visibility and slant of the picture surface, and consistent with our previous results does not depend on the contents of the picture. We also studied the perceived shape of objects at different positions in the picture. Observers set an ovoid to appear spherical under monocular or binocular viewing. The ovoid was presented in the center of the display or to the left and right of center. With

monocular viewing through an aperture, observers always set the ovoid such that it created the retinal image of a circle. With binocular viewing, they set it such that it was a circle on the display screen, whether it was in the center of the screen or not. Together with our previous results, this shows that perceived shape in pictures is determined by an adjustment to the retinal image based on measuring the local slant of the picture surface. We present a quantitative model that states how local slant measurements are made, and how they are used to adjust the retinal image. The model explains the failure of invariance with monocular viewing and the nearly veridical invariance with binocular viewing. It also explains perceived shape distortions with wide fields of view, the anamorphic effect, and the picture-in-a-picture effect.

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519 Aging and the Perception of Surface Orientation

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Previous research on aging and the perception of 3-D shape has focused upon stereopsis and motion (e.g., Andersen & Atchley, 1995; Norman, Dawson, & Butler, 2000; Norman, Clayton, Shular, & Thompson, 2004). No research has yet investigated how older observers perceive the 3-D shape of surfaces defined by image shading or specular highlights. In this study, 10 younger (< 31 years) and 10 older observers (65 - 81 years) judged the orientations of surface regions on randomly shaped 3-D objects. On each trial, the observers adjusted a gauge figure until its orientation matched that of an underlying surface region. Each of the observers performed 160 judgments: 20 judgments for 8 combinations of 2 viewing conditions (stereoscopic & monocular viewing) and 4 surface types (surfaces defined by shading & texture, shading & highlights, shading only, and highlights only). When the observers' overall errors were analyzed, there was no significant difference between the two age groups. When separate analyses were conducted upon the observers' judgments of surface slant and tilt (the 2 components of orientation), it was found that there was a very small, but significant effect of age for judgments of surface tilt ($F=5.3$, $p < .05$). Nevertheless, observers in both age groups exhibited high correlations between the actual surface tilts and the judged tilts (mean younger Pearson $r = 0.93$, mean older $r = 0.9$). The correlations were lower for surface slant for both age groups (mean younger $r = 0.47$, mean older $r = 0.4$). There was no effect of surface type for judgments of tilt ($F=0.8$, $p > .05$), but there was a significant effect for judgments of slant ($F=6.7$, $p < .001$). The performance of both age groups was similarly improved by stereoscopic viewing (for tilt: $F=16.7$, $p < .001$; for slant: $F=11.4$, $p < .01$). The results indicate that older observers can effectively perceive local 3-D surface orientation from optical patterns of shading, texture, and/or specular highlights.

520 The perception of symmetry in depth.

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The visual system is sensitive to symmetries in spatial position, and bilateral symmetry about a vertical axis has a particular salience. However, symmetries about an axis or point within the frontoparallel plane form only a subset of the symmetries realizable in 3-D space. Which among this larger set of symmetries are humans sensitive to?

To determine the existence of a specific sensitivity to symmetry in depth, I presented stereo displays of items (disks or Gabor patches) that were distributed symmetrically or asymmetrically in depth. The projection of the cyclopean array onto the frontoparallel plane was always symmetrical about a particular axis (vertical, horizontal, left oblique or right oblique). Disparity values were assigned symmetrically on either side of this axis. Asymmetrical arrays were generated by perturbing the disparity of a single one of these items.

Disparity thresholds were lowest for discriminating symmetrical and asymmetrical depths on either side of the vertical axis. Thresholds did not differ significantly between the horizontal and oblique axes of symmetry. To determine whether the results were due to differences in sensitivity to disparity across retinal locations, I also collected data for discriminating repetitions and non-repetitions of depth values; here translation rather than reflection determined correspondence. The items' frontoparallel positions (and retinal locations) were the same as in the symmetry-asymmetry discrimination task. However, thresholds as a function of the axis of symmetry were not the same in the two tasks. In the repetition task threshold did not differ across the four axes. Hence, humans do evince a specific sensitivity to the symmetry of patterns in depth, particularly patterns whose corresponding points have the same coordinates when projected onto the sagittal plane. These depth-symmetric patterns are 3-D analogs of the traditional focus of symmetry research 2-D patterns with symmetry about the vertical axis.

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521 Perceived size of stoplights: Further investigations into a failure of size constancy

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We reported previously that observers underestimate stoplight size at distances of 20 to 200m and that observers rely on assumed size when estimating the size of a distant stoplight (VSS, '03, '04). The stoplights in those studies were suspended above the ground. The present study investigated the perceived size of stoplights that rested on the ground. In Experiment 1 (N = 60), three groups of participants viewed a stoplight that rested on the ground at distances of 20, 120, and 200m. They estimated the size of the light's 30.5 cm lenses by selecting, from a set of nearby comparison circles, a circle that matched the size of the lenses. Size was estimated accurately at 20m but was underestimated, on average, by 17% at 120m and 30% at 200m. At 20 and 120m, size estimates are more accurate for stoplights that rest on the ground than for stoplights suspended above the ground. At 200m, size estimates are equally inaccurate for suspended lights and lights on the ground. The results indicate that the misperceived size of suspended stoplights at 20m is due to their suspension above the ground. At distances of 120m and greater, however, size constancy is not achieved for stoplights that rest on the ground. Experiment 2 (N = 80) investigated whether assumed size affects estimated size for stoplights on the ground. The experiment had two parts: a familiarization period and a test trial. During familiarization, participants studied a standard-sized or smaller-than-normal stoplight for 1 minute from a distance of less than 2m. In the test trial, participants viewed the standard-sized or smaller-than-normal stoplight from a distance of 120m. Test-trial size estimates conformed to the size of the stoplight seen during familiarization. The size of the stoplight seen during the test trial had no effect on size estimates. These results indicate that research participants rely on assumed size to make size estimates for objects on the ground as well as for suspended objects.

522 Monocular and binocular perception of 3D shape: the role of *a priori* constraints

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Purpose: Chan, Stevenson & Pizlo's experiments (submitted) showed that binocular perception of a 3D shape critically depends on simplicity constraints (e.g. planarity of contours, symmetry of an object). They formulated a model in which perceptual processing begins with 3D shape reconstruction from one retinal image. This reconstruction involves simplicity constraints. The role of binocular disparity in this model is limited to correcting the monocularly reconstructed shape. To test this model, we performed two experiments on 3D shape recognition, in which 3D objects characterized by various degrees of simplicity were viewed binocularly or monocularly. If binocular disparity is of secondary

importance, binocular and monocular performance should be correlated. In particular, binocular performance is expected to be high only in the case of objects for which monocular performance is high, as well. **Method:** We used six types of objects with different degrees of 'simplicity': (a) polyhedron represented by edges of the faces, (b) vertices of a polyhedron, (c) a polygonal line connecting the vertices of polyhedron in a random order, (d) partially non-planar, symmetric polyhedron (some visible contours were not planar), (e) planar, asymmetric polyhedron, and (f) non-planar, asymmetric polyhedron. Hidden edges of the polyhedra were removed. Three subjects (one naïve) were tested. **Results:** The correlation between binocular and monocular performance was fairly high ($r > 0.8$). In particular, high binocular performance was observed only in cases where monocular performance was high, as well. For all six stimuli, binocular performance was better than the monocular one. **Conclusion:** These results provide strong support for Chan et al.'s model, in which binocular and monocular perception of 3D shapes involves the same set of *a priori* constraints. Binocular disparity seems to be a secondary factor.

523 What can drawing tell us about our mental representation of shape?

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When we draw or sketch a three-dimensional object, what aspects of its geometric structure do we usually choose to depict and how are these depictions executed? More importantly, what can these renderings tell us about our mental representation of these shapes? Art instruction literature and practice is replete with techniques for depicting objects. Not surprisingly, in such a large variety of sources there is a large amount of contradictory advice. Despite this, it is obvious that even the simplest and most naïve drawing can convey information about shape. Willats et al. have investigated a wide variety of spatially representational drawing techniques and have developed a broad taxonomy based around them. We are interested in furthering our understanding of the mental representation of objects via direct comparison of drawing production with the depicted objects. We performed a series of experiments designed to correlate the markings made when depicting an object with the object's underlying differential structure. In one scenario, subjects were shown two-dimensional renderings of random, smooth, three-dimensional objects from a dynamically changing view point. As there was no fixed viewpoint the subject couldn't depict the object by simply replicating image information. (Many classical drawing techniques suggest this sort of 'drawing from the image'.) The resulting drawings are, therefore, likely to be based on a three-dimensional mental representation derived during the viewing period. In other conditions, subjects were shown static boundary contours, static shaded images, dynamic images with subject-controlled viewpoint, and physically realized three-dimensional models. Each of these conditions provides a different variety and quantity of image information to the illustrator. Results from each are compared to contrast the information derived and depicted directly from the optical image with the information available in some higher-level representation.

524 Texture amplitude is a cue to perception of shape from shading.

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When a textured surface is modulated in depth, the level of illumination varies across the surface, producing modulations of local mean luminance (LM). The shading also produces modulations in the luminance amplitude of the visual texture (AM). The AM co-varies with LM such that local contrast remains constant. It is well known that human vision can use LM cues to infer the shape of the underlying surface, but the role of AM has

not been explored. We conjecture that the phase relation between LM and AM is an ecologically valid depth cue that might be used by human vision. To examine this, we used a 2fc task in which both intervals contained a textured plaid: binary noise with oblique (+/-45 deg, 0.5 c/deg) LM and AM components. In one interval both obliques consisted of an LM+AM pair, but in the other interval one oblique was an anti-phase pair (LM-AM). We measured LM thresholds for discriminating the two plaid types at fixed levels of AM and found that observers always required more LM to distinguish the plaid types than they did to detect LM without AM. We also measured AM thresholds for plaid discrimination at fixed levels of LM and found that when LM was at its own detection threshold no amount of AM would enable observers to do the task. However, when LM was 8 times its detection threshold the amount of AM required to discriminate the plaids fell below the AM detection threshold. This facilitation of AM by LM suggests some integration of the two cues, perhaps at the level of surface depth coding. The 3-D appearance of the two plaids was very different: the plaid with the LM-AM component appeared corrugated only in the LM+AM direction, while the other plaid appeared doubly corrugated. The data thus suggest that supra-threshold LM may be necessary for shape from shading. Conversely, supra-threshold AM is not necessary for shape from shading but when present its phase relationship with the LM component may be a key determinant of 3-D surface interpretation.

525 Pictorial Relief in Equiluminant Images

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Question: Pictorial objects, other than physical objects, exist only in the mind of the beholder. Pictorial space is relief space and therefore not Euclidean, e.g., pictorial objects have only frontal sides thus cannot turn about certain axes. Pictorial relief is due to the pictorial cues. For isoluminant renderings all cues related to luminance contrast are missing. It has been suggested that as a result 3D pictorial space almost vanishes under isoluminant conditions. *To what extent does pictorial space deteriorate under isoluminant conditions?*

Methods: Stimuli were monochrome halftone photographs, either used as such or transposed to Red/Green or Green/Red hue modulations. In a previous experiment we probed pictorial pose. In the present experiment we used a method of probing pictorial depth via attitude settings of a gauge figure.

Results: The results of this experiment confirm the findings of the earlier study. In both experiments the depth reconstructions for Red/Green, Green/Red and monochrome conditions are very similar and observers perform equally well in Red/Green, Green/Red and monochrome conditions. The general conclusion is that observers do not do worse with the isoluminant Red/Green and Green/Red transposed images. Much of the depth structure of pictorial space is apparently preserved. The notion that spatial representations are not sustained under isoluminant conditions should be applied with caution.

526 Orientation Fields in the Perception of 3D Shape

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If you pick up a typical textbook on perception you'll learn that there are many cues to 3D shape, such as texture, shading, highlights, perspective, etc. Each of these sources of information has a different physical cause. Thus, to interpret each cue, the visual system must impose a different set of computational constraints. This has led to the widely held belief that each 3D shape cue is processed by a separate, dedicated processing stream or 'module'. A considerable amount of research has gone into working out how accurate shape estimates can be derived from each cue, and how these independent estimates can be combined optimally. However, surprisingly little work has been done to try and find *commonalities* between the various cues. Here we show theoretically how shape from

shading, highlights, texture, perspective and possibly even stereo can share some common processing tricks. The key insight is that the projection of 3D surfaces into 2D images introduces dramatic local image anisotropies that depend directly on properties of the 3D shape. Globally, these anisotropies are organized into smooth, continuous, swirling patterns, which we call 'orientation fields'. We have argued recently (Fleming, *et al.* JOV 4(9), 2004) that orientation fields can be used to recover shape from specularities. Here we show how orientation fields could play a role in a wider range of cues. For example, although diffuse shading looks completely unlike mirror reflections, in both cases there is a systematic mapping from 3D surface curvatures to 2D image gradients. Thus, both shading and specularities lead to similar orientation fields. The mapping from orientation fields to 3D shape is different for other cues, and we exploit this to create powerful illusions. We also show how some simple image-processing tricks could allow the visual system to 'translate' between cues. Finally, we outline the remaining problems that have to be solved to develop a 'unified theory' of 3D shape recovery.

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www.psy.gla.ac.uk/

527 Perception of Mirrored Objects

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Perfectly mirrored objects distort the image of the scenery according to the surface curvature of the object. It is theoretically impossible to completely recover the shape of a mirrored object (e.g. from a photograph) because there is an infinite number of possible combinations of illumination and surface properties which lead to the same appearance. Despite this, the human visual system seems to be remarkably adept at constraining the possible interpretations. Based on previous work (Fleming, Torralba, and Adelson. Journal of Vision, 4(9), 2004), this contribution presents two different methods for analysing images of mirrored objects to recover certain properties of 3D shape. We constrain the problem by assuming isotropic contrast information to be present in the surrounding scene. Our first method is a mathematical approach, based on the structure tensor. In this context, the eigenvectors of the tensor tell us the orientation of curvature and the eigenvalues of the tensor give us information about the anisotropy of curvature. Our second method is a biological motivated approach, based on Gabor filters. We apply an iterative refinement in a simple model of cortical feedforward/feedback processing (Neumann and Sepp, Biol. Cybern., 81, 1999). Context information is collected by cells with long-range lateral connections (bipole cells). This information is fed back to enhance regions where local information matches the context. Our approach shows that under the assumption of isotropic oriented contrast information in the reflected world, it is possible to recover two characteristic curvature properties of mirrored objects: (i) the direction of maximal and minimal curvature and (ii) the anisotropy of curvature (ratio of maximal and minimal curvatures). We further demonstrate that the model performs well even if the assumption is violated to a certain degree.

528 Lack of 'Presence' May be a Factor in the Underestimation of Egocentric Distances in Immersive Virtual Environments

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We report the results of a study intended to investigate the possibility that cognitive dissonance in 'presence' may play a role in the widely reported phenomenon of underestimation of egocentric distances in immersive virtual environments. In this study, we compare the accuracy of egocentric distance estimates, obtained via direct blind walking, across two cognitively different immersion conditions: one in which the presented virtual environment consists of a perfectly registered, high fidelity 3D

model of the same space in which the user is physically located, and one in which the presented virtual environment is a high-fidelity 3D model of a different real space. In each space, we compare distance estimates obtained in the immersive virtual environment with distance estimates obtained in the corresponding physical environment. We also compare distance perception accuracy across two different exposure conditions: one in which the participant experiences the virtual space before s/he is exposed to the real space, and one in which the participant experiences the real space first. We find no significant difference in the accuracy of distance estimates obtained in the real vs. virtual environments when the virtual environment represents the same space as the occupied real environment, regardless of the order of exposure, but, consistent with previously reported findings by others, we find that distances are significantly underestimated in the virtual world, relative to the real world, when the virtual world represents a different place than the occupied real world. In the case of the non-co-located environment only, we also find a significant effect of previous experience in the represented space, i.e. participants who complete the experiment in the real world first exhibit less distance underestimation in the corresponding virtual environment than do participants who complete the experiment in the virtual world first.

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529 Discrimination of Possible and Impossible Objects in Early Infancy.

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Our visual system is well equipped to rapidly inform us of whether or not an image depicts a possible viewpoint on a structurally coherent 3-D object. Adult observers can readily classify simple 2-D line drawings as depicting possible or impossible 3-D objects. We examined infants' capacity to detect critical structural variations that determine local relative depth of features and global 3-D object coherence.

Previous work has shown that young infants detect perceptual similarities and regularities in features and attributes of novel objects. We hypothesized, therefore, that infants can form a perceptually complete representation of coherent novel objects even when a critical junction is concealed.

We tested infants aged 4 to 9 months in a habituation paradigm using an 'impossible cube' with a small red occluder concealing the depth cues at the critical junction. The stimulus contained color, texture, and shadow-based depth cues in addition to contour junctions. After habituation infants were shown 6 test trials each consisting of the unoccluded possible or impossible cube. The impossible cube image was constructed by reversing the local interposition cue of two overlapping edges of the possible cube, causing it to be an 'accidental view' of any possible 3-D object.

The infants showed a novelty preference for the impossible cube ($p < .001$), providing evidence for discrimination between possible and impossible novel objects. This finding suggests that mechanisms for representing object coherence are available early in postnatal life. Further, whereas previous research suggests that static interposition and amodal completion cues (as well as other static, monocular depth cues) are not operative until about 6 months of age, the present study suggests that interposition without motion of the occluded object relative to the occluder may be a robust depth cue at 4 months of age.

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Faces: Cognition and Brain

530 The Time-course of Basic- and Subordinate-level Categorization of Faces and Objects

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Novices generally classify objects faster at the basic level than at a subordinate level of abstraction. However, experts can categorize equally fast at both levels (Tanaka & Taylor, 1991). Familiar faces can be categorized as accurately at the basic level ('face') as at the subordinate/identity ('Tom Cruise') level, even at short exposure durations (Tanaka, 2002). Are there sequential stages for categorizing objects at the basic and then the subordinate level but parallel categorization of faces at both levels? Or are there just differences in processing efficiency between objects and faces? We precisely examined the time-course of face and object categorization with a signal-to-respond procedure. In a category verification task, subjects first saw a basic- or subordinate-level label ('DOG' or 'BEAGLE'), and then verified if an object (faces, dogs, or birds) matched the label. Objects were presented for a variable duration (13ms-1664ms) and were pre- and post-masked. Subjects were required to respond immediately after a response signal at onset of the post-mask. At long durations (e.g., 1664ms), basic and subordinate-level categorizations reached ceiling. At intermediate exposure durations (e.g., 416ms), categorization of dogs and birds (but not faces) at the subordinate level was worse than at the basic level. But at short exposure durations (< 104ms), categorization of faces at the subordinate level was worse than at the basic level. This suggests that, even for face experts, categorization at the subordinate level is not as efficient as categorization at the basic level, although face categorization is more efficient than categorization of other objects irrespective of the level of abstraction. Moreover, for all three object categories, the time at which categorization performance increased above chance level was identical for the basic and subordinate levels. This finding argues against sequential stages for basic- and subordinate-level object categorization.

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531 How Holistic Processing is affected by Perceptual Load

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Holistic processing (HP) for faces (and objects of expertise) can be measured in a sequential matching task with two composite images (S1 and S2), when subjects try to selectively attend to one part of the composites (e.g., the top) and ignore the other part. HP is evidenced by a congruency effect between the correct responses on the attended and irrelevant parts. Last year, we reported that misaligning parts of a face composite at encoding did not substantially reduce HP, suggesting that the locus of this effect is not at encoding (Gauthier et al., VSS 2003). Here we investigate the possibility that selective attention during the perceptual judgment is the locus of HP. High perceptual load can facilitate selective attention and reduce the processing of irrelevant distractors (e.g., Lavie, 1995; Yi et al., 2004). We ask if a high perceptual load would increase selective attention to a face part (in other words decrease HP), especially with a load during the matching judgment. We increased perceptual load by adding Gaussian noise to the attended top half of the composites. In a sequential matching task where subjects matched the top of two composites, S1 and S2, the noise was either added to S1, S2 or both S1 and S2. Compared to a control (no noise) condition, perceptual load significantly impaired overall performance, without impacting the magnitude of HP in sensitivity. More importantly, perceptual load increased HP in reaction times, but only when added to S2. These results are consistent with prior findings that HP is more influenced by manipulations at test than at encoding. However, contrary to its influence

in studies where attended and irrelevant information are different objects, perceptual load increased rather than decreased distractor processing. This suggests that the relationship between perceptual load and selective attention depends on the nature of the load and the relationship between attended and irrelevant information.

532 Dissociating visual short-term memory and perceptual capacity for faces and objects

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Face recognition recruits both a different processing style and neural substrate compared to typical non-face object processing (Kanwisher, McDermott, & Chun, 1997; Tanaka & Farah, 1993). Does this influence the perceptual and/or visual short-term memory (VSTM) capacity for faces compared to other object categories? In Exp. 1, we used a probed recall match-to-sample task to estimate VSTM capacity for faces and two categories of non-face objects (cars and watches). Encoding time was manipulated to explore the influence of perceptual encoding limitations on VSTM capacity. A concurrent articulatory suppression task prevented verbal rehearsal. VSTM capacity generally increased with additional encoding time. VSTM capacity was smaller for faces than non-face objects at shorter encoding durations. However, at longer encoding durations VSTM capacity was equivalent for faces and objects. In Exp. 2, we compared the VSTM capacity for upright and inverted faces. Similar to Exp. 1, VSTM for upright faces benefited more from additional encoding time than that for inverted faces. However, VSTM capacity for inverted faces, unlike VSTM for non-face objects, did not reach the same level as that for upright faces. This suggests that experience can influence VSTM capacity. In Exp. 3, we explored the influence of perceptual expertise on VSTM and perceptual capacity. Preliminary results suggest that car experts demonstrate a similar pattern for cars as that found for faces: Car experts benefit from additional encoding time more than car novices. Car experts also appear to have a greater VSTM capacity for cars than do novices. Such results would suggest that object complexity and expertise both influence VSTM capacity. However, effects of expertise emerge with increasing encoding time, suggesting that the manner in which experts encode information may be more efficient and lead to more objects being stored in VSTM.

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533 Faces are processed holistically in the right middle fusiform gyrus

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Two identical top parts of a face appear distinct if their respective bottom parts differ. This notorious 'composite face effect' (Young et al., 1987) is taken as strong evidence for the holistic nature of face perception, i.e. the fact that faces are processed as undecomposed wholes. Here we tested the hypothesis that facial identity is coded holistically by face-sensitive neurons in the middle fusiform gyrus (MFG), where the largest sensitivity to face stimuli has been disclosed in neuroimaging. We used an fMR-adaptation design to compare activity in the MFG while 8 healthy normal subjects viewed blocks of face stimuli in which the top and bottom parts of the faces were either aligned or misaligned. Whereas the top of the face presented in a block was always the same, the bottom parts were identical in the 'same' condition, but differed from trial to trial in the 'different' condition. The design thus consisted of 4 conditions: mis/alignment X same/different bottom parts. The subject's task was to concentrate on the top part and detect rare colour changes occurring at this location. In the face-sensitive area in the right MFG we observed a significant recovery from adaptation to facial identity in the 'different' compared to the 'identical' condition, but only when the top and the bottom parts were aligned. This neuronal response pattern is consistent with the illusion of

viewing different faces, which occurs exclusively in the 'different' blocks consisting of aligned face parts. The neuronal composite effect was also significant, albeit slightly weaker, in the face sensitive areas in the left MFG as well as bilaterally in the inferior/lateral occipital gyrus. Based on these results we hypothesize that the coarse processing underlying holistic face processing takes place first in the MFG and subsequently serves as a header to the processing of detailed features, which relies on the integration of information from the MFG and the inferior/lateral occipital gyrus.

534 Spatially restricted perceptual expertise for faces in a case of prosopagnosia

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Impairments of face recognition have been associated with the failure of one or more of the following processes: fine-level discrimination, holistic processing (failure to selectively attend to a single part), and configural processing (use of the spatial relations between parts). We systematically investigated each of these factors in LR, who has severe prosopagnosia following damage to his anterior and inferior right temporal lobe. Surprisingly, LR showed preservation of all 3 processes: LR was able to detect subtle changes between faces (Exp 1), failed to ignore the irrelevant half of a face when judging whether the tops or bottoms of two faces matched (Exp 2), and also showed a disproportionate effect of inversion for detecting spatial versus feature changes (Exp 3). However, unlike his performance in Exp 1 and 2, LR seemed to process only the lower half of the face in Exp 3. Exp 3 differed from Exp 1 in that it involved a local unpredictable change, whereas the change in Exp 1 affected the entire face (thus attention to any one part of the face would be sufficient to detect a change in Exp 1, but not in Exp 3). Although the change in Exp 2 was also unpredictable, the nature of the change was subtler in Exp 3 than Exp 2 (isolated feature vs. half face). Our interpretation is that LR can encode coarse-level information from the entire face, but is able to extract precise internal details from only a small portion of a face at a time. Exp 4 confirmed that when attention to multiple face features was required, LR could determine the identity of only a single feature. This impairment was evident for nonface objects as well (Exp 5). We conclude that expert face mechanisms are not 'all-or-none', but rather can be impaired incrementally, such that they may remain functional over a restricted spatial area. This conclusion is consistent with previous research suggesting that perceptual expertise is acquired in a spatially incremental manner (Gauthier & Tarr, 2002).

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535 Own-race Face Effects in Processing of Configural and Component Information by Chinese observers

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People are generally better at recognizing own-race than other-race faces. Many current accounts of face recognition argue that this phenomenon occurs because recognition of own-race faces is based on configural processing, which requires perceptual expertise. Without such expertise, recognition of other-race faces must rely on individual components. We tested this hypothesis in Hong Kong Chinese participants, using photographic stimuli of Chinese and Caucasian faces. In Experiment 1, sets of faces were created using Photoshop such that either configural information (distances between eyes, nose, and mouth) or component information (darkness of eyebrows and lips; shape of nose) was different between two exemplars of the same face. Participants viewed a target

image, then were shown two images and were asked to identify the target. Faces could be Chinese or Caucasian, and upright or inverted. Participants showed better detection of changes to Chinese than Caucasian faces, and to upright than inverted faces; however, neither the size of the own-race detection advantage nor the inversion decrement varied between configural or component changes. In Experiment 2, participants initially learned 10 intact Chinese faces and 10 intact Caucasian faces. An old-new recognition paradigm was used at test, with both target and distractor faces of each race being either cut into components and then scrambled (requiring recognition based on features) or intact but blurred (requiring recognition based on configuration). Participants showed an own-race advantage, and better recognition of blurred than scrambled faces; however, the size of the own-race advantage did not vary across change type. In conclusion, both experiments found own-race advantages for both configural and component information. These results suggest that own-race expertise can be sensitive to both types of facial information.

536 The temporal extent of holistic processing

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When complementary halves of different familiar faces are combined into a new face, there is interference in the identification of either half (Young et al., Perception, 1987). This "composite face effect" has been taken as strong evidence for the recognition of faces as single and immediate wholes - "holistic processing". Here we ask if this effect persists when the two constituent parts appear at disjoint times. We presented human subjects with familiar faces briefly flashed in a dynamic stream of visual noise. Faces were shown both upright and inverted, and on some trials a variable interval (up to 160 ms) separated one part from the other. Subjects were instructed to respond according to the identity of one designated part only. Identification of chimeric faces was slower than identification of self-consistent faces; this difference was more robust with upright than with inverted stimuli. For simultaneous composites, this replicates the classical result: inversion disrupts our natural processing of faces as unified wholes and allows the irrelevant part to be disregarded. For sequentially presented parts, this demonstrates that the composite face effect persists across temporal discontinuities. In other words, our expertise at recognizing upright faces appears to involve processes that relate different parts of a face not only across space but also across time.

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537 A single recognition system for faces and objects in expertise-based experiments using synthetic stimuli

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Holistic processing, dominance of configural information, and inversion effect have been characterized for the special face recognition system differed from the object recognition system. However, many studies suggested a single mechanism for all objects and indicated that the degree of perceptual expertise might induce face-specific effects regarded as evidence for multiple domain-specific recognition systems. We investigated this issue using synthetic face and fish stimuli constructed by summation of radial frequency components. We examined (1) behaviorally whether these unfamiliar face and fish stimuli produce no face-specific effects for novices, (2) whether experts who learned the level of gender and race of synthetic faces and the level of body- and tail-shape of synthetic fishes exhibit these effects, (3) whether attention affects experts and novices in the recognition of synthetic stimuli, and (4) whether there are activation shifts of brain areas with expertise in recognizing synthetic stimuli in an fMRI study. In experiments, novices did not show characteristics of holistic processing in face recognition. Dominance of configural information and inversion effect were not observed, either. It was also found that the divided attention affects experts and novices

differently in recognizing faces. Meanwhile, an fMRI study revealed that synthetic faces produced stronger activation in the fusiform face area (FFA) for experts than for novices. However, synthetic fishes produced stronger activation in the parahippocampal gyrus and the anterior cingulate gyrus for novices than for experts, whereas the relative strength of activation in FFA to synthetic fishes was higher for experts than for novices. These results indicate that face and non-face object stimuli activate the same brain area with expertise in recognition. Taken together, our expertise-based behavioral and fMRI data directly provide evidence for a single recognition system for faces and objects.

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538 Neural bases of perceptual expertise in radiologists

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Previous work has established that visual processing in expert radiologists differs from processing in non-experts. To better understand the mechanisms of this expertise we used functional magnetic resonance imaging (fMRI) to compare neural activity in expert thoracic radiologists and beginning radiology residents as they detected abnormalities in chest radiographs. Subjects viewed intact and scrambled chest radiographs and indicated whether a lung nodule was present in a cued region of the image while BOLD fMRI data were acquired using a rapid event-related design. For each subject, regions of interest V1, V2, V3, lateral occipital complex (LOC), fusiform face area (FFA), and radiograph-selective regions were defined using separate localizer scans. Average event-related responses were computed using ordinary least squares from the fMRI time course averaged within each region. In experts regions in lateral occipital cortex showed higher fMRI response amplitudes for intact compared to scrambled radiographs. These radiograph-selective regions were not coincident with the FFA and were weaker or absent in residents.

539 Face-selective "double-pulse" adaptation of the M170 response

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Adaptation techniques provide a powerful means of characterizing underlying neural mechanisms of vision. Here we used a 'double-pulse' paradigm to examine adaptation of the M170 response, a 'face-selective' MEG component. Using this paradigm, Jeffreys (1996) showed reduction in the amplitude of the vertex positive potential (VPP), a face-selective component recorded with ERP, for faces preceded by other faces, but not for faces preceded by nonface stimuli. We replicated and extended this finding by varying the stimulus-onset asynchrony (SOA) between the first (S1) and second (S2) stimulus between 300 and 800 ms. Shortening the SOA dramatically reduced the amplitude of the M170 response to S2. There was also a significant effect of S1 stimulus category: the M170 response to S2 was weaker when S1 was a face than when S1 was a house. Thus, the adaptation of the M170 depends on the category of the S1 stimulus. However, while this differential effect of S1 could be due to stimulus selectivity of the adaptation, it could instead simply reflect the amplitude of the response to the S1 stimulus, with higher S1 amplitude producing greater adaptation of the S2 response. To test these hypotheses, we reduced the amplitude of the S1 face response by adding white noise. If double-pulse adaptation depends on the amplitude of the adapting stimulus, we would expect to see a decrease in adaptation with decreasing amplitude of the S1 response. Also, when the amplitudes of the S1 face and house are equated, the magnitude of S2 response attenuation should be equal. Instead, we found that while, as expected, S1 amplitude decreased with increasing noise, S2 adaptation remained roughly constant across noise levels. Direct comparison of conditions with equal S1 face and house amplitudes also showed greater S2 adaptation when S1 was a face. We

conclude that double-pulse adaptation of the M170 response is indeed face-selective and not due to the amplitude of the S1 response.

540 Is holistic perception of faces specific to our own-race ?

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Humans are experts at recognizing faces across a wide range of viewing conditions. A notable exception to this rule is that of recognizing faces of a different race, for which subjects perform poorly (the so-called 'other-race effect'). In order to understand this phenomenon, it is critical to clarify whether same- and other-race faces processing differs qualitatively. Here, we tested the hypothesis that same-race faces are perceived more holistically than other-race faces. Thirty Caucasian and 30 Asian participants without life experience among other-race faces and presenting a large other-race effect - as measured in an old/new recognition task - took part in the experiment. The differential holistic processing hypothesis was tested by measuring, on same- and other-race faces, the extent to which the recognition of the upper part of a 'composite face' was disrupted by the - to be ignored - lower part of the face (the 'composite effect', Young, Hellawell, & Hay, 1987). Both Caucasian and Asian participants showed a larger composite effect for same- relative to other-race faces, supporting the view that same-race faces are processed more holistically than other-race faces. In conclusion, same and other-race face processing differs qualitatively, the relationships between features being extracted more efficiently from same-race faces, most likely as a by-product of visual experience.

541 Faces are 'spatial'- Holistic perception of faces is subtended by low spatial frequencies

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Faces are processed as wholes more than as collections of elements. The holistic perception of a face is so robust that it influences the processing of its features. Both the whole-part advantage (Tanaka & Farah, 1993) and the composite-face effect (Young et al., 1987) illustrate this point. In the whole-part paradigm, subjects have to recognize (or match) facial features (eyes, nose, and mouth) presented either in a face, or in isolation. Holistic processing is indexed by the better processing of features when they are embedded in a facial context, than when they are presented in isolation. In the composite-face paradigm, the top half of a face is joined with the bottom half of another face, creating a composite face. Observers have difficulty finding that two top halves are identical if the bottom halves belong to different faces, supporting the view that the composite face is perceived holistically, i.e. as a new whole face.

Here, we used these 2 paradigms with spatially filtered faces to test the hypothesis that face holistic processing is supported by information conveyed in low spatial frequencies of the stimulus (Sergent, 1986; Morrison & Schyns, 2001). The whole-part and composite-face effects were measured with faces filtered to preserve the low spatial frequencies (32 cycles/image HSF), or the full spectrum of image luminance variations.

Both the whole-part and the composite-face effects were significantly larger with LSF as compared to HSF faces. While the whole-part effect observed for LSF faces had a similar magnitude as for full spectrum faces, the composite-face effect was larger for LSF faces than for full spectrum faces.

These results suggest that the holistic processing of faces is mostly subtended by coarse information, as provided by LSF. They also yield perspectives about how the various face cues (holistic, featural, etc) might integrate over time to build a robust face representation.

542 An "other-race" effect in perceptual expertise: The interaction between task and stimulus familiarity in bird experts

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Both blocked (Gauthier et al, 2000) and event-related (Xu et al, 2001) designs reveal significant BOLD activation in middle fusiform and lateral occipital gyrus for domains of expertise (e.g., birds and cars). That is, effects of expertise are observed in the same functionally-defined regions of interest (ROIs) associated with face processing. In addressing whether expertise recruits the same neural mechanisms as faces, two recent studies (e.g., Grill-Spector et al, 2004; Rhodes et al, 2004) have used stimuli drawn from the *object class* for which participants were experts, but not from their particular *subordinate* knowledge domain (e.g., antique cars for modern car experts and foreign butterflies/moths for native Lepidoptera experts). It is possible that such studies were subject to an "other-race" effect in expertise. We examine whether this manipulation contributed to findings that nominally argue against an "expertise account" for face-selectivity in ventral-temporal cortex. We compared the neural response in functionally defined face-selective ROIs for Rhode Island (RI) bird experts or novices while they viewed RI and Asian birds. Participants performed four different judgments depending on block: 1-back identity, 2-back identity, 1-back location, and passive viewing. For bird experts in both the passive viewing and 1-back location conditions, we observed little difference in the BOLD responses to RI and Asian birds, but a stronger response for RI as compared to Asian birds in the 1-back and 2-back identity conditions. In contrast, across all face-selective ROIs, bird novices showed similar neural responses for RI and Asian birds. This three-way interaction between task, stimulus familiarity, and expertise may account for apparent disparities in the literature, as well as generally demonstrating the multifaceted nature of face and object processing in the ventral pathway.

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543 Interaction of visual and auditory expertise in birders

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Selectivity in ventral-temporal cortex for domains of visual expertise appears to either overlap or be isomorphic with 'face-areas' (FFA and OFA). We extend such findings to audition, exploring whether similar category selectivity is obtained for domains of auditory expertise, and, if so, how auditory and visual expertise interact when they specify the same object domain. We studied local (Rhode Island) birders who are able to accurately identify individual bird species based on either appearance or bird song. We investigated how an individual birder's level of expertise correlated with neural responses (as measured by fMRI). Bird experts and novices performed two behavioral tasks: visual sequential-matching on images of cars and local birds (Gauthier et al., 2000); and audio-visual simultaneous-matching on images of birds paired with bird songs where an auditory-visual pair was drawn from either RI birds or Asian birds. Performance across these two tasks was used as an index to an individual's level of expertise. Interestingly, an individual's d' s across the two tasks correlated only weakly, suggesting that birders may be better at one modality or the other when recognizing birds.

These same experts and novices participated in a fMRI study in which we identified face-selective regions of interest (ROIs) using a visual 'localizer' and auditory ROIs using a comparison between songs from RI birds and songs from non-avian animals. Similar to the findings of Gauthier et al. (2000), for experts, we observed comparable responses for faces and birds in the face-selective visual ROI. The auditory 'localizer' revealed a cluster of voxels selective for familiar bird songs in inferior and superior temporal cortex. We also explored the cross-modal BOLD response for both bird-

selective regions, that is, visual neural responses when identifying birds by song only and auditory neural responses when identifying birds by sight only.

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544 Timecourse and Anatomy of Recognizing a Familiar Face

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When a familiar person comes into view, visual information, in the form of light, must traverse a vast network of brain regions before it reaches the final stage of conscious recognition of the individual. The present study uses a combination of functional magnetic resonance imaging (fMRI) and diffusion tensor imaging (DTI) to map the flow of visual information in face recognition. In the first part of the study, fMRI was used to map waypoints in the brain critical to recognizing familiar faces. The experiment employed a unique design in which visual information was titrated over time to delay recognition. In each trial, subjects were shown a gray scale image of a famous person (e.g. Bill Clinton) initially occluded by an 8 x 8 matrix of tiles. Tiles were then removed at a rate of 2 tiles/second gradually revealing the image over time. Subject's made a behavioral response the moment they recognized the person in the image. Using this paradigm, recognition of the individual in the image was delayed for several seconds after stimulus onset (mean = 14.67 seconds). The results show a clear delineation between cortical regions contributing to the perceptual encoding of the stimuli and high-level recognition processes. Activity in visual areas implicated in face recognition, including the fusiform gyrus and lateral occipital complex, began to rise the moment visual information was presented (i.e. stimulus onset) and maintained a sustained response up to the point of recognition. At this moment, a second wave of activity was observed in frontal regions in the anterior cingulate and insular gyri. In the second half of the study, DTI was used to assess the axonal connectivity between cortical regions identified in the fMRI experiment. The results of our initial analysis indicate the majority of inputs from the visual cortices come through the anterior cingulate, implicating this region as a potential bridge point between visual information and conscious recognition

545 The Influence of Holistic Information on Face Detection

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One of the central questions in human visual object recognition is whether there is a bottleneck of processing which involves detecting key features prior to recognizing whole objects. If visual recognition is dominantly a bottom-up process it implies that detection of local features precedes higher-level processing. In contrast if recognition uses holistic processing then high-level information provides top-down control for detection of features.

To address this question we carried out psychophysics experiments on 12 subjects who were asked to detect partial and whole face images embedded in visual noise. Control images only contained Gaussian random noise with the same noise variance. To equate the amount of information available in whole and partial images we adjusted the level of noise variance according to the revealed area so that both partial and whole images contained the same total contrast energy (Pelli et al 2003). The features revealed in partial images were selected via a computational

model (Ullman et al 2002) that finds category-specific features with high mutual information for the category and high likelihood for the category.

We compared detection performance on the whole images, partial images containing 1, 2 and 3 features respectively and partial images in which the location of the features were spatially rearranged. We found a progressive increase in detection accuracy when more features were revealed despite the progressively reduced local saliency of individual features. Further, detection accuracy was significantly higher for whole images than any of the partial images. Preliminary data suggests that having the normal configuration of features provides better detection performance than rearranged images. Overall these data imply that the detection of local features is not the bottleneck of processing for face perception and even a simple task as face detection is influenced by holistic information.

Inattentional Blindness

546 Visual short-term memory load induces inattentional blindness

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We have recently shown diametrically opposite effects of visual short-term memory (VSTM) load onto brain activity in two distinct regions of the parietal cortex: While posterior parietal/superior occipital cortex activity increases with VSTM load (Todd & Marois, 2004), the temporal-parietal junction (TPJ) is increasingly suppressed (Todd et al., submitted). Since the TPJ is a key neural substrate for stimulus-driven attention, we hypothesized that TPJ suppression with increased VSTM load should also impair the detection of novel, unexpected visual events. We tested this hypothesis using an inattentional blindness paradigm to measure detection performance for an unexpected salient stimulus while attention was engaged in a primary VSTM task. Subjects memorized the color and position of a set of discs and, following a 5s retention interval, determined whether a single disc presented in a probe display matched in location and color one of the discs in the sample display. The load of the VSTM task was manipulated between two groups of 38 subjects (Low load: 1 object, High load: 4 objects). We measured subjects' performance in detecting an unexpected, novel stimulus appearing in the periphery of the visual field during the retention period of the VSTM task. Far more subjects failed to detect the critical stimulus under High VSTM load than Low VSTM load (Fisher's exact test, $p=.007$). By contrast, almost all subjects detected the critical stimulus when the VSTM task was ignored, indicating that the stimulus was easily perceived under full attention. These results support the hypothesis that VSTM load suppresses the neural circuit for explicit perception of unexpected, salient stimuli.

547 Perceptual Load Induces Inattentional Blindness

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Lavie (1995, 2000) suggested that the processing of task-irrelevant stimuli depends upon the level of perceptual load in the relevant task. Conditions of low perceptual load leave spare capacity which spills over to irrelevant processing. Conditions of high perceptual load engage full attention leaving no capacity for any irrelevant processing. Support for the theory so far derives from indirect measures relying on distractor effects on RTs and visual cortex activity associated with distractor processing (see Lavie, 2005 for review). We report a series of experiments testing the implications of perceptual load theory for explicit awareness of task-irrelevant stimuli. The results show that the level of task-relevant perceptual load determines the extent to which observers are aware of an unexpected task-irrelevant stimulus or conversely exhibit Inattentional Blindness (Mack & Rock, 1998). Awareness reports for an unexpected stimulus (e.g. a square) presented in the periphery or at fixation on one final trial were

significantly reduced during tasks of high perceptual load (e.g. a visual search task with six letters; a hard line-length discrimination task) as compared with tasks of low perceptual load (e.g. a visual search task with just one target letter; an easy color discrimination task). These results demonstrate that visual awareness as measured in inattentional blindness paradigms, critically depends upon the extent to which an attended task engages full capacity. They also rule out alternative accounts for inattentional blindness in terms of expectation or intention, as these factors were held constant across all levels of perceptual load in the current experiments.

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548 The effect of edge filtering on inattentional blindness

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Neisser & Becklen (1975, *Cognitive Psychology* 7, 480-494) identified inattentional blindness; the inability of observers to maintain awareness of events in more than one of two superimposed scenes. The ability of the brain to make use of such multiplexed visual information and avoid confusion is central to the utility of many augmented vision devices, such as see-through head-mounted displays and head up displays. We are developing several such devices to aid people with vision impairments. Visual or perceptual phenomena such as binocular or perceptual rivalry and inattentional blindness may limit the utility of these devices. Many aspects of the display format might possibly affect these phenomena. Specifically, if the two scenes are easier to separate perceptually they may not rival to the same degree.

In this study we investigated the effect of edge filtering on inattentional blindness and the ability to follow superimposed/multiplexed scenes. We closely reproduced parts of the original Neisser & Becklen experiment, and then treated one or both of the video scenes with edge filtering to create a cartoon-like image. The special bipolar edge filtering produced white and black contours at each luminance edge, facilitating clear uninterrupted visibility of the edge-filtered scene over bright and dark sections of the other scene.

Normally-sighted young adults ($n=36$) viewed overlaid videos that included 6 trials with unexpected events, while attending scenes that did not have the events. Edge filtering was applied to the attended scene in two of the trials and to the unattended scene in two trials. We found no evidence that edge filtering affected the detection of unexpected events. However, filtering the unattended scene improved performance of the attended task, as measured by response time to actions in the attended scene. Filtering the attended scene reduced performance of the attended task.

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<http://www.science.mcmaster.ca/psychology/terri.html>

549 Why do we fail to perceive jump-cuts in motion pictures?

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Motivation: For more than a century, motion pictures have been extremely successful in attracting people's attention, yet their psychology is poorly understood or even addressed by the scientific community. One of the more puzzling practices in motion pictures is the frequent use of jump-cuts (abrupt transitions between adjacent scene shots), which are the staple of music television (MTV). Attention research suggests that our seemingly continuous and detailed perception of the real world is the product of highly incomplete internal representations that depend on selective on-demand sampling of continuous environmental inputs. If input continuity is so important, why do jump-cuts often go unnoticed?

Methods: In order to examine the effects of jump-cuts on attentional allocation, we first constructed MTV-style clips, which featured persistent context for 1-3 seconds, from a diverse collection of continuous clips that depict photography-based and computer-generated dynamic scenes. We then performed two eye-tracking experiments with separate groups of subjects, each inspecting either continuous or MTV-style clips. In order to measure the persistence of attention-guiding representations (AGRs), we quantified changes in their inputs and outputs using either local intensity contrast or saliency as probes for the ongoing impact of bottom-up influences on saccade target selection.

Results: Jump-cuts update AGRs within less than 250 ms. AGRs persist for less than 2 seconds even during inspection of continuous clips.

Conclusions: We propose that perceptual continuity is often unperturbed across jump-cuts, despite physical discontinuities, thanks to the brevity and sparseness of mental representations, combined with the ingenuity of moviemakers in manipulating these representations. Our results indicate that integrating computational attention research with the art and technology of moviemaking is technically feasible, and can advance the understanding and practice of both fields.

550 Detecting Transient Changes in Dynamic Displays: The More You Look, The Less You See

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A series of experiments was conducted examining the detectability of transient changes in a dynamic visual search paradigm. Participants viewed displays with numerous moving objects and were asked to detect when an item was added to the display (onset) or when an item changed color. Consistent with the attention capture literature, onset changes were detected better than color changes. This was true even when participants were highly motivated to detect color changes over onset changes. These results are consistent with contingent capture theory which holds that the attention system can be set to respond to either static or dynamic discontinuities, but cannot be set to selectively respond to different change types within each of these categories. Individual scan strategies could account for a large proportion of variance in detection performance in all experiments (up to 50%). Participants who made few eye movements performed best while participants who actively scanned the display performed worst. A surprisingly large number of participants engaged in this later maladaptive scan strategy. Saccadic suppression was ruled out as an explanation for poor performance. Additionally, improved performance for participants who did not move their eyes was not due to these participants fixating an optimal location in the display. We argue that the act of making eye movements hinders detection performance due to a difficulty in forming a stable representation of the display. When poor performers were instructed to reduce the number of eye movements made during search their performance matched that of the best performers. Conversely, good performers who were instructed to actively scan showed a large decrease in accuracy. These results indicate that the optimal strategy for detecting transient display changes is covert rather than overt search. Although intuition tells us that the harder we look for something the more likely we will see it, this may not be true for transient display changes.

551 Did you see that? Unexpected events and salience

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People often believe that they have a fairly accurate perception of the world and events that take place during normal waking life. We know this not to be true. When engaged in cognitively complex tasks, we do not attend to, perceive, and remember some aspects of a scene, even if glaringly conspicuous. A gorilla walking through a scene will often go unnoticed by observers concentrating on a counting task (Simons & Chabris, 1999). Failures in attention and perception have often been implicated in this inattentive blindness. In two experiments, the roles of

attention and perception on detection of an unexpected event are further explored. To do this, the salience of the unexpected event, a gorilla walking through a scene, was manipulated. In the first experiment, the salience of the unexpected event was manipulated by changing the extent to which the gorilla blended into the background of the scene. In the second experiment, the salience of the unexpected event was manipulated by presenting an auditory cue at various times during the observed scene. In both experiments, increased salience of the unexpected event leads to increased detection of the unexpected event, however a very salient unexpected event can still go undetected. Increases in the salience of unexpected events may still not be enough to change the focus of attention away from a cognitively demanding task. Are we simply not good noticers or are we just good filterers?

552 Failed change detection produces volatile short-term memory

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Aim: We probably all had experiences where we gave up looking for a lost item and resumed searching for it later. Although the initial search would be a failure in this case, it could still provide information to aid the exact same search later on, provided that some form of memory keeps such information accessible. The motivating question behind our study is: what kind of information, if any, gets encoded into memory from failed visual searches? Furthermore, if some form of memory arises from failed searches, we wish to know whether it is useful for the same future searches. **Methods and results:** We address these questions using a series of change detection experiments involving flickering displays of randomly arranged polygons. Experiments 1 and 2 present these displays for a predetermined time to limit search success on individual trials, and repeat these trials with novel trials mixed in throughout the experiment. We find that subjects perform on par with or worse than a model that assumes no memory benefits on each repeat of a trial, suggesting that even if memory remains from failed visual searches, it is unable to aid future searches and may cause some people to keep repeating their errant search patterns. Experiments 3 and 4 repeat these time-limited displays more rapidly than experiments 1 and 2 by alternating presentations of those displays with various types of short delays. In contrast to experiments 1 and 2, they suggest that some memory from previously failed searches can aid future searches that occur after delays lasting only a few seconds, but this memory can be disrupted by performing other search tasks during the delays. **Conclusion:** Taken together, these experiments suggest that although some form of memory develops from failed visual searches, it seems short-lived, appears prone to disruption, and may not always assist searches through the same display in the near future.

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553 Change detection in normal, jumbled and inverted scenes.

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Change detection has frequently been studied in well-structured natural scenes, but relatively few studies have explored the degree to which this structure actually facilitates change detection. In these experiments, subjects searched for visual changes in scenes that were normal, jumbled (by rearranging six square sections), or inverted (by a 180 degree rotation). In Experiments 1 and 2, jumbling did decrease change detection. Experiment 3 tested whether the prevalence of terminators at the edges of jumbled sections is the source of the interference by 'windowing' the jumbled sections with occluder strips. Again, jumbling reduced change detection. In contrast, inverting the scenes did not reduce change detection. Combined, these results point to the hypothesis that

reconfiguration of scene sections reduces change detection by effectively adding new objects and surfaces to the scene.

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554 Implicit Change Detection: The Fat Lady Hasn't Sung Yet

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Can undetected changes in visual scenes influence subsequent processing? This issue of implicit change detection is currently very controversial. Using a simple change detection task involving vertical and horizontal stimuli, Thornton and Fernandez-Duque (2000) showed that the implicit detection of a change in the orientation of an item influences performance in a subsequent color change detection task. However, Mitroff, Simons and Franconeri (2002) were not able to replicate this result and attributed Thornton et al.'s findings to methodological biases. We believe that Mitroff et al.'s failure to replicate might stem from several methodological differences between their study and that of Fernandez-Duque. In this study, we offer a conceptual replication of the Thornton and Fernandez-Duque's experiment in which we attempted to address all the methodological issues that we could identify. We found that implicit change detection does not appear to be artefactual, as we could replicate Thornton and Fernandez-Duque (2000) findings after having corrected all the potential biases identified so far in a single experiment. We end by discussing the implications of this new evidence in the debate about implicit change detection.

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555 Incidental Change Detection and Working Memory Load in a Dual-task Paradigm

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Many years of research have been devoted to examining the limits of our visual system. Not only are there limits on the amount of information we can attend to, but there also are limits in the number of items we retain from one moment to the next. Previous data from our lab suggests the capacity limits of short-term memory are relevant for incidental change detection tasks. For example, observers who searched for a complex visual cue during a change video detected fewer changes than observers who searched for a simple visual cue. In addition, observers performed poorly when they had to complete a verbal processing task in conjunction with incidental change detection. The current set of experiments further examined working memory load and change detection in a dual task paradigm, in which change detection was not the primary task. Observers were instructed to search for a more difficult concurrent visual cue. While the cue was much more complex than ones used in prior studies, the task only required observers to store that particular cue while watching the change video. In general, a working memory load effect was demonstrated only when the concurrent task involved the storage and manipulation of information. For example, any task that required observers to hold and process the given cue resulted in change blindness. However, if observers only had to store the given cue, they showed successful change detection. This suggests that the processing/manipulation component of working memory is particularly important for incidental change detection, while storage alone may have little effect on incidental change detection ability.

556 Method to Detect a Gist Change

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Although large changes in an image can go unnoticed, it is assumed that changes which affect the gist will be noticed. However, a method for detecting if a change affects the gist is lacking.

Gist is often viewed as the high-level meaning of an image, but images can have different meanings for different people. Gist is the *interpretation* of the essence of an image.

We have designed a method to determine gist change based on a Generator-Rater procedure. Since gist can be represented in a description, a change affecting the gist would result in a different description. As it is possible that people have a different interpretation of an image, even descriptions of the same image can be different. Therefore raters are used to judge the appropriateness of the descriptions for each of the images. The ratings for groups of descriptions can be compared.

To assess the method, 18 sets of 3 images were prepared. One is the original image. The second image has undergone a relatively large image transform but one that is likely to have no effect on gist. The Third image has undergone a relatively small transform, likely to affect the gist. Participants are shown one of the images and are asked to give a description. A different group of participants (the raters) is asked to rate the descriptions and indicate whether a particular description fits a certain image. Based on these ratings one can derive whether or not the gist of an image has been changed.

The method detects gist change, whilst allowing raters and generators to have different individual interpretations.

557 Threat Images Attenuate Change Blindness

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Ro, Russell, & Lavie (2001) found that changing face images attenuate Change Blindness (CB). We asked if this also was true for snakes which seem to have the capacity to capture attention which has been attributed to our evolutionary past (+hman & Mineka, 2003). Using a version of Ro et al.'s (2001) procedure, we asked whether CB would be attenuated for snakes and another threat stimulus (modern weapons) unlikely to have a long evolutionary history. Using the flicker paradigm 6 images from 6 different categories (snakes, weapons, appliances, clothes, food, and plants) were displayed in a notional circle. 24 Ss viewed alternating displays that either did or did not change. They pressed a computer key as soon as they detected change or no change and reported in which category the change occurred. Snake and weapon changes were reported more accurately than neutral changes. Surprisingly, the speed of snake change detection was not faster than for neutral stimuli, while weapon change detection was. A control experiment asked if the failure to find faster RTs for snake changes was due to the greater similarity between snake images which turned out to be so. Results indicate that weapons attenuate CB and suggest this may also be true of snakes. Like faces, imaged threat objects appear to have a special capacity to capture attention which cannot be entirely attributed to our evolutionary past.

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558 Distinguishing deficits in change detection from deficits in spatial attention in older adults.

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Accurate assessment of visual function in older adults is important for determining competence for everyday tasks. Standard acuity testing is inadequate, therefore measures such as 'useful field of view' have been introduced, showing attention deficits. How do change detection deficits compare with attention deficits in older subjects?

We compared two groups of healthy adults: young (18-30 years, n=15) and older (60-70 years, n=9). In all tasks the subject indicated by a key-press

where an "odd" pattern occurred. Subjects viewed a computer screen which was subdivided into four quadrants, each of which contained one pattern. Each pattern in the single element (acuity) condition was a single line, the odd pattern had a different orientation. In the uniform (attention) and mixed (change detection) conditions, each pattern consisted of four lines arranged in a ring. To control for pop-out effects in the uniform condition, the four patterns had different base orientations. The attention task involved searching for a (target) uniform pattern among non-uniform patterns (where one element had an incremented orientation). In the mixed condition, each pattern had elements of mixed orientations. Corresponding elements of the patterns were identical except the target which had an element with an incremented orientation. The stimulus was free viewed for 4 seconds.

Young subjects did somewhat better than the older group (58 vs 88 orientation thresholds) on single element discrimination. Performance on the attention task showed little change for the young adults (68 threshold), in contrast to significant impairment (158 threshold) for older subjects. For the change detection task, both groups had considerably poorer thresholds (418 for the young adults and 578 for older subjects).

Our results suggest that standard acuity tests and even 'useful field of view' tests significantly underestimate the degree and nature of impairments in real world situations.

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Lightness and Surfaces

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The Perception of Light Fields in Empty Space

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Question: The "Light Field" denotes the radiance as a function of position and direction in space. It generally varies from point to point. The light field is implied by the appearances of objects in a scene, since radiation itself remains invisible. Do human observers "perceive" the light field in the empty space between objects?

Rationale: The "perception" of the light field at a location in empty space can be operationalized as the *expectation* of what a test body would look like when introduced at that location. Expectations can be "measured" via answers to questions that depend upon the existence of such expectations.

Method: A physical scene was set up and stereophotographs were made under a variety of illumination conditions. Photographs were presented stereoscopically and an illuminated spherical gauge figure was introduced at various locations in the scene. Observers were free to adjust intensity, direction and diffuseness of the light field used for rendering the gauge figure. Their criterion was the "fit" of the illuminated gauge figure in the scene. This allows us to quickly "probe" the perceived light field at various locations in the perceived scene.

Result: Observers do perceive at least the intensity, direction and diffuseness of light field throughout the scene with remarkable veridicality. A marked exception is the fact that observers completely fail to perceive the *volume-shadows* of objects.

560 Humans perform brightness task under glare condition using ratio matching

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Purpose. It was shown previously that a peripheral glare source reduces the brightness of a foveal test. This reduction of brightness cannot be explained by a luminance match. In this work we performed an experiment to test the hypothesis that our brightness evaluation task is

affected by lightness intrusion. Methods. Using a magnitude comparison method we evaluated the brightness of a foveal patch and its near surround, when they are presented simultaneously to a transient glare source, for a wide range of patch luminances. The stimuli were in the mesopic range and two glare levels were used (30 lx and 60 lx) with the glare source located 10 deg away from the line of sight. Results. Results show that brightness of both the patch and the surround are reduced by the presence of the glare source. We found that equating local contrast ratios can explain our results if a unique veiling luminance is added to the stimulus for the whole patch luminance range. Conclusions. In coincidence with brightness literature, this finding indicates that brightness evaluations under glare condition have an intrusion of lightness that shift the brightness judgement from a luminance match to a local contrast ratio match.

561 Exploring the Spatiotemporal Dynamics of Brightness Perception by Reverse Correlation

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Illusions where a luminance border gives rise to illusory brightness percept have been taken as evidence that local border contrast plays a dominant role in perceived brightness. One of the key issues has been whether this is achieved by an active, temporally extended filling-in mechanism that propagates the 'brightness signal' initiated by the border responses.

Here, a reverse correlation technique was used to investigate the spatiotemporal characteristics of edge-induced brightness. We used a contrast polarity discrimination task for a 1-D Craik-Cornsweet-O'Brien stimulus in which the edges induce the perception of a 2.6 degrees wide bar appearing either brighter or darker than the background. The target stimulus was shortly flashed (4 frames, 67 ms) added in the middle of a dynamic white noise sequence of 36 frames. A fixation mark was used to indicate both the location and the duration of the target stimulus.

The resulting spatiotemporal classification image shows that brightness perception is associated with two spatiotemporally distinct responses: (1) a spatially local and temporally short border response and (2) a weaker response that corresponds spatially to the illusory brightness percept and is temporally more extended than the border response. Properties of this latter 'brightness' response resemble the output of a spatiotemporal low-pass linear filter. We did not find evidence for significant delays related to the propagation of the filling-in signal: the brightness response does not seem to be markedly delayed when compared to the border response.

562 Edge integration and anchoring in lightness perception: Further evidence against the highest luminance rule

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The highest luminance anchoring rule asserts that the highest luminance in an image appears white and the lightnesses of other image regions are computed relative to the white point. (Wallach, 1948, 1963; Gilchrist et al., 1999). We recently presented a model of lightness computation based on the principle of distance-dependent edge integration (Rudd & Zemach, 2004) and showed that our model predicts contrast induction effects for incremental targets, a prediction that violates the highest luminance rule (Rudd & Zemach, VSS 2003; submitted). Consistent with our model and contrary to the highest luminance rule, contrast effects were observed when subjects were instructed to match increments in appearance. It is not clear, however, whether our subjects were judging lightness or some other dimension of achromatic color. Here we repeat the experiment with instructional variations. Observers were instructed to match incremental targets in either brightness (perceived luminance), brightness contrast (perceived contrast), or lightness (perceived reflectance). Two different lightness conditions were run. In the first, observers were instructed to

imagine that changes in the luminance of the test surround were due to changes in the surround reflectance. In the second, the observers were instructed to imagine that the same luminance changes were due to changes in the illumination falling on the test and its surround. The latter instruction produced large contrast effects that strongly violate the highest luminance rule for lightness. Brightness matches and lightness matches made under the reflectance change instructions produced assimilation effects at high test ring luminances that violate both the highest luminance rule and the distance-dependent edge integration model. The results from all four matching conditions can be accounted for by a modified edge integration model in which the weights given to edges in a neural lightness computation are controlled dynamically by top-down influences.

563 White's effect: removing the junctions but preserving the strength of the illusion

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White's effect (also known as the Munker-White effect) is a lightness illusion in which, contrary to expectations based on simultaneous contrast and Wallach's rule, a gray rectangle predominantly surrounded by white appears lighter than an identical gray rectangle that is mainly surrounded by black. The illusion is often explained in terms of T-junctions that are formed by the three-way intersection of the gray rectangle, a black stripe and a white stripe. In our study we employed a circular variant of White's effect in which all the junctions had been removed. We found that the strength of the illusion was not significantly affected, suggesting that junctions are not an important consideration in all versions of White's effect. We argue that we can explain this new illusion, as well as certain other challenging versions of White's effect, in terms of Gestalt grouping laws and the Anchoring Theory of Lightness Perception (Gilchrist et al., 1999, *Psychological Review*, 106 795-834).

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<http://www.sn1.salk.edu/>

564 Effect of late visual information processing on simultaneous lightness contrast

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The simultaneous lightness contrast (SLC) has been mainly explained by the lateral inhibition in the retinal level of visual information processing. Agostini and Profitt (1993) have reported that the belongingness of target rather than the lateral inhibition could affect the SLC. In addition to common fate and figural alignment which Agostini and Profitt examined, the 3D depth of target and background might work as a critical factor in perceptual belongingness and affect the SLC. We examined this possibility. More importantly, we were interested in how common fate and 3D depth affected the SLC when both provided inconsistent perceptual belongingness information and how the perceptual belongingness interacted with the lateral inhibition in the SLC. In the experiments, the perceived belongingness of the target and the possible effect of lateral inhibition were manipulated independently. Four different conditions were examined; common fate only condition (i.e., perceptual belongingness was defined only by common fate), 3D depth only condition, consistent condition (i.e., both common fate and 3D depth defined consistent perceptual belongingness) and inconsistent condition. The amount of the SLC was measured with the method of constant stimuli. In general, the effect of perceptual belongingness on the SLC depended on the intensity of lateral inhibition. Specifically, the SLC was observed in the 3D depth only condition as well as in the common fate only condition. In the consistent condition, the SLC was perceptually most distinct.

Moreover, the lightness contrast was mostly determined by 3D depth rather than by common fate in the inconsistent condition. These results imply that 3D depth is more critical factor than common fate in determining perceptual belongingness to affect the SLC and that lightness is still processed even at the late level of visual information processing, e.g. after 3D depth information is processed.

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565 Semi-Transparent Layers Enhance the Simultaneous Lightness Contrast

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Helmholtz (1866) reported that the redness of a gray target on a red background was enhanced by covering it with a Semi Transparent Layer (S-TL).

We observed a similar effect in the achromatic domain: when a S-TL is superposed on the classic simultaneous lightness contrast display in order to cover both the targets, the lightness difference between the targets enhances compared to the condition without the S-TL. We explored this phenomenon in a CRT experiment using a simultaneous lightness contrast display with a mid gray (corresponding to 6 Munsell units) targets and S-TLs (transmittance = 50%) with different sizes and simulated reflectances. The relative size of the S-TL was varied amongst 5 levels: 1.3, 1, 0.74, 0.5 and 0.3 times the area of the black and white backgrounds. Two levels of the simulated reflectance of the S-TL were used: corresponding to 4 and 8 Munsell units. Observers were asked to select, from a Munsell scale, two patches: one matching the lightness of the target standing on the white background and the other matching the lightness of the target standing on the black background. Results showed that the lightness difference between the targets was enhanced, with respect to the condition without the S-TL, when the relative size of the S-TL was equal to 0.74, 0.5 and 0.3, while the lightness difference was reduced when the relative size was 1.3 and 1. Furthermore, the enhancement of the lightness difference increased as the simulated reflectance of the S-TL decreased. According to Soranzo and Agostini (in press) we suggest that these results could be explained by the relation among the luminance ratios between the Contextual edge (the edge in the surrounding area) and the Mediating edge (the edge in the enclosed area).

566 Elongations Near Intensity Maxima: A Cue For Shading?

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The term 'shading' typically refers to illuminance variations on a curved 3D surface. Familiar examples are a wrinkled shirt, or a snow pile. Shading is distinguished from 'texture' which refers to surface pigmentation variation only, familiar examples being marble or wood grain. A natural yet neglected issue in understanding perception of shading and texture is how the visual system distinguishes them from each other from a single image (Freeman and Viola NIPS 1998). We address this issue by studying a newly discovered signature for shading which occurs near intensity maxima, namely that isoluminance curves due to shading are significantly elongated near intensity maxima. We show that these elongations can produce large kurtosis in the outputs of Gabor filtered shading patterns. We show how this statistical property depends on the interaction of surface geometry and illuminant direction. We discuss conditions under which the elongations could be used as a cue for distinguishing shading from texture.

567 Combining achromatic and chromatic cues to transparency

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Metelli's model has inspired considerable research on achromatic and color transparency. However, the way in which the chromatic and achromatic components of a color display combine to determine percepts of transparency has not been investigated. For instance, do the two components serve as separate 'cues to transparency'? We used stimulus displays that are the superposition of chromatic and achromatic displays, and examined observers' setting variability in adjusting one part of a display to maximize perceived transparency.

Methods: We presented six-region displays containing a small filter upon a larger background. (Kasrai & Kingdom 2001). The achromatic stimuli varied in luminance, the chromatic stimuli varied along an equiluminant line segment from 'yellow' to achromatic (equiluminance measured separately for each observer). A display was consistent if the ratio of luminance or an analogous ratio for color was constant across the edge of the filter region. The stimulus in the L condition is an achromatic display, in the Lc condition, the superposition of the L display with a consistent chromatic display, and in the Li condition, the superposition of the (L) stimulus with an inconsistent chromatic display formed by exchanging two filter regions in the consistent chromatic display. In the Lc condition, the filter edge ratio was identical for the chromatic and achromatic components. Four observers made 135 settings for each of the displays, adjusting one filter region of the display to optimize transparency.

Results: We computed setting variance for each of the three conditions for all four observers separately and compared the variances across conditions. Across observers, Lc settings were less variable than Li settings. For three observers, Lc settings were less variable than L settings. Color enhances the precision of perceived transparency when it is consistent with transparency.

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568 Imperfect Scission in Achromatic Transparency

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In achromatic transparency, Beck and Ivry (1988)* have found that color scission is not perfect, i.e., observers report that the color of the background seen through the transparent region differs from the color of the background seen directly. The present study was undertaken to define the relations between stimulus luminances that produce such an imperfect scission. Following a black fixation point, experimental stimuli were displayed for 1 sec on a monitor screen. Each consisted of a bicolored rectangle (188 x 21.58) with a smaller transparent square (78 x 78) placed on the center of the rectangle. Let P and Q be the luminances of the left and right halves of the transparent region and let A and B be the luminances of the left and right halves of the rectangle outside the transparent region, respectively. Four values for A, B, P and Q were present. For each of the combinations of these values a stimulus was constructed with the restrictions that A had to be always smaller than P, Q, and B, that B had to be always greater than Q and P, and that P had to be always smaller than Q (thus $A < P < Q < B$). Eighteen naive subjects served as observers. To each of them, the entire series of stimuli was shown twice with stimuli presented randomly. Subjects were asked to report whether the colors seen through the transparent region on the left and right halves of the background were the same or were different from the colors seen directly on the left and right halves of the background, respectively. All subject showed imperfect scission. Mean response proportions indicate clearly that the relation A / P , when subjects look at the left half of the transparent square, and the relation B / Q , when subjects look at the right half of the transparent square, are the only factors that determine the extent of color scission.

*Beck J, Ivry R, 1988 P & P 44, 585-594

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569 Change in illuminant direction alters perceived surface roughness

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We investigated visual estimation of surface roughness of 3-d textures under various lighting conditions. To construct a texture, first we made a jittered planar grid. Next, vertices were chosen above each grid intersection with a random height. Vertices were joined to create a triangulated surface. The variance of the height distribution was our measure of roughness. These surfaces, with Lambertian (matte) reflectance, were rendered for binocular viewing (viewing distance: 70 cm) under one of three punctate illuminants located 20, 30 or 40 deg to the right of the surface normal. In Experiment 1, the surface patch was viewed in isolation through an aperture. Observers viewed two surface patches in succession, each rendered under a different punctate illuminant, and indicated which appeared to be rougher (2 IFC). Using interleaved staircases, for each pair of lighting conditions, we determined the roughness of a surface under one illuminant that appeared equally rough as a given surface under the other illuminant. Participants showed a strong bias for perceiving a surface to be rougher as the illuminant moved further away from the surface normal. Thus, observers were not roughness constant. In a second experiment, we removed the aperture and added both matte and specular objects (and their cast shadows) to the scene to provide additional cues to the direction of the illuminant. Roughness discriminations were performed with and without the added objects. The additional illuminant cues improved roughness constancy, but only slightly. In addition, the results displayed approximate transitivity: if surface A in 20 deg illumination appeared equally rough as B in 30 deg illumination, and likewise B in 30 deg and C in 40 deg, then A and C appeared approximately equally rough in their respective illuminants. This is the first study to directly test the visual system's ability to maintain a constant estimate of roughness under changing illumination conditions.

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570 Image statistics as a determinant of reflectance perception

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The perception of surface reflectance has typically been restricted to the case of smooth matte surfaces viewed in simple illumination. In the real world, many surfaces are neither smooth nor matte, and they are viewed in complex illumination. Complexity can sometimes make the problems simpler; for instance, it has recently been shown that the statistics of natural illumination give rise to image statistics that can be used in estimating the reflectance of smooth objects like spheres. We have taken up the case of rough surfaces such as stucco, and have asked whether simple low-level image statistics might be used by humans in estimating their reflectance. We took photographs of rough materials and distorted their luminance histograms. Subjects were asked to rate the reflectance (black to white, on a five point scale) of a surface in the image whose mean, variance, and skew were independently manipulated by means of histogram matching to variable Beta distributions. Skew had a strong effect, as did the mean, while the variance did not. With the same mean and variance, the surface whose luminance histogram was more positive was systematically judged to be less reflective. The same experiments were run with phase scrambled versions of the images, and in the cases where these images were seen as surfaces, the histogram statistics had similar effects. These results support the notion that simple image statistics can be important factors in the perception of surface reflectance.

Modal and Amodal Completion

571 Backward masking of illusory contours or their inducers depends on timing

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Objects in visual scenes may be only partly visible, rendering the extraction of context-induced illusory contours (ICs) an essential process in object and scene perception.

Physiological and psychophysical studies show interaction and overlap between real and illusory processes in the first visual areas, suggesting a feedforward-feedback mechanism with the IC being developed first in V2, but fed back to V1. In such a mechanism real lines would interact early with inducers only, but later predominantly with the IC.

We tested this hypothesis in an orientation discrimination task with an oblique abutting line pattern as inducer. The backward mask grating was identical to the inducers, oriented either the same, horizontal, vertical, or opposite oblique. The stimulus was presented for 100 or 130 msec, followed by a 100 msec mask. Orientation discrimination thresholds for the IC under each masking condition were obtained and compared to an unmasked condition. Real lines are masked best by parallel real lines. We thus expected strongest masks to be oriented parallel to the inducers if they interact with the inducers, but parallel to the IC if interfering with the illusory percept. In the hypothesized feedforward-feedback mechanism, we would expect only masking of the IC after completion of the illusory percept. Earlier, however, masks parallel to the inducing stimuli would interfere strongest with perception.

At 100 msec presentation time all line patterns were found to mask with varying strength, suggesting either a fragile state in processing, or an overlap between real and illusory processes. We found at 130 msec only masking by lines parallel to the IC, indicating IC-completion. We speculate that even earlier interaction would show solely inducer masking.

Our results support the hypothesized mechanism by distinguishing at least two steps of IC processing: mixed processing of inducers and IC at 100 msec, but later processing and neural representation of the IC alone.

572 Tolerance for misalignment in contour interpolation: retinal or relational?

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Problem: Contour interpolation has been shown to be scale-invariant in some respects, as in the effect of support ratio on contour strength. Kellman & Shipley (1991) hypothesized that the mathematical criteria of contour relatability included a small tolerance for misaligned parallel edges. Empirical estimates have suggested that collinear edges can be misaligned up to about 15 arc min and still support interpolation. We investigated whether a retinal metric or a scale-invariant notion, such as ratio of misalignment to edge separation, could account for the data. Methods: Tolerance for misalignment was tested in a two interval, forced choice, path detection paradigm. Targets were paths of 4 spatially separated contour segments (illusory contour inducers) that were collinear or misaligned to varying degrees. Paths were presented in noise consisting of identical contour segments, randomly oriented. The target inducers were collinear or misaligned relative to the axis of global alignment. Within each level of retinal misalignment, inducers were positioned to create 5 different relative angles between interpolating elements. Results: Angular misalignment had no independent effect on performance. Instead, a retinal tolerance of 10-15 min was confirmed. There was a reliable interaction between relative and retinal misalignment; at retinal misalignments beyond 10-15 arc min, larger relative angles markedly lowered performance. The geometry of the displays dictated that this increase in relative angle increased the distance (gap size) between the target elements. Further experiments tested whether this interaction was

limited to interpolation or involved other grouping processes. Conclusions: Tolerance for misalignment is largely determined by a retinal metric. Angular misalignment appears to modulate residual interpolation effects beyond 10-15 arc min, a result that may be explainable in terms of increased position or orientation uncertainty for more separated contours.

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573 Illusory shape pop out: Effects of perceptual learning

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It is well documented that odd elements are easily detected when embedded in a field of distractors that are similar to each other and differ categorically from the odd element in one feature, such as color, orientation, motion direction or shape. We have claimed that this "pop-out" effect is due to high-level rather than low-level mechanisms (Hochstein & Ahissar, 2002). We now ask whether the relevant shape needs to be defined by real edges or do illusory contours (Kanizsa, 1979) also induce a pop-out effect, though their perception is slower, and to what extent does such pop-out depend on illusory-contour training history. Previous studies investigated the possibility of a pop-out effect when subjects search for a set of illusory-contour inducers among a field of non-inducers (Grabowecky & Treisman, 1989; Davis & Driver, 1994), while we tested detection of an odd illusory shape among illusory distractor shapes (see Gurnsey et al., 1992). We tested subjects with different levels of training on a Kanizsa illusory contour task, detecting an illusory parallelogram among illusory triangles. Set-size effects and mean response time were analyzed to determine if the classical tests for pop-out (relative set-size independence for odd element present trials) is relevant also for slowly induced percepts. A significant difference in performance, as well as in learning rate, was found between subjects with different levels of training. In contrast, a control experiment with real (rather than illusory) figures showed significantly less dependence on training level. These results suggest that with training detection of Kanizsa figures is parallel - i.e. these figures do pop-out!

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574 Modes of Darkness Appearance: The Blacker-Than-Black Effect

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Blackness and whiteness are not symmetrical in figure-ground organization. Figures are usually light, they stand out against a darker background and they are cohesive. When contrast polarity is reversed, what used to be figure becomes a cut-out or hole. Holes are typically dark. They have no figural properties, are part of the ground and appear to lie behind. The shape of a hole is defined by the border around it, but the border belongs to the surround. Take a light blue annulus on a black background: the enclosed area looks co-planar and has no surface quality of its own. Now take an Ehrenstein figure with gray radial lines: the central area looks darker than the background and stands out like a disk. We demonstrate that when the blue annulus and the gray Ehrenstein figure are combined, the central disk assumes an emergent property: the blackness becomes blacker and its mode of appearance changes to a void. Method: An 4 x 4 array of Ehrenstein figures was used in which a light blue (or gray) annulus on a black background bounded the inner tips of the grey radial lines. Subjects rated the blackness in terms of self-luminosity, density and surface color when the number, length, width, and contrast of the radial lines were varied. Results: The illusory disks of the standard Ehrenstein pattern appeared as figure, darker and denser than the background. When blue annuli were added, the central areas appeared even darker and could be perceived as holes without any density.

Conclusion: Radial lines are crucial to the blacker-than-black effect, attesting to the importance of long-range effects on the mode of blackness appearance. The results suggest an explanation in terms of brightness and darkness systems involving long-range cortical mechanisms.

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575 Amodal Completion Improves Perception of Illusory Contours Defined by Motion

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Purpose. Illusory contours can be produced by moving the modulation of luminance in a random dot pattern. We study here how amodal completion interacts with contours defined by motion in a vernier acuity task. **Methods.** The stimulus consisted of a rectangular patch containing a random dot pattern in which no dots ever moved relative to the background. The luminance of the dots was modulated to define a vertical imaginary bar. The patch was horizontally divided in two equal parts. We used a vernier acuity test between the upper and the lower bar to evaluate how sharp the contour was perceived in each condition. To do this, we manipulated the phase of the modulation in both parts. Three stimulus configurations were used. For the first one, the area surrounding the patch was set to a luminance of 19 cd/m², and no amodal completion was used. For the second configuration, amodal completion was achieved by adding to the first configuration two rectangles to the ends of the bars (outside the patch area) with the same luminance as the dots bars. For the third configuration, the area surrounding the patch was set to the same luminance as the black dots, and amodal completion was achieved as in the previous configuration. Importantly, for all the three configurations, the patch background was set to a luminance of 19 cd/m², and the contrast between dots defining the bars (white) and the rest of the dots (black) was 1. **Results.** Vernier thresholds were measured for four different dot densities and for a wide range of speeds. Results show that thresholds obtained with the first configuration (no amodal completion) are higher than those obtained with amodal completion. The effect is less notorious as speed and density increases. No differences were obtained between second and third configurations. **Conclusions.** Results show that amodal completion improves the perception of illusory contours defined by motion. This suggests that there is an interaction between these two boundary completion modes.

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576 When Two Wrongs Do Make A Right: An Illusory Contour Phenomenon

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Illusory contours occur when alignment cues cause the visual system to see a contour when none is physically present. The best known examples are the line terminator type and variations on the Kanizsa Triangle. The phenomenon is interesting in many ways; it is a very strong percept for an experienced observer, but is sometimes not seen at all by naïve observers. A fun phenomenon always inspires a multitude of experiments, and in exploring illusory contours many comparison stimuli have been examined that are similar to the illusory contour inducer sets (collinear pacman wedges), but which dramatically weaken or even eliminate the percept of the contour and/or the resulting surface. Kanizsa-type illusory contours are weaker when 1) the inducers are farther apart, 2) the support ratio (inducer:gap) is lower, 3) the contrast is reduced, 4) the inducers are fuzzy rather than crisp, or 5) the inducing contours are misaligned by rotation

(so that the required contour would need to be inferred as curved) or by orthogonal translation (so edges remain parallel but not collinear). They are also less salient if 6) the corners of the inducers are rounded, or if 7) the path of the illusory contour is interrupted, either by something crossing the path or even by a real line which follows the path.

Not surprisingly, adding several of these weakening factors to a stimulus typically produces a yet weaker illusory contour percept. However, this is not always the case. When the inducers of a standard Kanizsa figure are blurred, they become less effective. When the inducers are rounded and moderately misaligned (rotation and translation), a boundary can still be inferred but there is no actual illusory contour perceived. But, when a stimulus with rounded, misaligned inducers is blurred (e.g. by squinting), a robust percept of a subjective figure emerges! Subjects' performance indicates stronger contours occur when both of these 'weakening' effects are present than either one alone.

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577 How Are Complex Stereograms That Define Partially Occluded Surfaces Amodally Completed In Depth?

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When we view a 3D scene, object features are seen on 3D surfaces infused with lightness and color at the correct depths. Most models of 3D vision do not explain how this happens. A 3D LAMINART model proposes how laminar cortical mechanisms interact to create such 3D surface percepts using interactions between boundary and surface representations (Grossberg and Howe, 2003; Grossberg and Swaminathan, 2004). The present work develops the model to predict how textured images with multiple potential false binocular matches, such as dense stereograms, generate the correct 3D surface representations of figures and their backgrounds. In addition, the model shows how, when textured stereograms define emergent occluding and occluded surfaces, the partially occluded textured surfaces may be amodally completed behind the occluding textured surface. The model hereby provides a unified explanation of data about stereopsis and data about 3D figure-ground separation and completion of partially occluded object surfaces. The model clarifies how interactions between layers 4, 3B, and 2/3A in V1 and V2 contribute to stereopsis, and proposes how binocular and monocular information combine in V2 and V4 to form 3D boundary and surface representations. The model extension includes an important role for surface-to-boundary feedback to eliminate many spurious boundaries that could otherwise interfere with correct object recognition at inferotemporal cortical processing stages. In particular, a disparity filter and 3D cooperative-competitive grouping laws are predicted to interact with 3D surface filling-in operations via feedback between V2 pale and thin stripes, respectively, to overcome this problem. This interaction also triggers figure-ground separation of occluded and occluding objects, and helps to convert the complementary rules for boundary and surface formation (Grossberg, 1994) into a consistent visual percept.

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578 The effect of occlusion on amodal completion and surface slant perception

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In natural environments, occlusion of objects occurs because of the unique viewpoint of an observer and the three-dimensional geometry of the scene. When one object partially occludes another, we perceive the visible portions of the occluded object as part of a single object. The perceptual completion of the visible features is called amodal completion (Michotte, Thines, & Grabbe, 1964/1991). In the present study, we investigated the role of occlusion in amodal completion for surface slant estimates based on stereoscopic cues. We used three surfaces composed of random dots. Two

large half ellipses with the same slant were aligned vertically and a small elliptical patch was centered between them. Subjects estimated the slant difference between the small central patch and the two large surrounding patches. In the first condition, the three random-dot surface patches were presented unoccluded. In the second condition, a fourth rectangular surface with a center aperture was added to occlude the space between the three random-dot surfaces. Under this condition, the three random-dot patterns were seen as a single partially occluded surface (i.e. amodal completion). The perceived slant difference between the center surface patch and surrounding patches was smaller when an occluder was present in the second condition than in the first unoccluded condition. The effect of amodal completion was independent of the depth and the slant of the occluder when varied independently of the surrounding patches. The results show that slant estimation of the center small surface is biased towards the slant of the outside surfaces and this amodal completion was enhanced by partial occlusion.

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Eye Movements: Physiology and Mechanisms

579 Saccadic modulation of activity in human LGN and V1.

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During saccades the visual image moves across the retina at high velocity, yet no blurring of the visual scene is perceived. Suppression of visual sensitivity at the time of saccades has been shown in many studies of human visual perception and may contribute to maintaining perceptual continuity across saccades. However, the neural mechanisms underlying this saccadic suppression are unclear. We used functional MRI in combination with retinotopic mapping to examine responses in cortical and sub-cortical visual areas during saccades in seven normal subjects. We found that activity in both primary visual cortex (V1) and the lateral geniculate nucleus (LGN) was strongly modulated by saccades. Furthermore, this modulation depended on the strength of concurrent visual stimulation. In complete darkness and in the presence of visual stimuli that evoked weak activation of V1 and LGN, saccades led to reliable signal increases in V1 and LGN (corollary discharge). However, in the presence of strong visual stimulation, saccades led to suppression of visually-evoked responses in V1 and LGN (saccadic suppression). This pattern of modulation of activity by saccades supports a model of saccadic suppression where corollary discharge has a suppressive effect on visually evoked responses at the earliest stages of visual processing.

580 Activity of superior colliculus neurons during parafoveal pursuit

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Purpose: The rostral superior colliculus (SC), which represents the central visual field, has been shown to be involved in smooth pursuit. However, it is not clear whether pursuit-related activity arises rostrally in the SC because the stimuli used to guide pursuit are typically foveal or because the gaze errors during pursuit are typically small. We investigated caudal and rostral SC buildup neurons in a task that dissociated the goal of pursuit from the visual stimuli driving it.

Methods: One monkey was presented with two moving bars (3°-5.6° high x 0.44°-0.9° wide) placed 13°-25° apart at symmetrically opposite locations in space. The bars were oriented perpendicular to the axis connecting the center of the screen with the bars' centers and translated together along this axis in a sinusoidal fashion (trajectory amplitude and frequency: 4° and 0.7Hz). In tracking trials, the monkey was required to maintain its

gaze within 2.5° of the midpoint between the moving bars. In fixation trials, the monkey fixated a stationary spot and ignored the bars. For caudal sites, one bar was placed in the neuron's response field; for rostral ones, the bars were placed as eccentric as possible. For all our sites, visual stimuli guiding pursuit never came closer than 4° to the monkey's gaze.

Results: Neurons in the caudal SC with no visual responses did not respond during parafoveal pursuit. Caudal neurons with visual responses were active, but not necessarily more so than during passive viewing of similarly placed bar stimuli during fixation. In contrast, rostral buildup neurons were modulated during parafoveal pursuit even though bars placed at the same retinotopic locations during fixation caused little or no change in their activity.

Conclusion: Pursuit-related activity in the SC remains rostral even when the visual stimuli are represented by caudal neurons. Thus, pursuit-related activity in the SC appears to reflect the goal of pursuit, not the stimuli guiding it.

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581 Interaction Between Visual and Prior Information on Superior Colliculus Neurons

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Purpose: Saccades are guided by prior information as well as by sensory signals. Saccade-related neurons in the SC are responsive to both of these factors individually, and it is typically assumed that visual and prior information have additive effects on the activity of SC neurons. To test this idea, we have measured the sensitivity of SC neurons to prior information on a millisecond timescale.

Methods: We recorded from buildup and burst neurons (n=85) in the SC of two monkeys during a luminance discrimination task. Monkeys initially fixated a central fixation cross on a random noise background, and two boxes at 6 deg on either side of fixation demarcated possible target locations. On cued trials one box briefly reversed contrast, indicating the likely location of the upcoming target (75% certainty). After a random interval, two Gaussian-blurred discs were added, one slightly brighter than the other. The monkey was rewarded for making a saccade to the brighter disc.

Results: We constructed 'cue weighting' ROC curves to assess the neuronal sensitivity to prior information. The 'signal' distribution came from trials on which the target and the cue were presented in the response field; the 'noise' distribution came from trials on which only the target appeared in the response field. For the population of neurons that showed higher activity with the cue (32/85), the average ROC area was significantly larger prior to stimulus onset than during the visual response. During both the baseline and visual epochs, neuronal sensitivity to prior information was correlated with the behavioral bias caused by the cue.

Conclusions: The sensitivity of SC neurons to prior information is not strictly additive with visual inputs but instead changes within a trial, especially during the visual response. The correlation of these effects with bias suggests that the interaction between visual and prior information on SC neurons reflects the current behavioral strategy of the subject.

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<http://mysite.verizon.net/vzeejf0b/index.html>

582 Vector Subtraction and Eye Position Gainfields in Macaque Frontal Eye Field

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Spatially accurate saccade planning and perceptual localization require the integration of retinal and extraretinal signals. The way that retinal and extraretinal signals are combined determines the specific computation that is performed. For vector addition, retinal and extraretinal signals are spatially correlated, while for vector subtraction, the signals are anti-correlated. To characterize the interaction of retinal and extraretinal signals, we trained 3 macaque monkeys to perform a delayed visually guided saccade task in which both target eccentricity and initial eye position were varied. We recorded from 70 neurons in frontal eye field. We first tested cells with a delayed memory saccade task to determine the receptive/movement field. Then, using the visually-guided saccade task, we determined the eye position sensitivity and retinal sensitivity for neuronal responses during the visual and pre-saccadic task epochs. These sensitivities give an estimate of the gain field and the retinal receptive field of the neurons respectively. We found that the initial response to the saccade target was modulated by initial eye position in 51/70 (73%) neurons. In 47/70 (67%), the retinal and eye position signals were spatially anti-correlated and thus satisfied the constraint appropriate for vector subtraction, while 4/70 (6%) satisfied the vector addition constraint. Presaccadic activity was modulated by initial eye position in 42/70 (60%) neurons. Spatially anti-correlated retinal and extraretinal signals were found in 30/70 (43%) neurons, while correlated signals were found in 12/70 (17%) neurons. Across the population, the manner in which retinal and extraretinal signals are combined in FEF strongly favors vector subtraction rather than addition. The results are consistent with a model in which vector subtraction is computed from the responses of a network of cells with retinal receptive fields that are modulated by eye position in a gainfield-like manner.

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583 Incomplete suppression of distractor-related activity in frontal eye field results in curved saccades

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Saccades made in the presence of distractors show significantly more trajectory curvature than movements made without distractors. Previously, we reported that saccades curving toward a distractor during visual search are accompanied by increased superior colliculus (SC) activity at the distractor site immediately before the onset of the movement (McPeck & Keller 2003; also see Port & Wurtz 2003). On the basis of this, we speculated that curvature results when a movement is initiated before selection of the target from distractors has been fully resolved. To test this hypothesis, we recorded activity in the frontal eye field (FEF) during search. In contrast to the SC, activity in FEF is normally poorly correlated with saccade dynamics. However, the FEF, like the SC, is known to be involved in target selection. Thus, if saccade curvature is due to incomplete target selection, we expect greater FEF activity at a distractor site for curved saccades, similar to what was seen in the SC. We found that saccades that curve toward a distractor are indeed accompanied by increased FEF activity at the distractor site. This curvature-related activity appeared to persist longer in the FEF than in the SC, where it was abruptly curtailed upon saccade initiation. To verify that the activity was causally related to curvature, we microstimulated in the FEF. The stimulation was sub-threshold for evoking saccades, but when it had a temporal structure similar to that observed for curved saccades, it induced systematic movement curvature. These results support the idea that saccade curvature in search results from incomplete suppression of distractor-related activity during target selection.

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584 Motivational Scaling of Visual Responses in Macaque Area LIP

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Both saccade reaction times and orienting choices are sensitive to the value of rewards associated with visual targets. Similarly, increasing the reward value of orienting to a visual target enhances neuronal responses in several visual-oculomotor brain areas. One question these observations raise is to what extent reward modulation of neuronal activity in such areas reflects nonspecific changes in motivation or arousal rather than the relative value of a particular target or eye movement. Here we show that increasing the size of fluid rewards in blocks reduced saccade reaction times and improved visual detection performance in monkeys performing a peripherally-cued saccade task, suggesting enhanced motivation. Area LIP neurons responded to visual cues spatially segregated from the saccade target, and these responses were enhanced by increasing reward. Moreover, neuronal responses closely tracked local changes in reinforcement rate associated with task performance rather than the specific value of each cue. These data demonstrate that dynamic changes in motivational state contribute to neuronal activity in LIP.

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585 Saccade direction information appears earlier in the caudate nucleus than the frontal eye fields and prefrontal cortex during conditional visuomotor learning

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Previous work by ourselves and others has shown that neurons in the prefrontal cortex (PFC), the frontal eye fields (FEF) and the caudate nucleus (Cd) carry task relevant information during conditional visuomotor learning in primates. Specifically, cells in all three areas show selectivity for the impending saccade direction during cue presentation and around the time of saccadic response. To delineate the specific roles of the Cd, PFC and FEF in the choice and execution of saccades, we compared the timecourse of direction selective activity in these areas as animals performed a conditional visuomotor learning task.

Monkeys learned associations between two novel visual cues and two saccades (right or left). A delay intersposed between the cue and saccade. Once the associations were learned, they were reversed and the monkeys then relearned the opposite contingencies. As reported previously, cells in the PFC, FEF and Cd carried information about object identity, saccade direction and their association during all trial epochs. During the cue and saccade epochs, population direction selectivity appeared earliest in Cd and peaked at the time of saccade. Selectivity appeared next in the FEF and last in the PFC. Half-maximum selectivity was aligned on saccade onset in the FEF and after saccade onset in the PFC. These findings suggest that the FEF is more closely associated with the motor control of saccades while Cd activity influences the choice of saccade direction. The pattern of PFC results fit well with its proposed role in executive control.

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586 Two components of oculomotor pursuit isolated by covariance based methods

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We assessed covariation in performance between 55 individuals on various psychophysical tasks as well as an oculomotor pursuit task to a ramped stimulus. This analysis isolated two pursuit components of particular interest: 1) an early 'latency' component consisting of latency to both presaccadic pursuit and the initial saccade, and 2) a later 'accuracy' component consisting of accuracy of eye velocity during the 120ms

following the first saccade. The early pursuit component was associated with three dynamic psychophysical tasks: motion detection ('Newsome' paradigm), velocity discrimination, and counterphase flicker identification. However, it was not associated with our two static psychophysical tasks: form detection and orientation discrimination. We propose that this pattern of results may reflect the presence of a high-level, temporal resolution of attention mechanism. It cannot reflect an entirely motion based mechanism because the counterphase flicker identification task does not evoke a motion percept, and moreover its thresholds are quite slow, ranging from 2 to 6 Hz. It is unlikely that it reflects a generalized visual or temperamental mechanism because then one would expect the static psychophysical tasks to covary as well with this early stage of pursuit. The later, 'accuracy' pursuit component was associated only with psychophysical velocity discrimination. Since this component was not associated with psychophysical motion detection, we propose that it reflects the presence of a mechanism devoted specifically to motion magnitude estimation, distinct from mechanisms devoted to the detection of motion.

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587 Effects of Structured Backgrounds on the Latency of Saccadic Eye Movements

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It has been suggested that remote distractors increase saccadic latency by increasing the firing rate of collicular fixation neurons near the time of target onset, and that the distributed network of these cells might extend as much as 10 deg from the foveal center. Since then several studies have pointed to the superior colliculus as the substrate behind an inhibited saccadic response due to non-target stimulation covering a large portion of the visual field (i.e., a display change). We examined this further by presenting a spatially continuous form of non-target stimulation (a patch of random noise) of various sizes while observers made a saccade to a simultaneously presented peripheral Gabor-target (4 c/deg, 4, 7 or 10 deg, left or right of fixation). A small patch (2.3 x 2.3 deg) of centrally displayed random noise produced a significant increase in saccadic latency consistent with the remote distractor effect. In contrast, a large patch (36 x 36 deg) did not increase latency despite the fact that it also provided raw stimulation to the region representing the fixation zone. This finding is inconsistent with several studies that show an inhibited saccadic response following a large transient onset. We also found a steady decrease in saccade latency as patch size increased from 1.6 x 1.6 deg to 4.5 x 4.5 deg. This confirms that non-target stimulation of the region representing the fixation zone is not in itself sufficient to produce the increase in latency typically found with remote distractors. The results are consistent with the idea that only a spatially confined object leads to a discharge of collicular fixation neurons.

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588 Signal Timing and Hemispheric Localization in the Human Saccadic System: Preparatory Processes and the Sensorimotor Transformation for Antisaccades

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Objectives: We used event-related functional magnetic resonance imaging (fMRI) and magnetoencephalography (MEG) to observe signal timing and hemispheric localization in the human saccadic system for preparatory processes and the sensorimotor transformation.

Methods: We carried out fMRI on 21 and MEG on 17 healthy subjects, using the same saccadic paradigm. Subjects performed blocks of randomly mixed prosaccade and antisaccade trials. A cue for prosaccades or antisaccades was presented for 300 ms and was then replaced by the fixation ring. After 1700 ms the fixation ring disappeared and a target appeared around one of the two peripheral dots for 1 s. After that, the fixation point reappeared and lasted for 1 s.

Results: In fMRI, beginning shortly after the cue, hemodynamic activity in the frontal eye field (FEF) and supplementary eye field (SEF) reached a peak at 4 s post-cue. Activity in superior temporal gyrus, inferior frontal gyrus, and posterior cingulate gyrus decreased after the cue and showed a negative peak at 4 s post-cue. Activity in the parietal eye field (PEF) showed a later peak at 4 s post-target (i.e. 6 s post-cue). Activity in the FEF, SEF, and PEF was greater during antisaccades than prosaccades. In MEG, the left FEF showed increased neural activity after the cue but 605-755 ms prior to the target, irrespective of the saccadic direction. During antisaccades, activity was observed in the PEF contralateral to the target around 110ms after the target, and in the PEF ipsilateral to the target about 15ms later, around 135 ms post-target.

Conclusion: FEF and SEF activation occur prior to PEF activity during saccades, and may thus reflect not only execution but preparation of saccades. A shift in activity from the contralateral to ipsilateral hemisphere consistent with the vector inversion (sensorimotor transformation) required for antisaccades was observed in PEF rather than FEF after target presentation.

589 The structure of fixational eye movements during turning gaze path

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Human gaze path consist of rotation to redirect focus of foveal vision with better resolution. The gaze has macro structure with well-known division to fixational and saccadic phases according to spatial and temporal behavior characteristics. Our experiments compared the Fixational Eye Movements (FEMo) in context of either continuous direction of saccades and direction changes, turnings. A matrix of arrowheads among T-letter shaped icons were used to construct a path that the subjects tried to follow. The eye movements were recorded with EyeLink II equipment having 250 Hz temporal resolution. The fixations (number= 2124, duration 268 ms, sd=104) were first classified qualitatively according to speed. The later comparison allowed us to rely on quantitative categorizations done by the EyeLink. As a result, there were several microstructures in FEMos as is the case with direct gaze paths. However, the general structure of FEMos during gaze turnings was different when comparing to direct FEMos. Thus, there are several different microstructures in FEMos related to different gaze tasks as seen in gaze path macrostructures.

590 Radial-flow vergence eye movements depend critically on the local Fourier components of the motion stimulus

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Busettini et al (1997) showed that radial optic flow applied to large random-dot patterns elicits horizontal vergence eye movements at short latency, expansion causing convergence and contraction causing divergence: Radial-Flow Vergence (RFV). We elicited RFV in 3 human Ss by applying radial motion to concentric circular patterns whose radial luminance modulation was that of a square wave lacking the fundamental ('Missing Fundamental' stimulus). The motion consisted of discrete steps at 20-ms intervals, each step being θ of the fundamental wavelength so the overall pattern and its luminance features, together with the 4n+1 harmonics (n=integer), underwent radial expansion (or contraction), whereas the 4n-1 harmonics, including the strongest Fourier component (3rd harmonic), underwent the reverse radial motion. Eye movements

were recorded with search coils. The radial motion began after the subject had fixated the center of the pattern (for at least 750 ms) and lasted for 200 ms. The earliest RFV had short latency (< 100 ms) and was always in the direction of the 3rd harmonic: *expansion* of the pattern resulted in *divergent* eye movements and vice versa. We also examined the RFV when the radial motion was applied in discrete steps to concentric circular patterns whose radial luminance modulation was a sum of two sinusoids of frequency $3f$ and $4f$, which created a repeating radial pattern with a 'beat' frequency, f . The steps were each $^\circ$ of the beat wavelength, so the feature-defined pattern shifted in one radial direction, whereas the $3f$ component shifted in the opposite radial direction and the $4f$ component was stationary. Initial RFV was again in the direction of the 3rd harmonic. In addition, the perceived radial flow in all cases was in the direction of the 3rd harmonic. These data indicate that the earliest RFV and the associated perceived radial flow depend on the local Fourier components of the radial flow consistent with a local motion-energy sensing mechanism.

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591 The structure of fixational eye movements during straight gaze path

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Human gaze path consist of rotation to redirect the focus of foveal vision for the perception with better resolution. The gaze has macro structure with well-known division to fixational and saccadic phases according to spatial and temporal behavior characteristics. Our experiments compared the Fixational Eye Movements (FEMo) in the context of continuous horizontal and vertical movement. A matrix of arrowheads among T-letter shaped icons were used to construct a path that the subjects tried to follow. The eye movements were recorded with EyeLink II equipment having 250 Hz temporal resolution. The fixations (number= 5947, duration 236 ms, sd=66) were first classified qualitatively according to speed. The later comparison allowed us to rely on quantitative categorizations done by the EyeLink. As a result, there was dominant vertical FEMos in context of horizontal saccadic movement and horizontal FEMos in vertical case. We also observed several qualitative modes of movement: 1) gradual accelerations, 2) abrupt saw-tooth shape, and 3) loops. More detailed quantitative analysis will be presented in the poster. Thus, there are several different micro structures in FEMos related to different saccadic macrostructures.

592 Miniature eye movements measured simultaneously with ophthalmic imaging and a dual-Purkinje image eye tracker.

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Background: Scanning laser ophthalmoscopes with adaptive optics correction of ocular aberrations provide retinal images of unprecedented resolution, allowing for real-time imaging of photoreceptors. Eye movements made by the subject/patient during recording produce distortions that must be corrected before multiple frames can be added together to achieve noise reduction or to build a mosaic image from different retinal areas. These distortions also provide a high spatial and temporal resolution record of the miniature eye movements made during fixation. Here we report simultaneous measurements of fixation eye movements with an Adaptive Optics Scanning Laser Ophthalmoscope (AOSLO) and a dual-Purkinje image (dPi) eye tracker in order to cross-validate these two methods of recording miniature eye movement. Method: Foveas of three subjects were imaged with a one degree square scan using the Houston AOSLO, at a resolution of 8 pixels per arc minute. A Generation V dPi tracker from SRI was placed in front of the AOSLO, and eye movements were recorded at the same time from the same eye being imaged by the AOSLO. AOSLO movies were analyzed off line to extract retinal image motion. The resulting traces were then overlaid on

the dPi recordings for comparison. Results: The two methods produced records that agreed to within about one arc minute, with more significant disagreements occurring after eye blinks. Microsaccades in the dPi record were accompanied by overshoots that have previously been associated with lens wobble. AOSLO traces also showed saccade-related overshoots, but of much smaller amplitude. Conclusions: Eye movement recordings measured with dual Purkinje image trackers predict retinal image motion to a precision of about 1 arc minute, except for 10-20 milliseconds following each saccade and 500 - 1000 milliseconds following each eye blink. Retinal image motion measured directly from AOSLO recordings can be recovered to a precision of just a few arc seconds.

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593 A pulse-step mismatch model of dynamic ocular disaccommodation

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Step changes in ocular accommodation are controlled by pulse & step signals to the ciliary muscle (agonist) that stretches the passive choroid (antagonist) (Schor & Bharadwaj, 2004). During disaccommodation (near-to-far focusing), the roles of the ciliary muscle & choroid are reversed: the ciliary muscle is the antagonist. Are pulse & step signals also used to control disaccommodation?

Peak velocity of accommodation step responses increase with response magnitude but peak acceleration is invariant. In contrast, peak velocity & peak acceleration of disaccommodation are invariant of response magnitude for a fixed starting position, but they increase with proximity of the starting position (Bharadwaj & Schor, 2005). This suggests that disaccommodation is initiated by a pulse signal toward a constant primary destination & it is followed by a step signal to achieve a desired final position.

In the pulse-step model of accommodation, pulse width is adjusted independently of pulse height to control velocity independently of acceleration. We used a similar pulse-step model for disaccommodation with two differences. First, instead of increasing the width of a fixed-height pulse with response magnitude, we increased height of a fixed-width pulse. Second, the magnitudes of the pulse & step were made independent. Pulse height was appropriate for a response initiated toward a primary destination & step height was proportional to a desired final position. Primary destination was estimated from the negative X intercept of plots of peak velocity as a function of starting position that correspond to the cycloplegic refraction. Time-to-peak-velocity indicated when the step occurred & this did not change with either response magnitude or starting position. The pulse-step model of disaccommodation predicts that when the discrepancy between final position & primary destination was large, mismatched amplitudes between a larger pulse and a smaller step cause overshoots of the step response.

594 Opposing motion aftereffects and storage in the eye movement system

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Prolonged viewing of motion in a single direction can induce a motion aftereffect (MAE); static objects are perceived as moving opposite the adapted direction while motions similar to the adapting stimulus are repelled away from the adapted direction, and perceptually slowed (Wohlgemuth, 1911). Placing observers in the dark before presenting them with a textured stimulus can postpone the MAE (storage). Motion adaptation can also induce a smooth pursuit MAE (Braun & Gegenfurtner, 2004), decrease the speed of smooth pursuit eye movements, and bias the

direction of pursuit away from the adapted direction (Heinen et al., 2003; Gardner et al. 2004). Here, we present evidence that MAE storage occurs in the pursuit system, and propose a model to explain it.

Observers adapted for 60 sec to a random-dot cinematogram (RDC) in which all dots moved upward at 10 deg/sec. After adaptation, observers were presented either immediately or following 1000 msec in the dark (GAP), with an RDC pursuit stimulus that moved at 0.5 deg/sec in one of five directions, -208 to 208, centered around rightward. A 10 sec adaptation top-up interval was presented before each subsequent trial. When stimuli were presented immediately after adaptation, eye movements were biased opposite the adapted direction, consistent with a pursuit MAE. Eye velocity reached a peak of 3-.5 deg/sec, before dissipating in ~ 800 msec. During the gap, the eyes moved in the adapted direction, presumably an optokinetic response. After the GAP, the MAE occurred with a similar time course and peak velocity as in the no GAP condition. We propose a model where adaptation creates an imbalance of activity between motion detectors during adaptation as a result of a recalibration of synaptic connections. The imbalance is too small to override the optokinetic eye movements during the GAP, but the presence of visual input magnifies the imbalance, thereby causing the eyes to move opposite the adapted direction for expression of the pursuit MAE.

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595 Guidance of eye movements by vision and hand

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Vision is needed for guiding the hand towards a visually specified target. In everyday situations, however, hitting or missing the target with the hand leads to different consequences than hitting or missing it with the eye. Here we asked how eye and hand interact in a task in which movements of the hand, but not the eye lead to monetary consequences for the movement planner. In a series of four experiments, we measured eye movements during a video-game-like pointing task. In the first three experiments, subjects were instructed to rapidly touch a target region (green) on a screen while trying not to hit a nearby penalty region (red). Each target hit yielded a gain of points; each penalty hit incurred a loss of points. Late responses were penalized. In the first experiment, the penalty was a filled red disk and the target a hollow green circle, the background was grey. In the second experiment, the penalty was hollow and the target was filled. In the third experiment, the stimulus configuration was the same as in the first experiment, but disappeared as soon as the pointing movement was initiated. Penalty value, overlap of the circles and stimulus locations were varied. In a control experiment (experiment 4), subjects performed a visual judgement indicating whether the target was on the right side or on the left side of the penalty. Four subjects completed all experiments. In experiments 1, 2 and 4, subjects made two saccades on average. This number was slightly lower in the third experiment. In all experiments, the majority of landing points of the first saccade was within the region of the filled circle, i.e. the more salient stimulus. The landing point of the second saccade shifted closer towards the touch point of the finger. In most trials, the second saccade was concluded before the finger hit the screen. We conclude that eye movements during pointing tasks are guided by both the visual properties of the stimulus and the hand.

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596 A General Purpose System for Eye Movement Contingent Display Control

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In experimental studies of visual functions, the need often emerges for modifying the stimulus according to the eye movements performed by the

subject. The methodology of eye movement contingent display (EMCD) enables accurate control of the position and motion of the stimulus on the retina. It has been successfully used in many areas of vision science, including studies of visual attention and eye movements and the physiological characterization of neuronal response properties. EMCD control is also crucial in a variety of applications ranging from augmented information displays to aids for subjects with visual impairments. Unfortunately, the difficulty of real-time programming and the unavailability of flexible and economical systems that can be easily adapted to the diversity of experimental needs have prevented a widespread use of EMCD control.

We have developed a general-purpose system to perform EMCD experiments on a personal computer, which combines flexibility, simplicity of use, and low cost of the components. Based on a Digital Signal Processor with analog and digital interfaces, this integrated hardware and software system ensures real-time performance with refresh rates up to 200 Hz. It is responsible for sampling and processing oculomotor signals and subject responses, and communicating with the graphic card on the host PC to allow real-time generation, visualization, and gaze-contingent modification of visual stimuli. A high-level programming language makes the system accessible to users with no real-time programming experience. We show system performances in a number of EMCD procedures. In particular, we compare the quality of retinal stabilization (a procedure in which the stimulus is moved in a way that eliminates eye movements) produced by the system to that of a stimulus deflector directly coupled to a Dual Purkinje Image eyetracker.

Demos of this system can be downloaded from:

<http://cns.bu.edu/~rucci/APLab/EMCD.html>

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Natural Images

597 Magnification Factors in a V1 Model of Natural-Image Discrimination

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Aim. We measured psychophysical performance of human observers for discrimination of monochrome natural images that could be either blended one into the other (Tollhurst & Tadmor, 2000) or morphed (Parraga et al, 2000). We propose a visual-cortex based model to predict such performance. The model consists of multiple narrowband spatial filters (Campbell & Robson, 1968) tuned to different spatial frequencies and orientations. **Methods.** Image discrimination was measured using a 2AFC procedure whereby observers binocularly identified which of two test images was different from a reference image. A staircase method was used to adjust the difference between the test and the reference images. We made related sets of images in which the changing target area could be a small or a large proportion of the overall size (3 deg square) of the image. Morphing the target area generated changes in texture, or shape, or both; blending the target area generated just changes in texture. **Results and Conclusions.** Observers' discrimination thresholds varied under different conditions, but were relatively unaffected by the size of the target area. To model the psychophysical data, we define an index of image discrimination threshold based on a weighted contrast difference (Minkowski sum with exponent 4) between pairs of images calculated over a range of spatial frequencies and orientations. At first, we treated the cues from different parts of the visual field equally; however, this predicted that the observers' thresholds should have been lower for the larger target sizes than for the smaller. We accounted for target area size, by modeling the regional variation in contrast sensitivity (Robson & Graham, 1981) and cortical magnification factor (Tollhurst & Ling, 1988) across the visual field. Now, the index of image discrimination remains

constant across the different sizes of the changing target and appears to be a good predictor of observers' image discrimination thresholds.

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598 The Effects of Natural Scenes and Saccades on V1 Orientation Selectivity

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In many experiments, control over visual stimulation is obtained by sacrificing much of the complexity of the natural world and visual behavior. For example, stimuli are presented on iso-luminant backgrounds and they are flashed instead of swept into view via saccades. In this experiment, we investigated the influence of complex natural backgrounds and saccades on the development of orientation selectivity in macaque V1. Four conditions were compared: Bars of light were either flashed into the receptive field or brought into the RF through a saccade. Different flash and saccade trials were run with iso-luminant gray and natural image backgrounds. Average response amplitudes were usually lower with a natural than gray background. Comparing flash and saccade conditions gave more variable results. From cell-to-cell the flash response was higher or lower than the saccade response. The differences in average response amplitude across conditions appeared to be consistent with gain changes rather than changes in optimal orientation or tuning width. There were also significant effects of the presentation paradigm on the timing of selectivity. Orientation selectivity generally appeared slower with a natural than a gray background. Selectivity usually developed faster when stimuli appeared from a flash rather than a saccade. Comparing the least (flash/gray) and most natural (saccade/natural) paradigms, there was often a significant difference in the timing of maximal selectivity (tens of msec). These results indicate that the more natural paradigms recruit additional neural circuitry that decreases response amplitude and delays orientation selectivity. This suggests that in natural visual situations, the earliest form-selective V1 response carries potentially important information about stimulus context that is different from that available in reduced paradigms.

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599 Contrast Gain Control in Natural Images

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Objective: Contrast sensitivity for grating stimuli is approximately invariant of the relative phase of components at other spatial scales (Graham & Nachmias, 1971, *Vision Research*, p251). In natural images however, the relative phases across scales define the distribution of structure and contrast. We examined how this property determines contrast gain control.

Methods: Contrast increments were applied exclusively to one octave spatial frequency bands within natural images. The relative alignment of the target octave was left intact or was de-correlated from the rest of the image by rotation, mirror reversal or spatial displacement, leaving the amplitude spectrum unchanged. RMS contrast increment thresholds were measured across the full contrast range as a function of spatial frequency.

Results: TvC functions were characteristically 'dipper' shaped and were used to infer sigmoidal contrast response functions. Contrast increment sensitivity was higher to decorrelated images by up to 4 dB and implied divisive gain control with no change in sensitivity. The magnitude of enhanced contrast sensitivity increased with the spatial displacement of the target band up to about 2 wavelengths.

Conclusions: Contrast gain control operates across spatial scales in broad band natural images, but only over a relatively limited spatial area. This property attenuates contrast responses in regions of high local contrast energy and leaves a greater dynamic range at other points in the image.

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600 Perceptually Based Range Compression for High Dynamic Range Images

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Natural scenes contain huge ranges of luminance, and it has recently become convenient to capture high dynamic range (HDR) images digitally. Unfortunately there is no easy way to display them. The classical way of handling dynamic range in photographs is through a point non-linearity, such as a log or power function. However, if we forbid clipping of highlights with an HDR image, this forces a loss of contrast, especially in shadows. Local gain control techniques can help, but they lead to an unnatural appearance where edges become "cuspy." More sophisticated techniques have recently been proposed, but they have disadvantages in terms of computational speed or visual quality. We have developed an alternate technique inspired by human vision. An image is split into subbands, and local gain control (i.e., contrast normalization) is applied to each subband, and then the image is resynthesized. This works remarkably well, allowing huge compression while keeping detail in both bright and dark regions and avoiding unnatural artifacts. Why should it work? We believe it solves the following problem statement, which is parallels that used in color: Given the limits of a display device, choose the displayable image that causes the relevant neural responses to most closely match the neural responses to the original scene. We say "relevant neural responses" because we can't make the retinal responses match those for the original scene, but we can try to attain approximate matches for later stages such as area V1. We can do this by applying gain controls in the luminance and subband domains, chosen so that they will be cancelled out by the gain controls in the retina and cortex. This gives us the degrees of freedom we need to best satisfy our conflicting constraints. In the present case, it means that we can greatly compress the dynamic range of an image, allowing it to be displayed on a monitor or printed on paper, while retaining detail and avoiding irritating artifacts.

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601 Natural images and the McCullough effect

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The McCullough effect (McCullough, 1965) can be induced in several minutes by viewing vertical black and green stripes in alternation every few seconds with horizontal black and red stripes. After induction, achromatic stripes appear black and pink if they are vertical or black and greenish if horizontal. When viewed after induction, different stimuli are differentially effective at reducing the effect. Explicit experiments involving natural viewing conditions (Skowbo et al, 1974) as well as the general persistence of the McCullough effect over time show that natural viewing conditions are not especially effective at reducing the effect, which is surprising if the effect is due to recalibration in a functionally important mechanism (Humphrey, 1998). Several features of natural viewing may contribute to this result, such as low power at the relevant spatial frequency and orientation or the presence of multiple frequencies and orientations. We tested two sets of natural images as post-induction stimuli. The two sets were created by finding 38 image pairs. The images within a pair were matched for overall contrast energy, but one image was balanced for contrast energy at vertical and horizontal orientations and the other was strongly imbalanced. We hypothesized that 'strongly oriented' natural stimuli would be more effective as reducers of the McCullough effect. We also tested achromatic gratings and white screen stimuli for comparison. Effect strength was measured by color nulling before induction, after induction, and after 20 minutes of exposure to the post-induction stimulus. Results for the two sets of natural images did not differ greatly, so additional experiments with greater power are underway. Natural stimuli were better reducers than the white screen, in

contradiction to Skowbo et al (1974), but in agreement with the hypothesis that natural images are what normally keep the mechanism calibrated.

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602 A Method of Estimating the Information Content of Natural Scenes

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The measurement of the true information content (i.e., entropy) of natural scenes is a computationally intractable problem. The true measure requires an estimate of the probability of all possible images: impossible even with small image patches. One can make estimates derived from conditional probabilities of some basis set, but that also can be shown to produce highly inaccurate measures unless all conditional probabilities are considered. Here we describe a new method that allows us to estimate the relative entropy of different data sets (e.g., natural scenes versus 1/f noise versus city scenes). An image patch is drawn at random from a large collection of possible patches. The image patch is then compared to patches in a comparison set to find the patch that is closest (Euclidean distance) as a function of the number of patches in the comparison set (e.g., 10 to 1 million). We find that the average minimum distance is typically a smooth monotonic function of the number of image patches in the comparison set. We also find that this function can be used to estimate entropy. For high contrast, 8x8 patches normalized for mean intensity and contrast, we find that natural scenes have approximately 1/5th the entropy of Gaussian white noise quantized to the same level. We discuss how this 'projected entropy' measure behaves as a function of patch size and image structure. We also show that this measure allows us to estimate dependencies of the 'independent components' as derived from ICA measures.

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603 Contrast statistics for foveated visual systems: Contrast constancy and fixation selection

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The human visual system combines a wide field of view with a high resolution fovea and uses high speed ballistic eye movements to direct the fovea to potentially relevant locations in the visual scene. This strategy is sensible for a visual system with limited neural resources. However, for this strategy to be effective, the visual system needs to employ sophisticated central mechanisms that exploit the varying spatial resolution of the retina. To gain insight into some of the design requirements of these central mechanisms, we have analyzed the effects of variable spatial resolution on local RMS contrast in 300 calibrated natural images. Specifically, for each retinal eccentricity ϵ (which produces a certain effective level of blur), and for each value of local RMS contrast c observed at that eccentricity, we measured the probability distribution of the local RMS contrast in the unblurred image. These conditional probability distributions can be regarded as posterior probability distributions for the 'true' (unblurred) contrast, given an observed contrast at a given eccentricity. We find that the mode of the posterior probability distribution of the unblurred contrast (i.e., the MAP estimate c_{est}) is given by $c_{\text{est}} = kc\epsilon + c$, the standard deviation by $\sigma = kc\epsilon + \sigma_0$, and the differential entropy by $h = 0.5 \log_2 [2\pi\epsilon(kc\epsilon + \sigma_0)^2]$, where k and σ_0 are constants. The formula for the MAP estimate of contrast suggests a simple rule the visual system could exploit to achieve approximate contrast constancy across eccentricity. Our results also suggest a potentially efficient algorithm/model for selecting fixation locations when the goal is to encode images as well as possible (maximally reduce uncertainty) with just a few fixations. We find that the algorithm works very well at reducing total contrast uncertainty, and also works well

at reducing the mean squared error between the original image and the image reconstructed from the multiple fixations.

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604 Classification of Natural Scenes Using Global Image Statistics

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The algorithmic classification of complex, natural scenes is generally considered a difficult task due to the large amount of information conveyed by natural images. Work by Simon Thorpe and colleagues showed that humans are capable of detecting animals within novel natural scenes with remarkable speed and accuracy. This suggests that the relevant information for classification can be extracted at comparatively limited computational cost. One hypothesis is that global image statistics such as the amplitude spectrum could underly fast image classification (Johnson & Olshausen, Journal of Vision, 2003; Torralba & Oliva, Network: Comput. Neural Syst., 2003).

We used linear discriminant analysis to classify a set of 11,000 images into animal and non-animal images. After applying a DFT to the image, we put the Fourier spectrum into bins (8 orientations with 6 frequency bands each). Using all bins, classification performance on the Fourier spectrum reached 70%. However, performance was similar (67%) when only the high spatial frequency information was used and decreased steadily at lower spatial frequencies, reaching a minimum (50%) for the low spatial frequency information. Similar results were obtained when all bins were used on spatially filtered images. A detailed analysis of the classification weights showed that a relatively high level of performance (67%) could also be obtained when only 2 bins were used, namely the vertical and horizontal orientation at the highest spatial frequency band.

Our results show that in the absence of sophisticated machine learning techniques, animal detection in natural scenes is limited to rather modest levels of performance, far below those of human observers. If limiting oneself to global image statistics such as the DFT then mostly information at the highest spatial frequencies is useful for the task. This is analogous to the results obtained with human observers on filtered images (Kirchner et al, VSS 2004).

605 Spatial frequency streams in natural scene categorization

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We used the *Bubbles* method (Gosselin & Schyns, 2001) to examine the effective use of spatial frequencies through time in natural scene categorization. Two observers (C.E and K.T) categorized a total of 8640 dynamic stimuli (6 deg² of visual angle*180ms) composed of one of 720 natural scenes from six categories (beach, city, mountain, forest, highway and landscape). Each of our stimuli was composed of 18 frames, made from the dot product of the Fourier spectrum of a scene with 2D white Gaussian noise convolved with a Gaussian function (Std's = 0.08 of the Nyquist frequency and 79 ms). We performed a linear regression on reaction times and sampling noise. The resulting classification image shows the use of different spatial frequencies across the 18 frames composing every animation. We conducted a one tailed Z-score analysis based on random field theory (Chauvin et al, submitted) in order to reveal the use of spatial frequency as a function of time. The classification image ($Z > 3.8$, $p < 0.01$) reveals the use of three narrow bands of spatial frequencies across time. Low frequencies (1 c/dg) are first to reach significance (between 10 and 90 ms), followed by mid frequencies (6 c/dg, significant between 30 and 120 ms) and finally higher frequencies (12 c/dg, significant between 70 to 100 ms). Superficially, this result corroborates

the coarse-to-fine hypothesis (Parker, Lishman, & Hughes, 1992) of natural scenes categorization. It allows, however, a much finer analysis of the information subtending the first moments of visual categorization.

606 Disparity statistics in the natural environment

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Stereopsis is undoubtedly useful for precise near work, but its role at viewing distances beyond a few meters is less clear. We sought to determine the statistics of naturally occurring binocular disparities in outdoor environments to find out if they could potentially play a role in vision under these circumstances. A data base of range images obtained with a scanning laser rangefinder from a wooded environment was used (Yang & Purves, 2003). Ranges along the horizontal meridian were converted to angular disparities by assuming a 6.5 cm interpupillary distance and either by 1) sampling from a histogram of fixation distances obtained from human observers in a similar wooded environment or 2) assuming that fixations are on objects and are distributed uniformly across horizontal angle in environmental coordinates. Disparities were also computed in the same manner from a simple model forest. All results indicate that the distribution of naturally occurring disparities is bell-shaped, centered roughly on zero, and spans several degrees. Suprathreshold disparities abound. Further, the distribution of naturally occurring disparities closely matches the distribution of peak disparity tuning found in area MT of macaques (DeAngelis & Uka, 2003). We thus find it likely that primate visual systems have evolved to exploit what seems to be a rich array of naturally occurring disparities in natural environments.

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607 Processing of image statistics with and without segmentation cues

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Statistical aspects of images are cues for texture discrimination and segmentation. In pre-segmented patches (VSS 2003), discrimination of local 1st order structure (luminance: LUM) and local 4th order structure (EO: even/odd isodipole textures) is much more efficient than that of non-local 2nd order structure (SYM: mirror symmetry), despite its visual saliency. This and other evidence suggests that symmetry detection uses a different computational substrate than processing of local statistical structure. Here we compare the relationship of these three statistical image classes to segmentation.

Stimuli consisted of four 8x8 arrays of black and white checks. In each trial, the target array deviated from that of the three distractor arrays in LUM, EO, or SYM. Arrays were positioned either 4 deg from fixation along the cardinal axes (fixed) or in "jittered" locations about the fixation point to introduce positional uncertainty. We used three display backgrounds, providing either a large segmentation cue (GRAY: uniform gray background), no cue (SAME: random checks of the same size as the targets) or an intermediate cue (HALF: random checks half the size of those in the targets). Practiced observers (N=5) were asked to identify the target in a 4-AFC task (stimulus duration: 100ms).

For LUM and EO, fraction correct without segmentation cues (LUM/SAME and EO/SAME) was 0.72 and 0.44, and increased when a segmentation cue was provided (LUM/GRAY, 0.98; EO/GRAY, 0.70). A modest segmentation cue (HALF) produced intermediate performance. Detection of SYM without a segmentation cue (SYM/SAME) was at chance, but increased to 0.46 for SYM/GRAY. There were no differences in fraction correct due to target position (fixed vs jittered) for any condition. Symmetry, while visually salient, does not support segmentation by itself. Moreover, segmentation effects are graded - even for image statistics that

support segmentation, additional segmentation cues further enhance performance.

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608 Distribution of Velocities in Movies from Natural Human Settings

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Introduction: Theories of vision, including those for motion, are increasingly relying on statistics of natural scenes. Much work has been done for stationary natural images, but little on natural movies. In this work, we analyzed the distribution of instantaneous local velocities in the natural optic flow, and their relationship with the distributions of spatial and temporal contrasts. Methods: We obtained and calibrated nineteen 1-min-long gray-level movies shot at outdoors human settings. We measured directly the spatial and temporal gradients, and from them, local velocities on 3000 points randomly placed on the movie frames. Noise affecting velocity estimates due to CCD fluctuations was eliminated with robust, nonparametric statistics. Results: The distribution of speeds of velocities parallel to the spatial gradient fall with speed (Horn & Schunck, 1981). A similar result holds for the distribution of real speeds, but they fall more slowly. The distribution of directions of motion shows a tendency towards horizontal (and sometimes vertical); the coefficient of variation quantifying this anisotropy is between 0.01 and 0.6. We see no correlation in the joint distributions of speed and spatial contrast, and speed and temporal contrast. Discussion: That the distribution of local speeds fall as speed increases is consistent with the analysis of Yuille & Ullman (1989). They predicted such a distribution from images of 3D-rigid objects moving in the world. This distribution supports the assumptions of the Yuille & Grzywacz (1988) and the Weiss et al. (2002) models of motion perception. In turn, our finding that there is no correlation in the joint distribution of speed and contrast, rules out simple Bayesian-prior explanations for why perceived speed of motion varies with contrast (Thompson, 1982). The anisotropy of direction of motions might be due to objects moving mainly parallel to ground.

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http://obelix.umh.es/mmartinez/optic_flow.html

609 Perception of Temporally-filtered Moving Natural Images

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Unlike smoothly moving sinusoidal gratings, natural images that move contain many temporal frequencies. Human sensitivity to a pattern having a single temporal frequency has been measured. The purpose of this study is to examine how individual image components having different temporal frequencies affect our perception of the motion of moving natural images.

We prepared movies from natural images (running animals, aerial landscapes, river flow, moving car, and so on). Various filters were applied in the temporal frequency domain to the sequence of (luminance or color) variations of each pixel to obtain a temporally-filtered moving image.

In psychophysical experiments, we measured the perceived speed, motion direction and perceived smoothness of moving images. Subjects observed non-filtered and filtered movies in succession and judged which object in

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the two movies appeared to move faster and more smoothly. Subjects also observed a single filtered movie and judged the motion direction of an object in the movie.

Temporal filtering greatly affected the impression of motion. Perceived speed was underestimated not only when a low-pass filter was applied, but also in high-pass filtered images. Perceived smoothness was much greater in low-pass filtered moving images than in the original movies. The impression of motion direction was drastically diminished in the high-pass moving images. The appearance of band-pass moving images was more strongly negatively affected than that of low-pass moving images. Color information improved appearance when the temporal filter was applied only to the luminance components of moving images. We also manipulated the amount of filtering (number of pixels to which a filter was applied) and found that a small number of unfiltered pixels greatly improved the appearance of the moving images.

These results demonstrate that lower temporal frequency information in both luminance and color is critical for the appearance of moving natural images.

www.michaelbach.de/ep2000.html

Visual Working Memory

610 Posterior parietal cortex activity predicts individual differences in visual short-term memory capacity

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Humans show a severe capacity limit in the amount of information they can store in visual short-term memory (VSTM). We recently demonstrated in an fMRI experiment that storage capacity for a visual scene (object color & location), estimated in averaged group data, strongly correlated with activity in bilateral posterior parietal/superior occipital cortex (PPC/SOC; Todd & Marois, 2004). However, individuals vary widely in their VSTM capacity, and this is reflected in their electrophysiological activity (Vogel & Machizawa, 2004). Here we re-analyzed the fMRI data of Todd & Marois (2004) to determine whether individual differences in VSTM capacity is reflected in the neural activity of specific brain regions. Subjects memorized the color and location of a variable number of discs and, following a 5s retention interval, determined whether a single disc presented in a probe display matched in location and color one of the discs in the sample display. A voxel-wise, individual differences analysis revealed a significant correlation between PPC/SOC activity and individuals' VSTM capacity. A second, slow event-related fMRI experiment showed that this relationship exists primarily during the maintenance phase of VSTM. In addition, a more sensitive, region of interest (ROI) approach suggests that visual and frontal cortex activity is weakly correlated with individual differences in VSTM capacity. Taken together, these results support a key role for the posterior parietal/superior occipital cortex in VSTM by demonstrating that its activity level predicts individual differences in VSTM capacity.

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611 Representing objects in visual short-term memory: The roles of the human intra-parietal sulcus and the lateral occipital complex

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An unresolved issue in visual short-term memory (VSTM) research concerns whether capacity is determined by a fixed number of slots or whether it is dependent on the complexity of the encoded objects. The intra-parietal sulcus (IPS) plays a central role in VSTM based on evidence that fMRI activations in IPS are modulated by the number of objects that observers can maintain in VSTM (Todd & Marois, 2004). In an event-related fMRI study, we varied shape encoding difficulty to manipulate

VSTM capacity, and examined how IPS activity was modulated by such changes. In addition to IPS, we also examined activations in the lateral occipital complex (LOC), an area involved in object shape processing. We used a standard change detection paradigm in which observers were shown 1, 2, 3, 4, or 6 objects, and after a brief delay, detected a possible shape feature change to one of the objects. With the same set of objects, we examined VSTM for two types of shape features: In the easy condition, observers remembered whether each object in the display contained a hole or not; and in the hard condition, observers remembered the shape contour of each object. This task yielded a VSTM capacity of about 3 to 4 objects in the easy condition and about 2 objects in the hard condition. We found that activations in the LOC, but not IPS, followed the number of objects that observers could hold in VSTM: Activations in the LOC asymptoted at 3 objects for the easy condition and at 2 objects for the hard condition, whereas activations in the IPS asymptoted at 3 objects for both conditions. These results suggest that: (1) The IPS may index the number of objects present in a display in a slot-like representation with fixed capacity that determines the maximum number of objects an observer can maintain in VSTM; and (2) the LOC supports object representations in VSTM using a resource-like representation with variable capacity that is determined by the nature of the visual features encoded.

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612 Involvement of the right inferior parietal lobule in shape retrieval is modulated by prior tactile experience with objects

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Previous research has suggested a role of the posterior parietal cortex in shape retrieval from semantic memory (Oliver & Thompson-Schill, 2003). This study was designed to clarify the role of this region in shape retrieval. During fMRI scanning, subjects listened to the names of common objects and decided whether each one was mostly composed of curved edges or straight edges. The data from this shape retrieval task were modeled with a covariate for the affordance rating of each object, a familiarity covariate representing the degree to which these subjects were exposed to this object through any modality, and a covariate representing an estimate of the proportion of the time that was spent touching the object. Shape retrieval associated activity in the right inferior parietal lobule (IPL) was significantly modulated by the history of tactile interaction with objects such that objects with a richer tactile history showed a stronger shape retrieval effect in the right IPL. This effect was observed despite the presence of general exposure and object affordance in the model, indicating that the extent of tactile experience explains unique variance in the magnitude of the fMRI response in the IPL during shape retrieval. This effect supports domain-specific distributed models of memory in that prior experience with the object shapes its ultimate representation.

613 Visual working memory for simple and complex visual stimuli

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Does the magical number 'four' characterize our visual working memory (VWM) capacity for all kinds of objects, or is the capacity of VWM inversely related to the perceptual complexity of those objects? To find out how perceptual complexity affects VWM and whether the observed performance limitation in change detection reflected a limitation in the perceptual or memory process, we measured the slope of visual search RT as a function of display set size to independently quantify the informational load and used a change detection task to measure VWM capacity for six types of stimuli of different complexity: colors, letters, polygons, squiggles, cubes, and faces. We found that the estimated capacity decreased for more complex stimuli, suggesting that perceptual complexity was an important factor in determining VWM capacity. However, the considerable correlation between perceptual complexity and

VWM capacity declined significantly if subjects were allowed to view the sample memory display longer. Although Alvarez and Cavanagh (2004) found that informational load was an excellent predictor of change detection performance, with a correlation coefficient of .996 between visual search slope and estimated VWM capacity, our findings show that informational load only accounted for 32% of the variance in VWM capacity with a memory display duration of 3 seconds or longer, indicating that informational load was a better predictor of the estimated VWM capacity at shorter durations. Because informational load should have a constant influence on the hypothetical VWM capacity, the increased correlation suggests that at shorter presentation durations, performance was additionally limited by perception. We conclude that when encoding limitations are minimized, perceptual complexity affects, but does not determine, VWM capacity.

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614 Controlling the Contents of Visual Short-term Memory

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The capacity of visual short-term memory (VSTM) is severely limited to about four or fewer items. Because of this limitation, it is important to understand whether we can accurately control the contents of VSTM through top-down and/or bottom-up control processes. To test this, subjects were presented with displays containing targets, marked by a distinctive cue, and distractors. If subjects are poor at controlling the contents of VSTM, distractors should intrude into memory, causing a high false-alarm rate.

When to-be-remembered items were presented sequentially, distractors were encoded into VSTM, suggesting that control processes fail to limit or purge VSTM of distractors. Distractors were encoded at both easy and hard set sizes, suggesting that memory load theory does not modulate distractor processing. Confidence ratings showed that subjects were similarly confident about their memories for targets and distractors. However, distractor memory traces were relatively short-lived, as assessed by a surprise recognition memory test at the end of the experiment. In contrast to these findings, distractors were not encoded into VSTM when to-be-remembered items were presented simultaneously. We speculate that control processes fail in sequential VSTM because visual transients cause unselective and automatic encoding of stimuli. Once stimuli are encoded, control processes have only limited success in managing the contents of VSTM.

615 Visual working memory for dynamic objects: Manipulations of motion and persistence in sequential change detection

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Recent work suggests that the units of visual short-term memory (VSTM) are integrated object representations. The primary evidence for this comes from sequential change detection studies in static displays. Here we study how VSTM operates in dynamic displays, wherein the identities of objects must be maintained over time and motion. On each trial, participants viewed 2, 4, or 6 colored moving shapes, each of which disappeared at an invisible occluder, and reappeared 900 ms later at the occluder's other edge. In the Occlusion condition, objects disappeared and reappeared via deletion and accretion along a single edge. In the No Occlusion condition, objects simply disappeared and reappeared instantaneously. Subjects had to detect color changes that occurred on half of the trials. Performance was compared (within subjects) to a Static condition, wherein objects disappeared and reappeared at the same location. Overall performance was equivalent in all conditions, but the interactions with set size proved interesting: There was no difference between conditions with 2 objects, due to a ceiling effect. With 6, performance was better in the Static condition. Most intriguingly, performance with 4 objects was actually

better with dynamic stimuli in the No Occlusion condition. These results suggest that VSTM storage may occur differently for displays of 4 or fewer objects: up to four objects can be simultaneously attended, with motion then serving as a cue to help divide attention. Efficient VSTM encoding thus occurs in terms of integrated object representations. In contrast, you cannot divide attention over 6 objects in the first place; thus the motion cue cannot aid VSTM encoding, and is only an added distraction. Most generally, these results demonstrate that change detection can be used to explore the factors which aid or constrain VSTM in dynamic displays, and further experiments investigate how manipulations of object persistence influence VSTM encoding.

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616 What's in an object file? Integral vs. separable features

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To make sense of the world we must track objects as the same persisting individuals over time and motion. Such processing may reflect mid-level 'object file' (OF) representations, which track objects over time on the basis of spatiotemporal information while also storing some of their visual features. OFs can be explored via 'object reviewing' (OR) effects, which yield 'object-specific preview benefits' (OSPBs): discriminations of a dynamic object's features are speeded when an earlier preview of those features occurs on the same object, beyond general priming. Here we ask what information is stored in OFs. OR intrinsically requires storing some features, but previous work has suggested that this information may be abstracted, such that changing low-level features of the probe information (e.g. the font of a letter) has no effect. We explored the limits of such abstraction in a modified OR task with more complex stimuli, asking whether the features stored in OFs are always separable (such that irrelevant features can be changed without cost) or may sometimes be integral (such that varying even irrelevant features yields interference). Two faces appeared briefly on objects which then moved, after which a single probe face (rotated to a partial profile) appeared on one of the objects. Observers judged whether the emotion of the probe face matched either of the initial faces' emotions. These judgments yielded robust OSPBs -- but only when the identity of the face itself (independent of the emotion) was also maintained. Identical results were observed with inverted faces, suggesting that these results reflect visual properties, and are not related to specialized categorical processing. In contrast, experiments with simpler stimuli yielded no such differences in OSPBs. We conclude that in some cases OFs store features which are integrally related, such that changes even to task-irrelevant features of the object will foil the maintenance of object-specific information.

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http://ego.psych.mcgill.ca/labs/mvr/Kathy/kmullen_home.html

617 The Binding of Features in Visual Short-term Memory

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Recent studies of visual short-term memory have revealed surprising limitations on the capacity and detail of its object representations. Several studies have demonstrated our ability to integrate features across dimensions in memory tasks, but few have examined whether or not task-irrelevant features from different dimensions may interfere in memory. We used a change-detection paradigm to investigate the binding and potential interference between features and locations of an array of boxes in a 3-dimensional virtual environment. Participants were asked to judge whether or not one of the boxes had moved between study and test and to ignore the patterns on the boxes. The boxes retained the same pattern on half of the trials; on the other half, all the patterns were replaced with new ones. Participants were more likely to judge that a box had moved when

the patterns were changed than when they were not. Thus, even though features from different dimensions may be integrated efficiently in memory, this integration may result in degraded performance on tasks that require the retrieval of only one feature dimension. These results then imply a restriction on the information retained when selective recall of a particular feature is required. Further studies will investigate the nature and strength of this effect.

618 Similarity Does Not Produce Interference Between Visual Working Memory Representations

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In this study, we sought to determine whether representations in visual working memory are stored independently of each other. Just as similarity impairs performance of LTM, similarity should impair working memory performance if representations are not stored independently. To test this hypothesis, we manipulated the similarity of the to-be-remembered items in a change-detection task. On each trial, subjects viewed a sample array consisting of 3 or 4 colored squares, followed by a retention interval and then a test array. The test array was either identical to the sample array or differed in the color of one item, and subjects indicated whether a change was present. The colors of the items were selected from three sets of colors: reddish colors, greenish colors, and bluish colors. On some trials, all the colors in the sample and test arrays were drawn from a single set and were therefore highly similar to each other. On other trials, the colors were drawn from all three sets and were therefore highly dissimilar to each other. In Experiment 1, we found that change-detection accuracy was no better for the dissimilar colors than for the similar colors. However, when we conducted a visual search paradigm using the same stimuli, the reaction time was much slower among similar colors, indicating that our similarity manipulation was robust. In Experiment 2, the stimuli were presented sequentially to avoid any relational encoding of the colors, which could potentially lead to better performance for similar colors. In Experiment 3, multi-feature objects (i.e., color, shape, and orientation) were used that contained identical features on either two dimensions or no dimensions. In all experiments, change-detection accuracy among similar objects was no worse than among dissimilar objects, suggesting that similar representations can be concurrently formed and maintained in visual working memory just as accurately as dissimilar representations.

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619 Visual working memory consolidation is not slowed by concurrent maintenance

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Although many studies have examined the transformation of perceptual representations into durable temporary memory representations, a process often called consolidation, little is known about the consolidation of information into visual working memory when it already contains information. To examine the relationship between these elemental working memory control processes we required subjects to remember simple objects that were masked to interrupt the consolidation process and estimate the amount of information consolidated prior to the mask presentation. We compared the rate of consolidation in two conditions. In the consolidation-baseline condition only a set of masked items had to be remembered, where as in a consolidation-during-maintenance condition subjects needed to remember a set of unmasked items and then were shown an array of masked items to remember. We hypothesized that if the control processes of consolidation and maintenance draw upon common resources then consolidation should be less efficient when performed concurrently with maintenance. In contrast, we found that an identical amount of information was encoded per unit time in both conditions.

These results indicate that visual working memory consolidation operates at the same rate regardless of whether information is being concurrently maintained in visual working memory. In addition, these findings suggest that visual working memory consolidation and maintenance are essentially independent processes constrained by a common capacity limit.

620 Knowing When to Remember and When to Forget: Expected Task Relevance Controls Working Memory Use

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Working memory capacity places a significant constraint on what visual information is selected and stored. There is evidence to suggest that working memory accumulates scene information over successive fixations. However, eye movements during ordinary behavior suggests that visual information is often acquired 'just-in-time' for a task. When do observers choose to use working memory over eye movements? Subjects performed a sorting task in a virtual environment with haptic feedback. Subjects picked up bricks based on one feature, and sorted the bricks by a different feature. In two different trial blocks, the feature relevant for sorting was either Predictable or Unpredictable. In the Predictable condition, subjects infrequently re-fixated the brick (29%). However, in the Unpredictable condition, subjects re-fixated the brick more often (47%). Infrequent re-fixations in the Predictable condition suggest that subjects used working memory for the sorting decision, whereas frequent re-fixations to the brick in the Unpredictable condition suggest 'just-in-time' acquisition. Thus, when the relevance of a brick feature is certain, subjects use working memory; when the relevance is unknown, subjects adopt a strategy of acquiring the feature only after its relevance becomes certain. To further probe working memory use, a change was made to one of the brick features on 10% of trials. When subjects missed the change in the Predictable condition, the brick was most often sorted by the pre-change feature (76%), implicating use of working memory. However, in the Unpredictable condition, the changed brick was most often sorted by the new feature (71%), suggesting 'just-in-time' acquisition. Thus, selection and storage of visual information in naturalistic tasks depends on both task relevance and its predictability. Subjects dynamically trade off memory use and eye movements depending on their expectations of what information is needed for the task.

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621 Relational information in visual short term memory: the structural gist.

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Storage of items in visual short term memory has been extensively studied over the past twenty years. In addition to questions concerning the format of object storage is a more global question that focuses on the organization of information in visual short term memory (Jiang, Olson and Chun (2000)). In a series of experiments using a change detection paradigm, we investigated how the inter-relations between visual items in a display determined the accessibility of each individual item. We conducted four experiments using the same paradigm as Jiang et al. We presented a sample screen composed of 2, 4 or 6 geometrical shapes and, after a blank, a test screen where one of the items was cued as target. The subject had to decide if the target had changed color (Exp1), orientation (Exp2) or shape (Exp3). Two kinds of changes could be made: a minimal change (only the target might change between the sample and the test screen) and a maximal change (all the non-targets changed). Target and non-targets

changes could be restricted to the same feature dimension or not (Exp4). A decrement in change detection performance was observed for the maximal change condition, showing that relational information deriving from irrelevant contextual items plays a role in recall from visual short term memory. The effect did not occur in Experiment 4, showing that relational information plays a role only within a given feature dimension. A fifth experiment using precueing of a subset of the items showed that attention was not necessary for the establishment of relational information. The experiments lead us to suggest that the notion of visual object should be widened to include the relations that the object has with surrounding objects. The results suggest a broadening of the parallel store model of visual short term memory proposed by Wheeler and Treisman (2002) to include the notion of what we call 'structural gist'.

622 Capacity limits in visual short-term memory within and between hemifields for colors and spatial locations

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Visual short-term memory (VSTM) and attention have been found to have a similar capacity limit of four items. VSTM capacity limits are usually investigated with the change detection paradigm, in which participants have to detect a change between two visual arrays separated by a brief interval (e.g., Luck & Vogel, 1997). Attentional capacity limits have been revealed with the multiple object tracking (MOT) task, in which participants have to attentionally track a number of moving identical items in a display of identical distractors (e.g., Pylyshyn & Storm, 1988). Last year at VSS, Alvarez & Cavanagh (VSS 2004) reported studies using the MOT paradigm and demonstrated that twice as many items could be simultaneously attended when they are displayed in the two visual fields as when they are all presented within the same hemifield. The goal of the current study was to examine whether the number of items that can be concurrently encoded into VSTM also increases when the items are split between the two fields. Two tasks were used, namely a color and spatial location change detection task, in which the items were displayed in two different regions located either in separate hemifields or in the same hemifield. The data revealed an interesting pattern of results, as only the capacity of spatial location VSTM appears to increase with the separation of the items between the two visual fields. These findings support the view of VSTM as a chain of capacity limited operations where the process of stimuli spatial selection, which dominates in both spatial location VSTM and MOT, may occupy the first place and show independence between the two fields.

623 Visual Working Memory: Capacity is Dependent on Perceived, not Physical, Stimulus Complexity

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What limits capacity in visual working memory (VWM)? Alvarez & Cavanagh (2004) reported that the greater the visual detail within an object, the fewer the objects stored. However, we found that VWM capacity for faces (Jackson & Raymond, 2004) is similar to that found for simple polygons. Perhaps, VWM capacity is not determined by 'physical' complexity but, rather, by 'perceived' complexity. We propose that, when people gain experience with a physically complex stimulus, it is perceived and encoded more simply, and thereby gains capacity. To test this we measured VWM capacity for Chinese characters ('Hanzi') in a group of fluent Chinese readers and a group of participants naïve to Hanzi. By using the same stimuli in both groups, physical complexity remained constant while only perceived complexity differed. To minimise input from verbal WM we used a verbal suppression task and 'traditional' Hanzi as stimuli. (Chinese readers, fluent only with modern, 'simple' Hanzi, were able to recognise stroke groupings but could not pronounce traditional Hanzi.) On each trial, stimuli were presented in a memory array (set sizes 1-8), followed 900 ms later by a test array. Participants reported whether

one item had changed between arrays. To ensure sufficient encoding time, arrays were displayed for durations derived from each observer's mean RT in a Hanzi visual search pre-task. Chinese readers had superior change detection performance, $p = .01$, and capacity ($K = 2.48$), $p < .01$, compared to non readers of Chinese ($K = 1.64$). Furthermore, inverting the Hanzi significantly reduced Chinese readers' performance, $p < .01$, and capacity ($K = 2.09$), $p = .03$, whereas inversion had non-significant effects for non readers ($K = 1.79$). We conclude that experience enables the integration of detailed object information to form a perceptually simplified representation. The degree of within-object element integration, modulated by experience, therefore appears to determine capacity.

624 Interference between motion direction and color-shape in visual working memory capacity of multi-dimensional objects

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A number of studies have shown that visual working memory (VWM) can hold approximately four objects, but it is not clear whether this capacity of memory is purely object-based or modulated by number and type of bound features. Luck and Vogel (1997) claimed that the unit of memory capacity is an 'object' and the number of integrated features does not matter. On the other hand, Wheeler & Treisman (2002) argued that when features come from the same dimension, (e.g. bicolored squares) capacity tends to decrease. Despite of these differences, it is accepted that as long as there is only one feature integrated from each feature dimension, there is no decrease in memory capacity relative to single feature objects. That is to say, the storage capacity does not change, for example, between simple colored patches and colored shapes. Although so far, most studies concentrated on integration of features represented in the ventral pathway, such as color, shape, orientation, size, etc.

The purpose of this study is to investigate whether the upper comment hold when features coded in different visual pathways, say, the ventral and dorsal pathways are integrated in a single object. We performed change-detection tasks using objects defined by colored dynamic random dots. There were 7 conditions, namely, color, shape, direction, color-shape, color-direction, shape-direction and color-shape-direction. We used single probe tests instead of whole-display tests to avoid the problem of interference when testing. Firstly, our experimental results confirmed the previous results where there was no drop in capacity by combining color and shape. To our surprise, the feature 'direction' acted quite differently. The capacity dropped significantly when direction was combined with color, shape and color-shape. We predict that there is some interference in visual working memory storage between features from different visual pathways.

625 Subitizing capacity is decreased when visual short-term memory capacity is exceeded

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Four seems to be a magic number in vision and in memory (see Cowan, 2001 and subsequent commentaries). We seem to have a capacity that is limited to about 3-4 items in several visual tasks: subitizing (Kaufman et al., 1948), simple change detection (Luck and Vogel, 1997) and in multiple object tracking (Scholl and Pylyshyn, 1999). Is it a mere coincidence that these tasks have the same capacity (Miller, 1956), or does a single capacity limit all of these tasks? We specifically explored the relationship between subitizing capacity and visual short-term memory (VSTM) capacity. We hypothesized that if subitizing and VSTM share a single capacity, then subitizing capacity would decrease as VSTM load increases. Alternatively, if they are independent, then increasing VSTM load would not affect subitizing capacity.

On every trial, we asked participants to enumerate briefly presented Gabor patches (0 through 9) during the delay period of a VSTM change

detection task. In separate blocks, participants detected a change in color, location or identity within a grid of 1,2,3,4 or 6 letters.

We found that increasing the number of gratings to be enumerated decreased performance on both enumeration and change detection accuracy. We also found that increasing VSTM load impaired change detection accuracy as well as enumeration accuracy. However subitizing capacity was preserved when participants were asked to remember 1-4 letters (i.e., accuracy was high and independent of numerosity up to three gratings). When VSTM load was increased to 6 letters subitizing capacity decreases to 2 gratings. Our results suggest that subitizing capacity and VSTM capacity are neither one and the same, nor are they completely independent. When VSTM capacity is exceeded, our ability to subitize is impaired.

Talk Sessions

May 9, 2005 – Monday AM

Goal-Directed Hand Movements (626-632), Face Perception: Neural Mechanisms (633-638), Attentional Selection and Tracking (639-645), Sensory Integration (646-652)

Goal-Directed Hand Movements

8:30 - 10:15 am

Hyatt North Hall

Moderator: Julia Trommershäuser

626 Planning movements with partial knowledge of target location encoded as a spatial prior

Todd E. Hudson (hudson@nyu.edu)^{1,2}, Michael S. Landy^{1,2}, Laurence T. Maloney^{1,2}; ¹Department of Psychology, New York University, ²Center for Neural Science, New York University

We investigate how observers plan rapid movements to touch a target when only the prior probability of target occurrence (at each spatial location) is available during the initial part of the movement.

Methods: Subjects were asked to touch visual targets (6 mm wide bars) on a computer screen placed approx. 40 cm in front of them. The targets could be at any of 5 equally-spaced fixed locations along a horizontal line across the middle of the screen. At the beginning of each trial, subjects saw a color-coded display that signaled the prior probability of the target being at each possible location on that trial. Each location was marked as low probability (LP) or high probability (HP); there was a 0.7 probability that the target would be one of the HP locations. The independent variable was the prior: the number of HP targets and their locations on the screen. If there was only one HP target, for example, then subjects knew that the target would be there on 70% of trials. The target appeared only after the finger passed through an invisible trigger plane 1/3 of the distance between the start point and the target screen. Touching the target earned a reward and missing the target or failing to reach the target screen within 700 ms incurred penalties. Subjects were instructed to earn the greatest reward possible. We used an Optotrak 3020 motion capture device to record the subject's fingertip trajectory on each trial. We analyzed the reach trajectories and distribution of movement endpoints for each possible target location and choice of prior.

Results: Endpoint variance increases for targets located further from the mean of the prior. Movement speed at the trigger plane varies with the shape of the prior distribution: more sharply-peaked distributions elicit faster reaches. We will describe a novel method of comparing human performance to optimal performance defined as maximizing expected gain.

Acknowledgment: NIH EY08266

627 Detection and costs of force perturbations during visually-guided pointing movements

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The successful execution of movements not only requires directing the movement towards the selected goal, but also detecting and compensating for perturbations interfering with the goal of the movement. Here we asked if participants are able to detect external force perturbations, how the executed movement is affected by the perturbation and, how the perturbation interferes with the goal of the task. Participants were instructed to rapidly hit a visual target, which was presented within a three-dimensional visuo-haptic virtual environment. Late responses and failures to hit the target were penalized. Participants were presented with a force pulse, which was applied to their right finger tip during the initial phase of the pointing movement. Force perturbations were applied orthogonally to the movement direction. We determined detection thresholds for perturbations from six different directions (up, down, upper right/left; lower right/left) using a two-interval forced choice paradigm. 5 participants completed the experiment. Surprisingly, detection thresholds for the applied perturbations (threshold about 10 N) were just slightly higher than tactile-kinesthetic detection in a single-task context (about 0.05 N, Lederman & Klatzky, 1999). Detection performance did not depend on the direction of the perturbation, but was better for short perturbations (30 ms presentation time) compared to longer perturbations (50 ms presentation time). Shorter perturbations differed from longer perturbations by a steeper increase in force amplitude (10% of the duration). Locally, perturbations (> about 0.07 N) affected the movement kinematics significantly as compared to trajectories without perturbation. However, the distribution of movement end points at the location of the visual target did not correlate with the direction of the perturbation. These results are a first hint that the brain is able to detect force perturbations during visually guided pointing movements without extra costs.

Acknowledgment: Deutsche Forschungsgemeinschaft (Emmy-Noether-Programm, Grant TR 528/1-2)

628 Visual feedback control of hand orientation in fast, goal-directed hand movements

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Purpose: We measured the dynamic properties of visual feedback control of hand orientation in a goal directed hand movement. **Method:** Subjects placed a cylinder onto a target surface while viewing a binocular image of the surface in a 3D virtual environment. A robot arm aligned a real target surface with the virtual surface image so that subjects actually placed the cylinder on a real surface on each trial. An optical tracking device measured the position and orientation of the cylinder throughout the movement. This data was used in real-time to render the cylinder in the virtual environment. On a small proportion of trials, we added a random perturbation to the orientation of the virtual cylinder early in the movement, either in the subjects' image plane or in depth. We used the recorded kinematic data to compute the strength and timing of subjects' corrections to these perturbations. As a baseline for comparison, we measured the same

responses for similar perturbations in the target surface. On all trials, the screen flashed repeatedly for 167 ms upon movement initiation to mask the motion cues added in the perturbation trials. Subjects reported that they were unaware of the perturbations. **Results:** Subjects corrected for feedback perturbations in both the image plane and in depth by 30%, with an average delay of 250 ms. Subjects corrected more completely for the target perturbations (75%), but with the same 250 ms delay. **Conclusions:** Humans use continuous visual feedback about the orientation of the hand for online control of fast, goal-directed movements. Depth information contributes as strongly to online control as information about orientation in the image plane and with similar effective delays. Visual information about the hand is probably less salient than information about the target because of both its greater uncertainty (moving in the periphery) and the presence of other cues about hand orientation (proprioceptive and feedforward motor information).

Acknowledgment: Supported by NIH EY-13319

629 Optimal data fusion in the presence of sensorimotor transformation noise

Erik J Schlicht (*schl0360@umn.edu*), Paul R Schrater¹; University of Minnesota

In order to integrate cues from different perceptual modalities the cues must be brought into a common coordinate frame. Previous work in cue combination assumes that no sensorimotor transformation noise (STN) is present during multi-modal cue integration. The goal of the present study is to show that the choice of common coordinate frame matters in the presence of STN, both to generate optimal estimates, and in terms of human performance.

Theoretically, we demonstrate that performing cue combination in the coordinate frame of the most reliable individual cue is optimal, when STN is present. In addition, we model integration of information across trials as Bayesian learning with forgetting, and show that the learned posterior distributions should also be stored in the most reliable coordinate frame. Given that vision is dominant for many tasks, this provides a possible theoretical explanation for the common empirical finding that object position estimates are stored in eye position coordinates (e.g., Batista, et. al, 1999).

These theoretical results will be used to model findings from a reaching task. The task involved reaching to a cylindrical object, whose location was specified by visual and haptic information. STN was varied by changing the relationship between the head, eyes, and object. The results show that reach trajectories systematically vary as a function of STN. Moreover, reaches are consistent with predictions made by storing estimates of the target's location in the most reliable coordinate frame. Overall, the results of this study suggest that coordinate frames are not interchangeable for a given task there may be a preferred frame of reference.

630 Human 'parietal reach region' encodes visual stimulus coordinates, not movement direction, during reversing prism adaptation.

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Previous investigations suggest that posterior parietal cortex, in particular the 'parietal reach region' (PRR) encodes reach-related activity in gaze-centered coordinates (Batista et al., Science, 1999; Medendorp et al., J. Neurosci., 2003). However it is not known if PRR encodes the visual direction of the goal relative to gaze, or the direction of PRR of movement relative to gaze. To dissociate these two variables and correlate them with cortical activation, we imaged subjects using 4-T fMRI with a 'surface coil' placed over the posterior cortex while they pointed to remembered leftward and rightward targets; before, during, and after adaptation to left-right reversing prisms. 6 subjects were tested using a block design in which they first fixated and pointed to a central target, and then a pointing target was briefly

flashed, followed by a 2.5s memory delay with a visual mask, and finally the pointing movement. 9 subjects were also tested in an event-related paradigm with the memory interval extended to 10 seconds. The control task revealed a network of cortical areas putatively labeled V2/V3, V7, LIP (Lateral Intraparietal Area), and PRR that were more active for contralateral than ipsilateral pointing. After prism adaptation, this reversed, so that lateralized activation in all these areas stayed linked to visual input and was dissociated from motor output. Another area in the supramarginal gyrus showed the opposite motor (or world)-fixed pattern of activation. Event-related recordings showed that PRR held a sustained contralateral activation during the memory interval leading up to pointing, which again reversed following prism adaptation. Apparently, the learned transformation from visual to motor coordinates in the reversing prism task was implemented 'downstream' from PRR. These data show that PRR does not encode the kinematics of movement direction, but rather the goal of the intended movement in visual coordinates.

Acknowledgment: Canadian Institutes for Health Research

631 Parietal cortex involvement in visually guided, non-visually guided, observed, and imagined reaching, compared to saccades

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In macaques, visuomotor neurons in and around MIP and V6A have been found to respond more during planned reaches than during planned saccades to visual targets. Recent fMRI studies have attempted to find a human homologue of this area. However, in those studies, (1) pointing, instead of reaching, was compared to saccades, (2) delayed (planned), rather than immediately executed hand movements were used, and (3) the effect of seeing the hand was not investigated. It remains unclear whether naturalistic reaching activates human medial parietal areas more than saccades, whether that activation is present during execution of reaching, and whether the activation depends on whether the reaching hand is visible. Also, it is unknown if observation and motor imagery of reaching activate those medial parietal areas. Here, we addressed these questions with fMRI and cortical-surface-based methods. In experiment 1, subjects either fixated centrally, or reached or saccaded to peripheral visual targets. In experiment 2, subjects reached on a visually hidden horizontal plate by moving their hand from the center to peripheral locations corresponding to visual target locations (e.g. targets at "12 o'clock" corresponded to an upward movement on the plate) and made saccades as before. Both visually guided and non-visually guided reaching activated a medial parietal area more strongly than saccades. Saccade activations partially overlapped with the medial region activated by reaching, but were generally less strong. In experiment 3, subjects either observed, imagined, or executed reaching to targets presented on a screen. Interestingly, observed and imagined reaching activated the same medial parietal region identified above by comparing reaching with saccades. These findings suggest the presence of a medial parietal human homologue to monkey MIP/V6A that is activated more by reaching than by saccades, and that may contain neurons involved in execution, mental simulation, and observation of action.

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632 Monkey Area V6A codes Reaching Movements in the Three Dimensional Peripersonal Space

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We used a 3-D reaching task to reproduce the spontaneous reaching movements performed by primates in every day life. We recorded neural activity from the medial parieto-occipital cortex (area V6A), while two monkeys performed a three dimensional instructed-delay reaching task in darkness. The animals reached a small target starting from a button placed near the chest. The target to be reached out could be in one of several posi-

tions in the peripersonal space. After arm holding on these positions, the animals had to bring their hand back toward the body, to reach the memorized position of the home button.

The present study demonstrates that many V6A neurons are spatially tuned by arm movements aimed at reaching gazed objects placed in the peripersonal space (57/150, 38%), and also by movements starting from different spatial locations and directed toward objects placed near the body, outside the field of view (61/150, 41%). Several V6A cells (52/150, 35%) are also able to encode the position of the hand in space. A consistent number of cells are involved in more than one epoch during the task. V6A population in the whole codes all the tested directions of reaching. Modulations during reaching execution occur in V6A in the absence of any visual feedback and are not due to eye movements. The study of neural discharge latency allowed us to discard the hypothesis of a reafferent signal as the only possible source of reach-related modulations, and suggests a corollary discharge from dorsal premotor cortex as one of the sources of reaching modulation in this area.

We suggest that the visuomotor area V6A plays a key role in updating an internal representation of the external world as well as the status of the upper limbs which interact with it, in order to monitor and/or control goal-directed voluntary arm movements.

Acknowledgment: This work was supported by MIUR and Fondazione del Monte, Italy

Face Perception: Neural Mechanisms

8:30 - 10:00 am

Hyatt South Hall

Moderator: Galit Yovel

633 Predicting Human Face Discrimination Performance and FFA Activation using a Computational Model of Face Neurons

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The nature of the quantitative relationship between stimuli, neural activation and behavior is crucial to understanding how the brain performs complex cognitive tasks such as face perception, yet it is still poorly understood. We have recently presented a computational model of face processing in cortex (Rosen&Riesenhuber,VSS,2004). The model shows that a population of highly selective "face neurons" (FN) can explain human face discrimination performance and effects such as the "Face Inversion Effect". This predicts a direct link between FN tuning specificity and discrimination performance: If face discrimination is based on the comparisons of FN activation patterns, performance should increase with dissimilarity between target (T) and distractor (D) faces, as the corresponding activation patterns get increasingly dissimilar. Crucially, due to the tight tuning of FNs, for some T-D dissimilarity, both will activate disjoint subpopulations of FNs, and performance should asymptote, as further increasing the T-D dissimilarity will not increase the dissimilarity of FN activation patterns. Likewise, in an fMRI rapid adaptation paradigm (fMRI-RA), adaptation of FFA FN stimulated with pairs of faces of increasing dissimilarity should decrease, and asymptote when the faces activate different subpopulations of FN. We used the model of FN to quantitatively predict the T-D dissimilarity (using morphed faces of parametrically varied similarity (Blanz & Vetter, 1999)) for which BOLD adaptation and behavior are expected to asymptote. We then conducted psychophysical (2AFC, 9 subjects) and fMRI-RA experiments (6 subjects, 3T Siemens Trio magnet) to test these predictions. We find that i) behavioral performance

asymptotes as predicted, ii) BOLD adaptation decreases and asymptotes with increasing T-D dissimilarity, as predicted, and iii) the asymptotes in behavior and fMRI are in good agreement with model predictions. This supports the predicted quantitative link of FN tuning, FFA response, and behavior.

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634 The FFA Shows a Face Inversion Effect That is Correlated With The Behavioral Face Inversion Effect

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The behavioral face inversion effect (Behavioral-FIE) is one of the most established markers for specialized face processing. Functional MRI studies testing for a correspondingly reduced signal for inverted compared to upright faces in face selective fusiform areas (FFA-FIE) have reported mixed results. Two studies (Haxby et al., 1999; Aguirre et al., 1999) reported no face inversion effect in the FFA, whereas one study found a significant but a small effect (Kanwisher et al., 1998). Importantly, the studies that found no FFA-FIE did not obtain or did not test for a Behavioral-FIE in accuracy measures. Here we report two experiments that yielded a significant Behavioral-FIE and a reduced signal for inverted relative to upright faces in the FFA (FFA-FIE). Further, this FFA-FIE was correlated with the Behavioral-FIE across subjects in both experiments. In Experiment 1, 14 subjects performed a same-different matching task on upright and inverted faces presented in separate blocks. Our data show a significant reduced signal to inverted than upright faces and a positive correlation between the FFA-FIE and the Behavioral-FIE ($r(12)=.56$). To examine whether this effect is specific for faces, in Experiment 2, 15 subjects matched upright or inverted faces and chairs in an event-related design. The fMRI response in the FFA and accuracy were higher for upright than inverted stimuli for both faces and chairs. However, the FFA-FIE was correlated with the Behavioral-FIE ($r(13)=.45$), whereas the behavioral chair inversion effect was not correlated with the fMRI chair inversion effect ($r(13)=.16$). Our findings suggest a close link between the behavioral and FFA inversion effects for face stimuli only.

635 Cortical Networks Mediating Face Familiarity and Identity in the Human Brain

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Functional imaging studies have consistently documented face-selective activation in a core set of regions in human occipitotemporal cortex, particularly in the fusiform gyrus (FFA). However, the role of the FFA in face processing is still controversial and evidence supporting its exact contribution to face identification is not clear-cut. Here, we examine this issue by exploring whether there is a differential sensitivity for familiar vs. unfamiliar faces in the FFA and other cortical regions. We then determine whether face representation within regions showing such sensitivity is based on precise facial geometry or whether it is more abstract and based on facial identity irrespective of the exact physical appearance. To do so, we used a rapid event-related fMRI adaptation paradigm in which trials contained two consecutive faces for same/different identity judgment. 'Same' trials included two identical pictures or two different pictures of the same individual whereas 'different' trials included two pictures of two different individuals. Better performance (RT and accuracy) was found for familiar than unfamiliar faces, with poorest responses for different pictures of the same unfamiliar individual. fMRI findings revealed a differential response for familiar vs. unfamiliar faces in right (but not left) FFA, reflected in an overall elevated signal for familiar faces and a stronger adaptation effect when the exact same face was repeated. Interestingly, this region showed no adaptation for the identity of familiar faces but

exhibited a signal enhancement when the identity of an unfamiliar face was repeated. Additional foci of activation in the left posterior cingulate and medial prefrontal gyrus also showed preferential response for familiar faces but each exhibited a different adaptation pattern. Thus, our results show that a network of cortical regions, each contributing a unique pattern of activation, is involved in familiarity and identity coding of faces.

636 Evidence for maturation of the fusiform face area (FFA) in 7 to 16 year old children

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Behavioral and electrophysiological studies in humans suggest that face processing begins in early development and undergoes a slow maturation during childhood. Little is known about the underlying neural systems or the role of experience in this maturation process. In adults, a specialized region in the FFA responds preferentially to faces compared to other objects. Some studies have suggested a role for 'expertise' in FFA's responsiveness to faces. Thus, one possibility is that less face recognition expertise in children (compared to adults) is associated with less face selectivity in children's fusiform gyrus. Here we used functional magnetic resonance imaging (fMRI) to examine FFA's maturation during childhood. Fifteen adults and 21 children (ages 7 - 16) underwent fMRI in a 3 T scanner, while viewing 10 epochs of each of 5 image categories presented in pseudo-random blocks. Image categories included: faces (male faces with neutral facial expressions), novel objects (abstract sculptures), places (indoor and outdoor scenes) and textures. Data were analyzed in SPM2. For each subject, regions of interest were defined as contiguous voxels in the fusiform gyrus that were selectively activated for faces or objects. We found fewer face selective voxels (faces > abstract objects, $p < 0.001$) in the fusiform gyrus of children (ages 7-12 years) compared to adults (right FFA in children: 6.5 ± 1.8 voxels, in adults: 30.2 ± 6.9 voxels, $p < 0.005$; left FFA in children: 6.4 ± 4.3 , in adults: 18.9 ± 8.9 voxels, $p < 0.05$). In contrast, numbers of activated object selective voxels (abstract objects > textures, $p < 0.001$) were similar in children and adults (right fusiform gyrus in children: 45.5 ± 16.6 voxels, in adults: 28.3 ± 9.8 voxels, $p < 0.46$; left FFA in children: 37.3 ± 13.1 , in adults: 34.3 ± 10.1 voxels, $p < 0.85$). These findings provide evidence for maturation of FFA during childhood perhaps due to accumulated exposure to human faces.

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637 Behavioral and Electrophysiological Evidence for Configural Processing in Fingerprint Experts

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Visual expertise in fingerprint examiners was addressed in one behavioral and one electrophysiological experiment. In an X-AB matching task with fingerprint fragments, experts demonstrated better overall performance, immunity to longer delays, and evidence of configural processing when fragments were presented in noise. Novices were affected by longer delays and showed no evidence of configural processing. In Experiment 2, upright and inverted faces and fingerprints were shown to experts and novices. The N170 EEG component was reliably delayed over the right parietal/temporal regions when faces were inverted, replicating an effect that in the literature has been interpreted as a signature of configural processing. The inverted fingerprints showed a similar delay of the N170 over the right parietal/temporal region, but only in experts, providing converging evidence for configural processing when experts view fingerprints. Together the results of both experiments point to the role configural processing in the development of visual expertise, possibly supported by idiosyncratic relational information among fingerprint features.

638 Preservation and impairment of featural and configural processing for faces as a result of prosopagnosia

Richard Le Grand (rlegrand@uwic.ca)¹, Cindy Bukach², Martha Kaiser¹, Daniel Bub¹, James Tanaka¹; ¹University of Victoria, ²Vanderbilt University

This research examines the effects of prosopagnosia on the processing of featural and configural information in faces. Featural and configural information was manipulated in a face matching task by incrementally varying the size and distance of the eyes and mouth features respectively. In a control study with visually normal adults, the featural and configural conditions for the eye and mouth regions were equated for their overall perceptual discriminability. Using the same task, we assessed featural and configural processing in two cases of acquired prosopagnosia: LR and HH. Compared to age-matched controls, both prosopagnosic patients performed normally in their ability to discern differences in the size and spacing of the mouth feature. In contrast, the two patients were selectively impaired in their ability to detect featural and configural differences in the eye region. The same pattern of results was found whether the stimulus faces were presented sequentially or simultaneously. The findings indicate that brain-damage does not necessarily result in a global impairment of face processing ability. Although LR and HH showed an impaired ability to detect differences in the eye region, they were spared in their ability to discriminate differences in the mouth region. Interestingly, the face processing deficits identified in the patients did not correspond to impairment in sensitivity to featural or configural information.

Acknowledgment: Supported by the James S. McDonnell Foundation, and the Natural Science and Engineering Research Council of Canada

Attentional Selection and Tracking

10:30 - 12:15 pm

Hyatt North Hall

Moderator: Alex Holcombe

639 Top-down control over unconscious response priming through stimulus-specific gating.

Edward Awh (awh@uoregon.edu), Ulrich Mayr¹, Andrew Kohnen¹; University of Oregon

Using metacontrast masking, we observed robust response priming from stimuli that could not be consciously identified. When the masked primes matched the imperative target, responses were faster and more accurate. Past research has explained these unconscious priming effects in terms of the overlap between prime and target response codes. However, using a 4:2 stimulus response mapping, we found that these priming effects were largely contingent on a physical match between the prime and target stimuli. Thus, unconscious priming effects were mostly stimulus-gated, and were only weakly influenced by stimulus-independent response codes. Further experiments suggest that stimulus-gating of unconscious priming was determined only by the response-relevant feature of the prime and target stimuli; the overlap between response-irrelevant features of primes and targets did not modulate priming. Finally, we examined the degree to which unconscious priming effects could be flexibly modulated by top-down settings. Top-down selection of the response-relevant features elicited trial-by-trial changes in unconscious priming effects. By contrast, top-down selection of the relevant stimulus-response rules had virtually no effect. We suggest that unconscious priming effects are caused by stimulus-driven retrieval of specific S-R associations. Top-down control can determine which stimuli will trigger this retrieval process, but not which S-R links will be expressed for a given stimulus.

640 Distinguishing pre-selection from post-selection processing limits using a moving window of selection

Patrick Cavanagh (patrick@wjh.harvard.edu)¹, Alex O. Holcombe²; ¹Psychology, Harvard University, Cambridge, MA 02138, ²Psychology, Cardiff University, Wales

A new test determined whether a task's temporal limits are set by processes before or after selection. We use a moving window of attention to change rapid local alternation into a constant signal at the post selection level. Our two tasks were letter masking and feature pairing. Results: speed of letter masking was limited pre-selection whereas feature binding was limited post-selection. Here are 4 frames for the letter masking task ("=" is the mask). Reading down a column

+++++ shows that each location alternates in time between letter and mask.

Frame 1++A = A = A+++ Reading across a row (across space in one frame) shows that adjacent

Frame 2++= A = A =+++ locations alternate out of phase. Therefore, if we select an adjacent item on

Frame 3++A = A = A+++ each subsequent frame (follow along a diagonal), we always retrieve the

Frame 4++= A = A =+++ letter. To guide attention, a circle marked one letter in a frame and moved to

+++++ the adjacent letter on the next frame. In the nontracking condition without the guide circle, Ss monitored individual locations to report letter identity. Result: tracking the letter with moving attention did not increase the maximum rate at which Ss could report the letter. Therefore the mask had irretrievably degraded the letter prior to selection. On the other hand, tracking greatly improved the maximum speed in a feature binding task. For example, Ss reported letter pairs when shown AB alternating with CD, as on left below, or AD with CB, as on the right. Monitoring individual locations, Ss could only manage accurate report at 3Hz whereas with tracking (follow the diagonals), they could achieve rates of 5 Hz or higher. Here, the rate of feature pairing or binding is limited by processes following selection.

Frame 1++AB CD AB CD ++++++ Frame 1++AD CB AD CB

Frame 2++CD AB CD AB ++++++ Frame 2++CB AD CB AD

Frame 3++AB CD AB CD ++++++ Frame 3++AD CB AD CB

Acknowledgment: NEI EY09258

641 The neural site of attention matches the spatial scale of perception

Steven J Luck (steven-luck@uiowa.edu)¹, Jens-Max Hopf^{2,3}, Kai Boelmans², Mircea A Schoenfeld², Nicolas Boehler³, Jochem Rieger², Hans-Jochen Heinze^{2,3}; ¹Department of Psychology, University of Iowa, ²Department of Neurology II, Otto-von-Guericke University, ³Leibniz-Institute for Neurobiology

What is the neural locus of visual attention? In this study, we provide evidence that attention does not always operate in the same set of visual areas; instead, the neural locus of attention changes rapidly to provide a match between the spatial scale of task-relevant information in the current scene and the sizes of neural receptive fields. To examine this hypothesis, we obtained electrical (ERP), magnetic (MEG), and hemodynamic (fMRI) measures of attention from human subjects while they detected large-scale or small-scale targets within multi-scale stimulus patterns. Subjects did not know the scale of the target prior to stimulus onset, and yet the neural locus of attention-related activity between 250 and 300 ms reflected the scale of the target. Specifically, attention-related activity was confined to a high-level, relatively anterior visual area (the lateral occipital complex) for large-scale targets; for small-scale targets, attention-related activity was observed in both this relatively anterior visual area and a lower-level, more posterior area (V4). This rapid change indicates that the neural locus of attention in visual cortex is not static, but can change rapidly depending on the nature of the task-relevant information in the current visual input.

This suggests that the operation of attention within a given visual area is not tonically controlled by top-down executive systems, but is instead determined on a moment-by-moment basis as a function of interactions between top-down control signals and local information about the current visual input.

642 How does attention select and track spatially extended objects?: New effects of attentional concentration and amplification

Brian J. Scholl (Brian.Scholl@yale.edu)¹, George A. Alvarez²; ¹Yale University, ²Harvard University

Much recent research has demonstrated that attention can be allocated to discrete objects in addition to spatial locations, but relatively little research has explored the allocation of attention within individual uniform objects. While it may be that attention spreads uniformly through relatively small objects, real-world situations (e.g. driving) often involve attending to spatially extended objects, often under conditions of motion and high processing load. Here we explore how attention is used to select and track spatially extended objects in a multiple object tracking (MOT) task. Instead of the punctate objects used in most previous MOT studies, observers had to track of a number of long moving overlapped line segments in a field of identical distractors. At the same time, observers had to respond to sporadic probes, and their probe detection performance is used as a measure of the distribution of attention across the lines. In four experiments we discovered two novel phenomena: First, attention seems to be concentrated at the centers of the lines during tracking, despite their uniformity: probe detection was much more accurate at the centers of the lines than near their endpoints. Second, this 'center advantage' grew as the lines became longer: not only did observers get relatively worse near the endpoints, but they became better at the lines' centers -- as if attention became more concentrated as the objects became more extended. Both of these effects were unusually large and robust. Additional results suggest that these effects reflect automatic visual processing rather than higher-level strategies. Beyond demonstrating that objects can serve as units of attention, these results begin to show *how* attention is actively allocated to extended objects over time in complex dynamic displays.

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643 How Many Objects Can You Track?: Evidence for a Flexible Tracking Resource

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The number of moving objects that can be tracked with attention is often reported to be 4, suggesting that there is a 'structural limit' on tracking. We show that the tracking limit is not fixed, but depends systematically on the speed of the objects, such that at slow speeds observers can track 8 targets as well as a single target moving at a fast speed. Critically, the function relating the speed limit to the number of targets tracked is continuous, without any noticeable break in the 3-5 target range, suggesting that tracking accuracy is limited only by the amount of resources devoted to each target, not by a structural limitation. **Method:** Observers performed a multiple object tracking task in which they tracked 1-8 circles among a set of 16 identical moving circles. In session 1, observers adjusted the speed of the objects to find the maximum speed at which they could perfectly track the targets for 5 seconds. In session 2, we verified the accuracy of these settings by having observers track 1-8 targets moving at their 'personal' speed limit for each number of targets. **Results:** With each increase in the number of targets, the speed limit decreased significantly. Moreover, the function was continuous, without any noticeable discontinuities in the 3-5 object range ($r = .998$ between speed and log of the number of targets). All speed settings were greater than zero indicating that on average observers estimated there was a speed at which they could perfectly track as many as 8 moving targets. It also appears that observers were able to accurately estimate their speed limits for tracking different numbers of targets, as track-

ing performance was near 100% for each number of targets in the second session and did not differ for different numbers of targets. **Conclusion:** These results are inconsistent with models that assume a fixed 4 object limit on tracking, and suggest that that tracking capacity is limited only by the amount of resources devoted to each target.

644 Counting without individuals: Rapid parallel enumeration of sets implicates preattentive object files.

Justin Halberda (halberda@jhu.edu), Lisa Feigenson; Johns Hopkins University

Human adults have a core computational system that allows for the rapid approximate enumeration of large set of objects (e.g. 36) in parallel. This system is shared broadly throughout the animal kingdom and may rely on representations in the parietal lobe. Humans also have the ability to attend to a small number of individual objects in parallel (approximately 4). With rare exception, studies of parallel enumeration and visual attention have continued in isolation from one another. A paradox presents itself. It has been suggested that visual attention binds the basic-level features of an object together making them into a coherent individual. But, if visual attention is limited to approximately 4 individuals, and it is visual attention that makes an object available to higher-level processes like approximate enumeration, how are we capable of enumerating upwards of 50 visual objects within a single flash of only 250 msec? Is this counting without individuals? In a series of experiments, participants were flashed arrays containing large numbers of colored dots or shapes. Between 1 and 8 different colors (Experiments 1-3) or shapes (Experiment 4) were presented. Participants were required to enumerate multiple subsets of the array in parallel, defined by color or shape, within a single masked presentation. Participants succeeded at enumerating multiple subsets (up to 4 on any given trial) when they were defined by a unique basic-level feature (e.g. color), but not when they were defined by a salient higher-order feature (e.g. shape). We demonstrate that it is the representations of preattentive vision that underlie parallel enumeration, and that humans are capable of enumerating up to 4 sets in parallel.

645 Attentional tracking across display translations

Adriane E Seiffert (a.seiffert@vanderbilt.edu); Vanderbilt University

What is the reference frame for attentional tracking of multiple targets? The premotor theory of spatial attention predicts a retinotopic reference frame, because if peripheral attention is akin to saccadic preparation then it should be generated relative to fixation. However, object-based attention theories predict a more allocentric reference frame because targets are perceptually grouped into a non-rigid virtual object from their arrangement in the display. We tested these theories by discretely shifting the entire visual display during tracking, thereby changing the retinal coordinates of the targets while keeping constant their relative arrangement. Participants were asked to keep track of a subset of 2, 3 or 4 disks in a display of 8 disks randomly moving inside a display box (10X10 degrees visual angle) on a computer monitor (24X32 dva). At 1-second intervals during the 9-second tracking task, all the disks disappeared for 0.5 seconds. When the disks disappeared, the box either immediately shifted to one of eight positions on the monitor or remained in the same location. The disks then reappeared in the same position as they disappeared relative to the display box. Average tracking performance was impaired when the tracking display shifted (62% correct) compared to when the disks merely blanked without shifting (86% correct; $F(2,143)=35, p < .001$). Shifting the display in a predictable way (clockwise around the monitor), in order to encourage predictable eye movements, improved performance (62% to 68%, $F(1,65)=4, p < .05$). Encouraging participants to group targets into a non-rigid virtual object, both with explicit instruction and a canonical arrangement of the targets at the start of the trial (as in Yantis, 1992, *Cog. Psy.* 24:295-340) had no effect on performance. These experiments demonstrate that attentional tracking is impaired by discrete display translations, suggesting that a retinotopic reference frame may be used by the mechanism

that tracks target motion.

Acknowledgment: NIH EY014984-01

<http://vision.arc.nasa.gov/personnel/jbm/home/presentations/vss05/>

Sensory Integration

10:30 - 12:15 pm

Hyatt South Hall

Moderator: David Alais

646 Motion parallax in movies: Background motion, eye movement signals, and depth

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With mounting evidence that an extra-retinal eye movement signal is used to disambiguate depth order in motion parallax (MP) (Nawrot, 2003a; 2003b; Naji & Freeman, 2004; Nawrot et al. 2004), the perception of vivid and unambiguous MP in motion pictures presents an interesting and important challenge to this eye movement theory. It is unclear how a stationary observer viewing a motion picture on stationary screen might be generating the prescribed extra-retinal eye movement signal. Filmmakers have long recognized the depth-enhancing value of parallax created by camera translation. An under-appreciated aspect of this camera translation is the broad background motion field created behind the object of interest at center-of-frame. We hypothesized that this background motion drives a reflexive OKR signal and a countermanning pursuit signal is generated to maintain fixation on the object of interest. This pursuit signal is then available to disambiguate the perception of depth from MP. This hypothesis was tested using a random-dot MP stimulus (Rogers & Graham, 1979) presented upon a translating OKR grating background. Observers remained stationary and were required to maintain fixation on a stationary point on the display (monitored by video based eye tracking). Results show that background translation was sufficient to disambiguate the perceived depth of this MP stimulus. Perceived depth order was identical to that found in all other MP conditions; dots moving on the retina in the same direction as the pursuit signal are perceived as nearer than fixation. A static grating did not disambiguate the perceived depth of the MP stimulus. We conclude that the eye movement theory provides a parsimonious explanation for unambiguous depth from MP in many different conditions. Indeed, the neural mechanism might be found in MSTd where many neurons respond to broad field motion in one direction and to pursuit eye movements in the opposite direction (Komatsu & Wurtz, 1988).

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647 Guiding The Eye With The Hand: Role Of Proprioception In Spatial Updating For Saccades

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The saccade generator accounts for previous saccades in order to 'update' internal representations for subsequent saccades. Here we tested the role of limb proprioception on updating the locations of hand-held objects for the saccade generator. We measured radial saccades (8 directions, approximately 7 and 13 degrees eccentricity) from a central target in 6 human subjects under the following conditions: 1. Visual controls (saccade to the peripheral flashing LED, with or without memory delay); 2. Proprioception alone (after hand-held LED target was extinguished, hand was moved passively or actively from the center to the periphery, followed by saccade to the perceived target location); 3. Combination of vision and proprioception (like #2, but target flashed again after the hand movement). In all trials, the eye held the central fixation point until an auditory command told

them to saccade to the peripherally shifted target (in complete darkness). We recorded eye and arm movements with search coil and optotrak systems respectively. Subjects were able to use the spatial updating from proprioception to generate approximately accurate saccades, but tended to overshoot the targets. Proprioception alone trials were least accurate, followed by combination of vision and proprioception, and then vision alone (which was best). In addition, proprioception-related errors were different for different movement directions (being greater for horizontal and centripetal movements). Surprisingly, compared to visual controls, the combination of proprioception and vision gave reduced saccade accuracy, perhaps due to the proportionate weighting of each of these two different inputs during the integration.

Acknowledgment: Supported by CIHR

648 Ames' Window, Vision, and Proprioception

Nicola Bruno (*dirpsicologia@units.it*)¹, Alessandra Jaconuzzi¹, Raffaella Del Bello¹, Alessandro Dell'Anna²; ¹Università di Trieste, ²Università di Genova

Ames' trapezoidal window is a well-known demonstration of the effect of monocular information about surface slant on other visual processes, such as motion perception (Ames, 1951). While performing informal observations of a hand-held reproduction of Ames' display, we noted some peculiar effects that may be due to the interaction of vision with proprioception. Specifically, during monocular observation while holding the trapezoid with the arms fully extended, several observers experience a striking proprioceptive distortion (e.g., one hand appears farther from the other, or one arm appears longer than the other). Furthermore, in bimodal judgments of slant several observers are strongly biased by vision despite clear, unambiguous proprioception. In this sense, the effect may appear as an instance of visual dominance in the multimodal perception of one's position in space. However, our data suggest that the proprioceptive misalignment of the hands is, in fact, rather less than the apparent slant of the window when this is not held. This finding argues against a 'visual capture' account, supports an explanation in terms of bimodal integrative processes, and underscores the importance of supplementing phenomenological observation with objective measures. Implications of the visual-proprioceptive Ames' window for current models of bimodal integration are discussed.

649 The ventriloquist illusion as an optimal percept

Ulrik R Beierholm (*beierh@caltech.edu*)¹, Steven R Quartz¹, Ladan Shams²; ¹California Institute of Technology, Computation and Neural Systems, 1200 E California #139-74, Pasadena, California 91125, ²Department of Psychology, University of California, Los Angeles, Franz Hall 7445B, Los Angeles, California 90095-1563

Human perception is highly multisensory. In nature several sources can be the cause of the stimuli and the nervous system has to decide in which cases the inputs received are from a single or multiple sources. This presents the nervous system with the constant problem of deciding which signals should be integrated and how, and which signals should be segregated. We investigated this question in the context of the so-called ventriloquist illusion, by which a ventriloquist can induce the perception of the sound being projected by a puppet by moving the puppet in synchrony with the sound. Depending on the angular separation of the visual and auditory sources, the percept can either be of two different causes (puppet moving, sound from ventriloquist) or a single one (puppet talking). It has been previously shown that an ideal observer model of multisensory processing derived from Bayesian inference can account for the sound-induced flash illusion and the general task of reporting number of pulsations which is primarily a temporal task. We examined whether this model can explain the ventriloquist illusion which involves a spatial task. We presented subjects with flashes of gabor wavelets on a noisy background accompanied by brief bursts of auditory noise. The visual stimulus and auditory stimulus were presented at the same or different locations, each at one of 5 locations along a horizontal line. The task was to indicate

the location of the visual stimulus as well as that of the auditory stimulus in each trial. The subjects' auditory and visual responses were surprisingly consistent with the ideal observer in all conditions ($R^2=0.91$). The finding that the Bayesian inference model can account for auditory-visual integration/segregation in two complementary tasks and paradigms suggests that Bayesian inference is a general principle governing multisensory information processing in humans, spanning situations of segregation to partial interaction to complete fusion.

650 Neural correlates of coherent audio-visual motion perception

Oliver Baumann (*mark.greenlee@psychologie.uni-regensburg.de*), Mark W Greenlee¹; Institute of Experimental Psychology, University of Regensburg, Germany

Moving objects in a cluttered scene are often detected by multisensory cues. We investigated the cortical activations associated with coherent visual motion perception in the presence of a stationary or moving sound source. Subjects ($n = 12$) judged 5s-episodes of random-dot motion containing either no (0%), meager (3%) or abundant (16%) coherent visual direction information. Simultaneous auditory noise was presented via MR-compatible headphones with an in-phase moving, out-of-phase moving or stationary sound source (simulated with generic head-related transfer function). In a 4AFC response paradigm, subjects judged whether visual coherent motion was present, and if so, whether the auditory sound source was moving in-phase with the visual motion, was moving out-of-phase or was not moving. Threshold-level performance was achieved by all subjects at the 3% visual coherence level, and the false alarm rate remained below 20%. T2*-weighted images were acquired using a 1.5 T Siemens Sonata with an 8-channel phase-array headcoil, and fixation was monitored with the MR-Eyetracker (CRS Ltd). To eliminate interference with the noises created by the gradient system (with headphone dampening, 80 db), a sparse imaging, whole-brain (36 slices) design was employed with TR = 3.4 s and inter-acquisition breaks of 11.6 s. An SPM2 fixed-effects analysis revealed significant BOLD clusters in extrastriate and associational visual cortex that increased in magnitude with visual coherence level. Auditory motion activated an extended region (> 1000 voxels) of the STG, exhibiting a right-hemispheric preponderance. Combined audio-visual motion (contrast: in-phase > static sound) led to significant activations in the supramarginal gyrus and STG, and the resulting effect size was larger for the in-phase than for the out-of-phase condition. Our findings indicate that the lateral parietal and superior temporal cortex underlies our ability to integrate audio-visual motion cues.

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651 Seeing music, hearing gestures

Michael Schutz (*schutz@virginia.edu*), Michael Kubovy¹; University of Virginia

Musicians disagree whether it is possible to produce notes of varying durations on percussion instruments. According to some, a longer physical gesture produces a longer note; others maintain gesture length in and of itself has no effect upon duration. In an attempt to reconcile these disparate viewpoints, we investigated the relative contribution of audio and visual information on perceived note duration.

Stroke preparation and release of single undamped short (S) and undamped long (L) notes performed by a world-renowned percussionist served as the base material. These were separated into visual (Sv, Lv) and auditory (Sa, La) components. Additionally, the auditory component of artificially damped notes (Da) provided extremely short auditory information. We generated audio-visual stimuli by crossing the two visual (Sv, Lv) and three auditory (Sa, La, Da) conditions. Subjects were asked to rate the duration of notes presented in audio-alone (A), and audio-visual (AV) conditions. In AV, subjects were instructed to make duration ratings based only on auditory information. To discourage subjects from ignoring visual information all together, we included a second question as to the level of agreement between audio and visual components.

RESULTS:

- 1) In the A condition, duration ratings of undamped notes (Sa, La) did not differ, although Sa and La were both rated longer than Da.
- 2) In the AV condition, ratings of undamped notes were affected by visual (SvSa vs. LvSa), but not auditory (SvSa vs. SvLa) information.
- 3) As measured by d' , discrimination between damped and undamped auditory was weaker in AV (SvSa vs. SvDa; LvLa vs. LvDa) than A (Sa vs. Da; La vs. Da)

We will propose a reconciliation between two implications of these data: (1) Although the attempt to produce longer notes with longer gestures is an acoustic failure, it is a perceptual success due to the visual influence on perceived duration. (2) The presence of visual information reduces auditory discriminability.

652 From Independence to Fusion: A Comprehensive Model for Multisensory Integration.

Marc O. Ernst (marc.ernst@tuebingen.mpg.de); Max Planck Institute for Biological Cybernetics, Tübingen, Germany

Recently we demonstrated that humans integrate visual and haptic information in a statistically optimal way (Ernst & Banks, 2002). I.e., subjects make optimal use of the information provided in order to reach the decision necessary for the task. As shown by Hillis et al. (2002), however, this does not necessarily imply that the sensory signals are completely fused into a unified percept. If subjects would completely fuse the signals, by definition, they would not at all retain access to the incoming sources of information. In contrast, Hillis et al. found some weaker form of interaction between the sensory signals. The degree of interaction between the sensory signals can be taken as definition for the strength of coupling between the signals: there is no coupling if the signals are independent; there is maximal coupling if the signals are fused. Using Bayesian decision theory I here propose a comprehensive model that can account for both results. The prior used in this model represents the probability of the physical relationship (mapping) between the signals derived by the sensory systems. This probability has a narrow tuning if the mapping between the physical signals is relatively constant (such as e.g., the mapping between texture and disparity signals). If the mapping changes easily (such as e.g. the mapping between visual and haptic signals), the distribution of possible mappings reflected in such a prior is wider. This is called the 'coupling prior' because the tuning of the prior will determine the level of interaction, i.e., the strength of coupling. I will further present data from a visual-haptic discrimination experiment that will support these theoretical considerations. Taken together, I propose that such a Bayesian model that uses a 'Coupling Prior' for describing sensory interactions is a convenient theoretical framework for understanding multisensory integration as a continuous process between independence and complete fusion.

Acknowledgment: This work was supported by the 5th Framework IST European Program (Touch-Hapsys, IST-2001-38040)

Poster Session F

May 9, 2005 – Monday AM

Motion 2 (653-670), Neural Coding (671-679), Neural Mechanisms and Models of Attention (680-691), Orienting and Eye Movements (692-702), Bistable Perception (703-709), Perceptual Learning 1 (710-716), Lateral Interactions and Filling-In (717-727), Motion in Depth 2 (728-736), Object Recognition (737-748), Sensory Integration: Vision and Touch (749-759), Temporal Processing (760-771)

8:30 am - 2:00 pm (Authors present 12:15 - 2:00 pm)

Municipal Auditorium

Motion 2

653 Detection of motion-defined form in the presence of veiling noise

Robert S Allison (allison@cse.yorku.ca)¹, Todd Macuda², Sion Jennings², Paul Thomas³, Pearl Guterman¹, Greg Craig²; ¹Centre for Vision Research, York University, Toronto, Canada, ²National Research Council of Canada, Flight Research Laboratory, Ottawa, Canada, ³Topaz Technology Inc., Toronto, Canada

Purpose. Perception of motion-defined form from apparent motion depends on the ability to detect and segregate regions of coherent motion. We investigated the effect of superimposed luminance noise on the ability to detect motion-defined form.

Methods. Stimuli consisted of randomly textured squares that subtended 8.6 degrees of visual angle. The image sequences depicted either a motion-defined square subtending 4.3 degrees (the target) or only the moving background. If the difference in the speed between the foreground dots and the background dots exceeded a certain threshold, the form of the foreground was visible. The images were rendered in Open GL at 100 Hz and displayed at 80% contrast.

Observers viewed the displays from 1.2 m with their head stabilized on a chin rest. For each trial, subjects were shown a pair of image sequences and required to indicate which sequence contained the target stimulus in a two-interval forced-choice procedure.

Poisson distributed spatiotemporal image noise was added to both the background and foreground of the display. At each of a variety of stimulus speeds (20.1, 50.4, 100.7, 201.4, and 302.2 arc min/second), we measured detection threshold as a function of stimulus signal to noise ratio.

Results and discussion. All subjects could easily detect the motion-defined forms in the absence of any superimposed noise. As the power of spatiotemporal noise was increased, subjects had increased difficulty detecting the target. The influence of added noise was most pronounced at the lowest and highest image speeds. These results will be discussed in terms of models of motion processing and in the context of the usability of enhanced vision displays under noisy conditions.

Acknowledgment: The support of Government of Ontario (CRESTech) is gratefully acknowledged.

654 Second-order motion shifts apparent position

David W Bressler (xwd40x@hotmail.com), David Whitney¹; Center for Mind & Brain, UC Davis

Many studies have documented that first-order motion influences perceived position. Here we show that second-order (contrast-defined) motion influences the perceived positions of stationary objects. We used a Gabor pattern as our second-order stimulus, which consisted of a drifting sinusoidal contrast modulation of a dynamic random dot background; this

carrier was enveloped by a static gaussian contrast modulation. Two vertically aligned Gabors had carrier motion in opposite directions. Subjects judged the relative positions of the Gabors' static envelopes. The positions of the Gabors appeared shifted in the direction of carrier motion as a function of the second-order carrier's temporal and spatial frequency. The results show that second-order motion detection mechanisms contribute to perceived position. Further, the differential spatial and temporal tuning of the illusion supports the idea that position is determined independently for first and second-order motion.

655 Compression of Perceived Motion Trajectories

Rick H Cai (rcai@wisc.edu); Dept. of Psychology, University of Wisconsin, Madison, WI

In this study, we investigated whether the perceived length of a motion trajectory is equal to its veridical length. A bar moved on a computer screen along a straight path. One segment of the trajectory was marked out by turning the bar into a different color. The length of this marked segment was compared with that of a comparison stimulus displayed below the motion trajectory, which consisted of the very same motion segment but displayed statically (i.e. in constant view as a rectangle). The length of this comparison stimulus thus revealed the veridical length of the marked segment. It was found that the marked segment drawn out by the moving bar was perceived as shorter than the static comparison segment. This shortening was not caused by the color difference per se. Marking the segment by a different bar size produced the same results. Nor was it caused by the marker onset. A segment produced by the offset of the moving bar (i.e. a gap inserted into the motion trajectory) was also perceived as shorter. Prior research on the 'flash-lag illusion' has shown that a moving stimulus is perceived as located ahead of, not behind, its veridical location. The current finding thus poses a dilemma: if the motion trajectory is perceived as shorter than its real length, how can the moving stimulus be perceived as located ahead of its veridical position? Additional experiments explore this dilemma in the context of possible differences in the neural representation for continuous and discrete events.

656 The neural correlates of motion processing on the basis of trackable features

Gideon P Caplovitz (peter.u.tse@dartmouth.edu), Po-Jang Hsieh, Peter U Tse; Dartmouth College

Contour curvature maxima/minima and discontinuities, such as terminators, junctions, and corners, can serve as trackable features (TFs) that solve the aperture problem faced by motion-tuned cells (Pack et al, 2003, 2004). Another contour-dependant motion signal, component-motion, can account for many percepts of motion (e.g. Bowns 2001) and may work in conjunction with TFs to determine perceived motion. The goal of our experiments was to characterize the relationship of contour curvature as a TF in the context of rotational motion. A further goal was to

locate the areas of the visual cortex that support the use of these TFs for motion processing. Behavioral experiments: Pairs of ellipses were rotated and 2AFC speed judgments were made. The perceived speed of rotation varied with ellipse aspect ratio. Modified ellipses and rectangles were also used to examine the interaction of curvature, component motion and perception. Data imply that component motion models are insufficient to account for the aspect ratio at which the veridical speed is observed. fMRI experiments: Modified ellipses called 'bumps', consisting of two half ellipses joined along their common major axis were used. Groups of rotating bumps defined by the degree of curvature discontinuity were presented. Stimulus groups were either rotated at the same speed or at subjectively equal speeds. 17 subjects were run in a standard fMRI block-design, GE 1.5T, one-shot EPI, FA 90 degrees, epochs 20s, TR = 2.5secs, 25 axial slices. Results: Areas of the brain where the BOLD signal varied parametrically with perceived speed included superior/anterior MT+. Areas of the brain that varied parametrically with curvature discontinuity (i.e. TF) included inferior/posterior MT+. We propose that contour curvature and other TFs are processed in more inferior/posterior regions of MT+ and V3A, and that perceived motion is computed by more superior/anterior regions of MT+/MST on the basis of TFs, component-motion and other cues.

657 Can the perception of causality be measured with representational momentum?

Hoon Choi (*h.choi@yale.edu*), Brian J. Scholl¹; Yale University

In a collision between two objects, we can perceive not only properties such as shape and motion, but also the seemingly high-level property of causality. It has proven difficult, however, for vision researchers to measure causal perception in a quantitatively rigorous way which goes beyond subjective perceptual reports. Recently researchers have attempted to solve this problem by exploiting the phenomenon of representational momentum (RM): estimates for the final position of a moving target that disappears are displaced in the direction of the motion. Hubbard and colleagues measured RM in the context of 'launching' events, wherein an object (A) moves toward a stationary object (B) until they are adjacent, at which point A stops and B starts moving. In this situation, RM for B is reduced compared to the case when B moves in isolation. This is explained by appeal to a hardwired visual expectation that a 'launched' object is inert and thus should readily cease its movement without a source of self-propulsion. A limitation of these studies, however, is that perceived causality was always associated with either (1) the number of objects in the display, or (2) the existence of spatiotemporally continuous motions -- both likely to influence RM. We studied RM for displays which did not differ in these respects, contrasting causal launching vs. non-causal 'passing' (wherein one object is simply seen to pass through another stationary object). With such displays, however, RM is no smaller for launching than for passing -- despite the fact that we first successfully replicated the results of previous experiments using these same stimulus parameters and statistical power. Our null effect for launching vs. passing replicated several times using various parameters, well matched to those in previous experiments. We conclude that the RM-attenuation effect may not be a pure measure of causal perception, but may rather reflect lower-level spatiotemporal correlates of some causal displays.

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658 The case of the misperceived saltire: oblique motion of two intersecting lines is biased

Gunter Loffler (*gloe@gcal.ac.uk*), Camilla McG Magnussen¹, Harry S Orbach¹, Gael E Gordon¹; Department of Vision Sciences, Glasgow Caledonian University, Scotland, UK.

The perceived direction of a translating tilted line shows strong biases for motion along non-cardinal axes (up to 408, Loffler & Orbach, 2001). Are these biases restricted to single lines? Do they vanish if additional motion information is present?

Methods: Two high-contrast, intersecting (intersection visible or occluded) lines (4.85x0.25dva) translated for 195ms with average speed of 5deg/s. 16 different absolute directions were tested (0 to 360). Different cross shapes were created by varying the angle between the two lines (208, 458, 908 and 1208). The axis of the cross was aligned with the direction of motion (symmetrical) on some trials and misaligned in others.

Results: For crosses, as for single lines, there are no biases for motion along the cardinal axes. Biases are reduced but not eliminated for oblique motions (up to 208). Biases with two lines are different to that observed with a single dot (which usually yields the smallest bias), even when the intersection of the two lines is visible and could be tracked. The bias for crosses depends on the angle between the lines and the angle between their axis and the direction of motion. Generally, they are smaller when the lines are symmetrical around the direction of motion. In this case, a narrow angle (208) shows the smallest bias (=108). Perception changes when the two lines are not arranged symmetrically and is biased towards the line closest in orientation to the direction of motion of the pattern.

Conclusions: Against expectation, strong biases persist even where a host of motion signals are available. In addition to the veridical signals from each of the line-endings and the intersection of the lines, the combination of two 1-D signals from each line segment permits, in theory (IOC), veridical motion estimation. Our results show that neither strategy is used successfully for oblique directions of motion.

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659 The Contributions of Edges and Surfaces to the Perception of Object Motion

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The motion of objects moving through space potentially can be perceived based on the displacement of their borders or surface parts. When an object shifts multiples of its width, the location of its borders and surface both change, and thus both could give a motion signal. However, when an object with a uniform surface shifts only a small fraction of its width, luminance changes are confined to its leading and trailing edges. Experiments were conducted to determine whether there are two motion signals available for the motion system to use, an edge-based signal and a surface-based signal. The experimental paradigm involved a solid rectangle that remained fixed in place, flanked on each side by an adjacent rectangle. The luminance of the flankers alternated in two-frame display cycles. When the flankers were small, the static central rectangle was perceived to move back and forth. When the flankers were larger, motion was perceived locally within the flankers. With even larger flankers, the perception was of a flanker moving back and forth across the central rectangle. The above results, as well as the results of other experimental manipulations, are consistent with a system of motion perception that extracts edge-based and surface-based motion information, competition arising when they signal different motion paths. Both the edge-based and surface-based motion depends on counterchange in activation, i.e. activation decreases in one location and increases in another, with motion being signaled from the location of the activation decrease to the location of the activation increase (Gilroy & Hock, 2004; Hock & Gilroy, 2004; Nichols & Hock, 2004).

660 Spin-orbit coupling in vision: Evidence from representational displacement

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When a moving object vanished, it is mislocalised toward the moving direction. Three experiments examined the effects of spin on the mislocalisation. The target stimulus was a circle with an axis bar (in its center). In the first experiment, the target moved horizontally from left to right and vice versa with a uniform velocity. Additionally, the target had a

spin in (forward) or against (backward) the direction of motion. Observers' task was to point with cursor the vanished position of the target as accurately as possible. The results revealed that when observers fixated on the fixation mark forward displacement varied with the direction of spin, the larger displacement for forward spin. This suggested that the displacement was attributed to the internalised representational friction. On the other hand when observers pursued the target, the forward displacement was promoted by the spin itself (regardless of its direction). In the second experiment, the orientation of axis in the target circle was randomly changed in each frame. Forward displacement was still observed only in the condition in which observers pursued the target, indicating that mere axis action made the forward displacement. In the third experiment, the target was stationary while spinning and no displacement was observed, and so spin was considered to have no self-propulsion. The results of three experiments suggest that two kinds of motion, namely, orbit and spin, interact in visual short-term memory, the by-product of which is the mislocalization.

661 Attention and Figure-Ground Segregation in a Model of Motion Perception

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Transparency presents a difficult problem for motion segmentation because multiple velocities have to be represented at each spatial location. We analyze a feedforward/feedback neural model of area V1 and MT that is capable of solving the motion aperture problem (Bayerl, Neumann, Neural Comp., 16(10), 2004) and propose an extension of it that explains how transparent motion is integrated and segregated in early parts of the dorsal pathway. First, we incorporate an unspecific attentional signal from higher areas that influences the disambiguation process realized by early feedback between model V1 and MT. We demonstrate how such an attentional signal (e.g. priming any rightward motion) achieves the selection of detected motion patterns in the presence of transparency. Second, we employ a pair of figure/ground layers of motion sensitive cells to represent transparent motion. We show that such neural network architecture is capable of successfully detecting and representing transparent motion. Without explicit transparency detection motion of the figure is segregated from ground motion in the presence of transparency, while no such separation occurs for opaque motion. Model experiments with random dot stimuli consisting of horizontal stripes alternatively showing leftwards and rightwards motion generate results consistent with psychophysical experiments. For thin stripes motion cannot be separated spatially and thus transparent motion estimations are generated, while broad stripes are nicely segregated in space (Van Doorn, Koenderink. Exp. Brain Res., 45, 1982). In conclusion, the presented contributions show how simple local mechanisms in conjunction with feedback processing can generate complex behavior of a neural network, consistent with experimental observations. Importantly, the model consists of model areas described by similar mechanisms and, thus, presents a step towards a modular model of cortical motion processing in the dorsal stream.

662 Neural Correlates of Illusory Motion Perception in the Pinna-Figure

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We investigated the recently discovered Pinna-Illusion using the fMRI technique. The original figure investigated by Pinna and Brelstaff (2000), which induces the illusion of rotatory motion, consists of two concentric rings of circular arranged micro patterns bounded in a specific way by

light and dark lines. The illusion of rotatory motion occurs whenever this class of flat static patterns are moved across the peripheral visual field during an observer's own movement towards or away from the figure. To create the illusion suitable for the MR scanner a simulation of the subject's self-movement was created by a computerised animation. The animation generated contraction and expansion of the concentric circles on the retina i.e. outward and inward radial flow. In a block design we compared the rotatory motion illusion with two controls and one baseline condition, which all did not show the effect of the illusion, when animated. 10 volunteers, participants with normal or corrected to normal vision were tested. Statistical analysis of data acquired in this study was carried out with SPM2 using t-tests. Two bilateral occipito-temporal activation sites, and a unilateral activation in the frontal lobe were revealed to be more activated during the motion illusion in comparison to the non illusory visual stimulation ($P < 0.05$, FDR). The bilateral occipito-temporal activation was found to be adjacent to the V5 area, probably within the V5 complex and LOC and corresponds partly to the activation found in a PET study, which investigated the rotatory motion illusion in a static figure called Enigma (Zeki et al., 1993). Our results might challenge the view, which considers illusory motion to be detected by the same visual channels as real motion. We propose further psychophysical and brain imaging investigations and experimental improvements in order to gain insight into the general perceptual mechanisms of illusory motion.

663 How the past gives way to the present: Evidence for Bayesian updating with repeated presentation of ambiguous motion quartets

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Introduction: In a motion quartet (MQ) with one repetition, two disks that fall at the endpoints of a diameter of an invisible circle are briefly presented and then replaced by two disks that fall on a second diameter. The observer sees rotation of the first pair into the second. By varying the angle between the diameters, one can estimate a psychometric function $P[L | \text{angle}]$. We reported last year that recent task history exerted a strong effect on perceived direction of motion, shifting the threshold parameter of the psychometric function. In particular, the observer is strongly biased to see motion in the same direction as the motion perceived on the most recent trial. This hysteretic effect (measured as the change in threshold) is little affected by increasing the time interval between trials (to as much as 30 seconds). Purpose: We sought to determine how repetitions of the same motion quartet would affect hysteresis. It is plausible, for example, that multiple presentations of the same sensory information would eventually 'overpower' the influence of recent task history, reducing hysteresis to 0. But precisely how? Methods: We measured the hysteresis induced by the previous trial for two subjects who judged 3840 MQ trials each. In different blocks, the MQ was presented 1, 2, 4 or 8 times in each trial. The observer reported the direction of motion of the last presentation only. Results: For both observers we found that hysteresis decreased rapidly with number of repetitions and that a log-log plot of hysteresis versus repetition was approximately linear with slope -1. Doubling the number of repetitions halves the hysteretic effect. This outcome is consistent with a Bayesian updating model where an initial prior probability that the stimulus will go left (based on recent task history) is successively combined with independent likelihood terms, one for each repetition of the stimulus.

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664 Moving into adult vision: Five-year-olds' immaturities in detecting second-order motion versus discriminating its direction

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We compared sensitivity to second-order (contrast-modulated) motion in 5-year-olds and adults using tasks that required the detection of motion vs. the discrimination of the direction of motion. For the motion detection task, participants viewed two 15x158 vertical sine-wave gratings separated by a 58 gap. Randomly, on each trial, one grating was stationary and the stripes in the other moved outward. Participants indicated which grating was moving. For the direction discrimination task, participants viewed one 15x158 vertical sine-wave grating that moved randomly to the left or right on each trial, and indicated the direction of motion. Each participant was tested on one of four temporal frequency-velocity combinations for each task. Contrast was modulated over trials according to a staircase procedure (Harvey, 1986) to measure the minimum contrast modulation yielding 82% correct responses. Results to date from 16 adults and 16 5-year-olds indicate that 5-year-olds' thresholds are lower for detecting motion than for discriminating its direction ($p < .05$), while there is no difference between the two tasks for adults ($p > .20$). Mean thresholds were lower in adults than in 5-year-olds for both tasks ($ps < .001$). The findings suggest that, at 5-years of age, the neural mechanisms underlying the detection of second-order motion are more mature than the mechanisms underlying the discrimination of the direction of second-order motion. A possible explanation is that, under the conditions tested, 5-year-olds relied on relatively mature temporal frequency-sensitive mechanisms to detect motion and relatively immature motion-sensitive mechanisms to discriminate the direction of motion. This hypothesis is supported by evidence that sensitivity to high temporal frequencies is mature at 12 weeks of age (Regan, 1981), while sensitivity to direction of second-order motion is still immature at 5 years of age (Elleberg et al., 2003).

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665 Aging and the detection of motion direction in random-dot stimuli

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Age related decrements in detecting coherent motion are the result of a decreased ability to integrate direction information. Previous research has determined thresholds for determining the overall direction of motion using random dot cinematograms (Watamaniuk and Sekuler, 1992; Williams and Sekuler, 1984). We used the 'Best PEST' (Lieberman and Pentland, 1982) method to derive the threshold level of noise at which direction can be detected. This experiment employed random-dot cinematograms in a two alternative forced choice presentation that varied in magnitude of mean direction, and duration. Each individual dot's path was varied by sampling from a probability distribution in which the standard deviation ranged from +/- 5 to 65 degrees from the primary direction. The magnitudes of mean directions between two presentations of each trial were 4, 7, 10 and 13 degrees. On each trial one presentation had a mean direction that was 20 degrees to the left or the right of an upward direction. The duration for each trial was either 500 or 1000 milliseconds. Four younger (average age of 25) participants and four older (average age of 75) individuals participated in our study. The subjects' task was to determine if the second presentation was to the right or left of the first. The results indicate main effects of age, duration, and direction difference magnitude. Noise thresholds decreased with increasing direction difference, and increasing duration. In general, older observers had elevated thresholds compared to younger observers, with less tolerance to direction noise at short durations.

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666 Spatio-temporal Integration, Kinetic Occlusion and Aging

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Most perceptual tasks require the integration of information over space and time. In the present study we examined whether age-related differences exist in the integration of spatio-temporal information from motion. 16 younger (mean age of 21.3) and 16 older (mean age of 74.1) observers were shown random dot patterns specifying one of five shapes whose contours were defined by kinetic occlusion---the accretion and deletion of texture. Three independent variables were examined: presence or absence of kinetic occlusion (object alone or object with background), density (0.61, 1.22, 1.83, or 2.44 dots/deg²), velocity (0.6, 0.8, 1.0, or 1.2 deg/s) and size (4.2 or 6.5 deg height). No age-related effects were found for baseline measures of object motion without kinetic occlusion. However, older observers, as compared to younger observers, had significantly lower sensitivity to stimuli with kinetic occlusion. Older observers, as compared to younger observers, had lower accuracy at lower speeds and density, suggesting that although older observers showed decrements in both spatial and temporal integration, the loss of temporal integration was more pronounced. In a follow up study we examined limitations in temporal integration by varying the lifetime of each dot in the display (2, 3, 4, and 6 frame lifetime). The subjects were 9 younger and 9 older observers from the first study. The results indicate that both older observers, as compared to younger observers, had greater difficulty in identifying shape for the 2 and 3 frame lifetime conditions when the contour was curved (the circle shape).

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667 A differential origin-of-motion response in V1 for first-order, but not second-order stimuli as revealed by fMRI.

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Recent studies have shown that an edge defined by motion accretion (the origin or trailing edge of a moving pattern) produces stronger fMRI activity than the same edge defined by motion deletion (the trailing edge or disappearance of the moving pattern; Koyama et al., 2003; Liu et al., 2004; Whitney, Goltz, et al., 2003). For example, a stimulus moving toward the fovea produces stronger activity in the periphery, whereas a pattern moving away from the fovea produces more activity near the fovea. Here we tested whether this difference in activity is due to a mechanism that selectively processes first-order (luminance-defined) motion. Using a 4T fMRI scanner, we measured visual cortex activity in seven subjects while they viewed randomly interleaved first-order and second-order (texture-based) moving patterns that moved toward or away from fovea. Subjects performed a letter discrimination task at the fixation point to control for attention.

GLM contrasts of first-order motion toward versus away from the fovea revealed a significant increase in activation at the origin of motion in all subjects, consistent with previous reports. The same GLM contrast for second order stimuli, however, produced significantly less activity at the origin of motion (the edge defined by motion accretion).

These results demonstrate a difference in processing of first and second order motion in primary visual cortex. While we found a significant overall response to second-order motion in early visual areas (consistent with previous studies; Seiffert et al., 2002; Smith et al., 1998), only first-order motion produced a selective response at the origin of motion. The results suggest that the mechanism that operates on the trailing edge or origin of a moving pattern is due to a luminance-based motion detection process, and not to a generalized alerting or salience-based mechanism.

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668 Neural correlates of illusory motion perception: the influence of apparent motion on plaid motion aftereffects

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It has been proposed that enhanced activity in the human motion complex (hMT⁺/V5) underlies the perception of illusory motion. Recent studies, however, have argued that in the case of motion aftereffect (MAE) this increase is due to visual selective attention rather than to the perception of MAE itself. It has also been reported that no net increase of activity occurs in hMT⁺/V5 upon MAE-eliciting motion adaptation if subjects report on a motion property of the test stimulus itself. These findings raised the question whether it is possible to disentangle MAE-related activity in area hMT⁺/V5 from motion specific selective attention. We have analyzed blood oxygen level dependent (BOLD) responses in visual area hMT⁺/V5 to stationary test patterns under adapting and non-adapting (variable directions) plaid motion conditions. Visual attention was controlled for using a superimposed apparent motion (AM) stimulus: participants had to report speed changes of the AM signal. Superimposed AM yielded a motion signal that had much lower amplitude activation in hMT⁺/V5 than plaid motion. Our participants reported strong MAEs upon adapting and no MAEs upon non-adapting conditions even when there was an overlaid AM-task during the plaid motion period. The observed MAEs were only represented in terms of hMT⁺/V5 activation when there was no motion specific attention task during the test phase. In summary, our results show that focusing attention to an AM stimulus during plaid adaptation does not have a profound effect on MAE generation; however the same attention task during the test phase minimizes differences in hMT⁺/V5 activation levels comparing adapting and non-adapting conditions. These findings extend previous knowledge on how selective attention modulates activity in hMT⁺/V5, suggesting that the amplitude of attentional modulation is in the magnitude of illusory motion elicited activations.

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669 Direction Tuning Curves of Motion Adaptation in the Visual Cortex Revealed by an Event-Related fMRI Study

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BACKGROUND Although a sampling unit of fMRI contains subpopulations of cells with diverse response selectivities, the fMRI adaptation paradigm (Grill-Spector et al., 1999) provides a means to reveal selectivities of a subpopulation of cells by measuring the extent to which cortical responses are reduced by adaptation to a specific stimulus feature. We exploited this paradigm further by conducting fMRI experiments in conjunction with a linear population model (Maurer et al., 2004) to estimate direction tuning curves of individual cells in motion-sensitive areas. **METHOD** A stimulus display consisted of distributed patches of dots moving in a specific direction. Two types of events—*stimulus* and *blank*—were randomly mixed in each scan. A stimulus event was composed of four epochs in the following order: a 1.5-s *adapting epoch*, a 0.9-s *blank epoch*, a 0.9-s *test epoch*, and a 3.9-s *blank epoch*. Both in the adapting and the test epochs subjects viewed moving dots and performed the speed discrimination task for attention control. Blank events, identical to stimulus events except that there was no test epoch, were included to isolate responses to the test epoch only. The direction difference between adapting and test dots was varied to assess the direction selectivity of adaptation. **RESULT** The amount of adaptation was maximized at 08

direction difference, and gradually dropped as the direction difference increased, resulting in a tuning curve with a Gaussian half-width of 608~1408. The tuning half-width was narrower in MT (608) than in V1 (1408) while the amplitude was greater in MT (.61) than in V1 (.37). With a linear population model we derived the tuning curves of 'representative' responses of individual cells, which compared moderately well to those from electrophysiological studies (Kohn & Movshon, 2004). **CONCLUSION** An fMRI adaptation experiment combined with a linear population model can depict the detailed nature of direction selectivity of motion-sensitive cells.

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670 Perception of Motion Induction for Naturalistic Images in the Human Visual Cortex

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Our visual perception often differs from the physical reality of the natural world. We exploited this discrepancy, with a perceptual illusion known as motion induction, to examine motion processing of naturalistic stimuli in the human visual cortex. When an incoherently moving stimulus is placed in a coherently moving surround, observers perceive the incoherent pattern moving in the opposite direction to the surround. We used psychophysics and fMRI to investigate the neural basis of motion induction for naturalistic images. Specifically, we used natural texture stimuli with 1/f amplitude spectra that consisted of a central region in a moving surround. The surround moved up or down with 100% coherent motion. We manipulated the coherence of the motion of the center: the center moved (up or down) at different coherence levels between random and 100%. When tested psychophysically, subjects misreported the direction of motion of the center. When the center had 0% coherence, observers perceived it moving in the opposite direction to the surround. The observers' point of subjective equality (PSE), i.e. when observers reported the center moving up and down an equal number of times, occurred when it had 30-50% coherent motion in the same direction as the surround. Based on the physical properties of the stimulus, we predicted that fMRI responses would be lower at 0% coherence than at the PSE where the motion coherence is higher. Alternatively the perceptual results predicted that the difference between these two conditions would be absent, or even reversed. That is; stronger fMRI responses would be observed at 0% coherence where there is more perceived motion than at the PSE. Our results in hMT⁺/V5 showed that fMRI responses correlate with the perceptual rather than the physical coherence in the stimulus. Our findings suggest that the motion induction effect can be mediated by a combination of motion coherence and motion contrast mechanisms in hMT⁺/V5.

Neural Coding

671 Redundant populations of simple cells represent wavelet coefficients in monkey V1

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An analysis of the distribution, $H(f)$, of the preferred spatial frequency (SF) of ~200 simple cells (SC) in monkey as measured by J. Cavanaugh and T. Movshon illustrates how the sparse wavelet decomposition of an image is represented by a highly redundant population code in V1. A strong dependence of the distribution $H(f)$ upon the eccentricity E at which the SC receptive fields are centered can be removed by rescaling f by the local Nyquist SF $f_{Nyq}(E) = 1/0.02(E+1.3)$, resulting in the normalized SF, $q(f,E) = f/f_{Nyq}(E)$, eq(1).

A model based on the number of neurons being proportional to the signal to noise ratio (SNR) of the wavelet coefficients and a modified $1/f^2$ power

spectrum of natural images leads to $H(q) \sim q^2/(q^2+q_0^2)\exp(-q^2/2s^2)$, using octave bin widths, eq(2).

The low SF cutoff parameter q_0 arises from the finite distance over which the retinal ganglion cell inputs can be pooled in V1. Its estimated value of 0.03-0.05 corresponds to a radius of 2.5-5mm of cortex, or a radius of $1/2 E$ degrees centered at eccentricity E . The high SF cutoff parameter arises from the spatial filtering in the retina that enforces the Nyquist sampling theorem. Its estimated value of 3.5-4.5 is consistent with size of the center spatial filter of the retinal P cells when scaled by eq (1). $H(q)$ spans 6 octaves with almost all the SCs lying within the central 2-3 octaves. Having only 2-3 SF channels may explain the difficulty of finding maps of SF magnitude with optical techniques. The redundancy of simple cells to wavelet coefficients at the peak of $H(q)$ is at least 100 leading to a SNR of $\sim 100:1$, which is consistent with the peak sensitivity of the MTF lying ~ 3 octaves below the SF limit of the visual system.

In summary, the majority of the information in V1 resides at low SFs that is pooled from 100s of ganglion cells, and hardly any information is at the highest SFs. Thus, both the retina and visual cortex utilize highly redundant population codes, not sophisticated spike codes of individual neurons.

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672 The Neural Code for Luminance

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How the visual system encodes light patterns on the retina and transforms this information into the full range of perceptual values that humans experience is arguably the central challenge of vision. A key aspect of this problem is how such encoding generates perceptions of brightness. A range of observations dating back a century or more have shown that the same amount of light can elicit radically different perceptions of target brightness as a function of context. Debate about the coding strategy responsible for these phenomena, initiated by Helmholtz, Hering, Mach and others, continues today. One approach to understanding coding has been to assume that the neural code for luminance that ultimately elicits brightness percepts arises from low-, intermediate- and high-level neural processing. This assumption, however, has not led to a satisfactory account of the percepts elicited by a variety of stimuli.

Based on an extensive analysis of natural scenes, we suggest that the encoding of luminance is governed by the probability distributions of luminance values in such stimuli, the rationale being a means of dealing efficiently with all possible occurrences of luminance patterns in typical images. Such coding thus represents the conditional probability distribution of target luminance within contextual light patterns, always making use of the full capacity of the system. The brightness of any target would then correspond to the value of the underlying luminance encoded in this way. In confirmation of this idea, the relevant probability distributions obtained from natural images predict a wide range of otherwise difficult to explain brightness phenomena. These results support the conclusion that the visual system encodes luminance according to the probability distributions of the co-occurring luminance values experienced in natural environments, and that the ensuing brightness percepts are always a consequence of this optimal coding strategy.

673 Shape Representation in V4: Investigating Position-specific Tuning for Boundary Conformation with the Standard Model of Object Recognition

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The computational processes in the intermediate stages of the ventral pathway responsible for visual object recognition are not well understood.

A recent physiological study by Pasupathy and Connor (2001) in intermediate area V4 using contour stimuli, proposes that a population of V4 neurons display object-centered, position-specific curvature tuning. The *standard model* of object recognition, developed by Riesenhuber and Poggio (1999) to account for recognition properties of IT cells (extending classical suggestions by Hubel, Wiesel and others, and incorporating standard findings and assumptions about the architecture of the ventral pathway), is used here to model the response of the V4 cells. The model is a feedforward processing hierarchy of increasing invariance and specificity, necessary for object recognition. Our results show that a simple network-level mechanism can exhibit selectivity and invariance properties that correspond to the responses of the V4 cells described by Pasupathy and Connor. These results suggest how object-centered, position-specific curvature tuning of V4 cells may arise from combinations of complex V1 cell responses. Also see the abstract by Serre and Poggio (VSS, 2005) on how such tuning may be learned through a biologically plausible learning mechanism. Furthermore, the model makes predictions about the responses of the same V4 cells studied by Pasupathy and Connor to additional classes of stimuli, such as gratings and natural images. These predictions suggest specific experiments to further explore shape representation in V4.

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<http://www-scf.usc.edu/>

674 The Costs of Ignoring High-Order Correlations in Populations of Model Neurons

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Background: Investigators debate the extent to which neural populations use high-order statistical dependencies among neural responses to represent information about a visual stimulus. A number of recent studies, using either performance or information measures, suggested that correlations between neurons play only a minimal role in encoding stimulus information. An important limitation of these studies is that, in approximating the joint distribution of responses, they considered only pairwise or 2nd-order correlations, thereby ignoring the information contained in higher-order correlations. Methods: To study this issue, we used three statistical decoders to extract the information in the responses of model neurons about the binocular disparities present in simulated pairs of left-eye and right-eye images: (i) the Full Joint Probability Decoder considered all possible statistical relations among neural responses as potentially important; (ii) the Dependence Tree Decoder also considered all possible relations as potentially important, but it approximated high-order statistical correlations using a computationally tractable procedure; and (iii) the Independent Response Decoder which assumed that neural responses are statistically independent, meaning that all correlations should be zero and, thus, can be ignored. We used both information-theoretic and performance measures to calculate the information extracted by the different decoders.

Results: Simulation results indicate that high-order correlations among model neuron responses contain significant information about binocular disparities, and that the amount of this high-order information increases rapidly as a function of neural population size. The results also highlight the potential importance of the Dependence Tree Decoder to neuroscientists as a powerful, but still practical, way of approximating high-order correlations among neural responses.

675 A Vectorial Model of Sensory Perception

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The decomposition of a sensory stimulus into vectorial components is quite evident in some modalities, such as the activation of the semicircular canals by rotations of the head. More abstract applications of vector spaces

are found in other instances of sensory processing, such as color perception. Here I propose a vectorial model that is able to capture some significant properties of sensory perception. Its essence is the construction of a percept from the components of a stimulus vector acting on a pool of sensory detectors. A primary characteristic of this model is the intrinsically probabilistic nature of perception, in which a perceptual outcome is represented by a vector or, more generally, by a subspace of a vector space S . A sensory stimulus is initially broken down into its components, which are then further transformed yielding the generation of a normalized vector representing a sensory state in a Hilbert space. A given class of perceptual outcomes would be thus equivalent to an observable specified by an operator \hat{O} . If v is an eigenvector of \hat{O} , E is its corresponding eigenvalue and P the projection operator onto the ray containing v , for a system in the state w the probability $p(\hat{O}, E)$ that a sensory processing will result in the percept E is given by $p(\hat{O}, E) = \langle w | P | w \rangle$. This equation, sometimes called the 'statistical algorithm', here relates perceptual outcomes to the probabilities of their occurrence. The model is able to assimilate some familiar results, such as the influence of attention or response bias on the probability of a perceptual outcome. Moreover, the model also offers a simpler and straightforward alternative to the mathematical description of psychometric and ROC curves obtained under psychophysical procedures.

676 Nonlinear Overcomplete Coding in Visual Cortex

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The information-theoretic approach successfully explains the properties of visual neurons in terms of the exploitation of statistical redundancies. An apparent problem for this view arises from the high number of neurons in the visual cortex, which considerably exceeds the number of incoming fibers. With the classical linear filter mechanisms this would lead to an overcomplete representation in which the multi-dimensional tuning functions (the selectivity range in state space) of the neurons would overlap extensively and the responses of the individual neurons would inevitably be highly correlated. We show how this effect can be avoided by nonlinear operations which increase the selectivity in state space as compared to that obtainable with linear mechanisms. We further show that a direct consequence of this nonlinear encoding is the emergence of "non-classical" effects in which the stimulation of "unresponsive" regions leads to context-dependent modifications of the neural response.

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677 Synchronous activity in cat visual cortex encodes collinear and cocircular contours

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Synchronous neural activity has been proposed as a possible foundation for perceiving coherent visual stimuli. We found that synchronous activity in cat visual cortex is more reliable in detecting collinear or cocircular contours than changes in firing rate. A 10x10 microelectrode array was used to record from 51 cells in areas 17 and 18 in two paralyzed and anesthetized cats. We used drifting sinusoid gratings and concentric rings for collinear and cocircular stimulation. We studied cell pairs with minimal overlapped receptive fields and defined cocircularity as the orientation difference within a cell pair. We classified cell pairs with cocircularity = 10° as cocircular (N = 51) if they were tangent to the same circle, and those with cocircularity < 10° as collinear (N = 76). The relationship between the stimulus and receptive fields predicts that

collinear and cocircular cell pairs would show different activation for rings versus gratings. Collinear cell pairs showed greater synchrony under drifting grating stimulation than under concentric ring stimulation. In contrast, cocircular cell pairs showed greater synchrony under concentric ring stimulation than under drifting grating stimulation. The relative synchrony from rings versus gratings increases in cocircular cell pairs as cocircularity becomes greater, and decreases in collinear cell pairs as cocircularity becomes more negative. The relative total firing rate showed no patterned dependence on cocircularity in either collinear or cocircular cell pairs. Regression analysis (N = 127) for synchrony and firing rate versus cocircularity provides evidence that synchrony is more sensitive and reliable than response rates in detecting both collinear and cocircular stimulation. We believe that coherent perception is maintained through synchronous neural activity that is primarily induced by the temporal character of the stimuli, such as common fate, though the spatial structure does augment the synchrony.

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678 An integration model for detection and quantification of synchronous firing within cell groups

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Cooperative firing among groups of cells is a reliable and efficient means of communication throughout the cortex. Synchrony may serve to bind relevant information across the visual field by increasing the probability of eliciting postsynaptic action potentials, thus ensuring transmission to other cortical areas. We have developed a biologically representative model of excitatory postsynaptic potential integration that detects and quantifies the degree to which groups of cells are synchronized, thus gauging their effectiveness in transferring salient information. The approach utilizes a progressive clustering algorithm and similarity measures for both identification of cooperative cell groups and descriptions of synchrony within those groups. The method may be applied to multi-cellular array recordings to determine joint correlations among groups of cells. Traditional cross-correlation techniques also identify synchrony, but can only predict pair-wise relationships. We applied this method to multi-cellular array recordings from the visual cortex of cats anesthetized with N₂O and propofol and found that the average synchrony for cell groupings varied predictably over the range of stimuli presented, in that the amount of synchrony increased for stimuli that were collectively more optimal for the group. Optimal stimuli yielded response structure (synchrony, bursting) that embraced over 80% of the total spikes generated by a group. Group membership was dynamic, depending on the spatial configuration of the stimuli. These results support speculations on encoding of structure by neural assemblies and may have important implications regarding the biological substrate underlying contour detection and object recognition.

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679 Latency Derived Receiver Operating Characteristics Support a Neural Integration Model of Decision Making

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If 'decision neurons' code for the likelihood of a sensory event by integrating the difference in activity of opposing sensory neurons over time, then the rate at which evidence favoring that event is accumulated can be treated as a measure of response confidence. From this, a simple, quantitative relationship follows; the likelihood of a response being correct should vary linearly with inverse response times. Latency derived receiver

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operating characteristics (RT-ROCs) were used to convincingly demonstrate that this is the case. Human subjects performed a visual discrimination task at perceptual threshold while the degree of response urgency was manipulated. When accuracy is stressed, inverse response times correlate extremely well with the likelihood of a correct response ($r^2 > 0.9$, $p < 0.005$). When response speed is stressed, however, the linear relationship weakens ($r^2 > 0.5$, $p < 0.05$), and eventually vanishes. These results provide a method with which to quantify the extent to which a subject is relying on underlying sensory evidence to make a perceptual decision, as opposed to other aspects of decision making, such as response urgency and response bias.

Neural Mechanisms and Models of Attention

680 Persistent neuronal activity for remembered visual targets in macaque posterior cingulate cortex

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Posterior cingulate cortex (CGp) is strongly connected with areas involved in vision, attention, and eye movements. Furthermore, CGp neurons respond both to visual stimulation and after gaze shifts, and the strength of visual responses predicts saccade accuracy. These observations suggest that CGp neurons may signal covert processes associated with orienting. The goal of the present study was to determine quantitatively whether neuronal activity in CGp persists during delays when the saccade target is no longer visible. Single CGp cells were studied in monkeys (*M. mulatta*) performing memory saccade trials in which the saccade target was extinguished 200-600 ms before the cue to shift gaze to the remembered location of the target. For many neurons, firing rate increased following target onset, transiently decreased after target offset, and increased again during the memory delay prior to movement. Spatial selectivity for remembered target locations was similar to that for visible targets. These data suggest a role for CGp in covert processes associated with spatial orienting.

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681 The time course of sensory amplification by feature-based attention: a direct measure on frequency-tagged evoked responses

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Selective attention is controlled by a network of dynamically interacting cortical areas. Attentional commands originating in frontal and parietal cortices act as top-down signals sensitizing the sensory areas, resulting in enhanced sensory responses to attended stimuli. How long does it take for the sensory response to an attended stimulus to be enhanced? Electrophysiological studies showed that the first differences between attended and unattended objects appear as early as 150 ms in extrastriate cortex. However, do these differences reflect the enhanced response to a stimulus, or the reception of attentional top-down commands? Indeed, because attentional top-down commands are received in sensory areas, their electrophysiological signature often merges with sensory driven responses. We used Steady-State Visually Evoked Potentials (SSVEPs) to a flickering object in order to selectively monitor the bottom-up sensory response in extrastriate cortex. We show that 400 ms are necessary for feature-based attention to enhance the sensory response to an attended object. In addition, attentional modulations in the classical evoked potentials, originating in extrastriate cortices, occur earlier than the sensory enhancement. This attentional-related activity could reflect the

conversion of attentional top-down commands into a local tuning of extrastriate areas. Last, because the attentional sensory enhancement by feature-based attention measured here (400 ms) is shorter than the amplification of the sensory signal by spatial attention (600 ms, Miller et al., 1998a), our results add to the view that feature-based attentional mechanisms precede the deployment of spatial attention.

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682 Are photoreceptors in the attention spotlight? Efferent neuromodulators accelerate and/or retard the time course of photoreceptor responses evoked by light.

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Change blindness can be modified by selective attention so that stimuli that are otherwise too fast or too slow become visible. This fact has always been consistent with the idea that attention might operate on the timing of photoreceptor responses. But, to our knowledge, this idea was not explored even though photoreceptors clearly limit the temporal bandwidth of vision.

We now report that neuromodulators released by efferents from the brain modify the temporal properties of photoreceptor responses. This discovery leads to a further development of the spotlight theory of attention; it implicates efferents to photoreceptors as candidate neural components of the spotlight.

We reached this conclusion by executing two types of experiments on the influence of neuromodulation on the timing of photoreceptor potentials (RPs). In one type, intracellular microelectrodes were used to record from single receptor cells residing in eye slices perfused in vitro with neuromodulators. In the other type, electroretinograms (ERGs) with a clear photoreceptor component were obtained in vivo from intact animals while efferent neuromodulation was manipulated. The logic of this approach is that the in vitro RP data directly demonstrate the effects of modulation at the cellular level in a highly reduced preparation while the in vivo ERG data determine whether these effects are physiological and natural.

Converging evidence from virtually intact living animals indicated that various methods of mobilizing efference all affect the timing of receptor responses. No matter whether efference is produced by electrical stimulation of efferent fibers or whether the activity of these fibers is modified by variation in the time of day or whether an efferent neuromodulator is infiltrated into the eye, the result patterns are always the same: ERG indicators of photoreceptor timing clearly change in ways that are linked to both efference and to the RP timing changes that occur under perfusion of eye slices in vitro.

683 The effect of attention and contrast on the BOLD response in V1 and beyond

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Purpose: To investigate the effects of attention on the response contrast function of the BOLD response of the visual cortex, the results of passive viewing were compared to that of a 2-back memory task, which diverted attention.

Methods: A randomly reversing, scaled dartboard display, typically used for multifocal VEP experiments, was presented at 6 contrasts ranging from 0 to 100% during whole brain functional imaging. A central fixation cross, which also served as the target of the task, was presented as a random sequence of red and green 0.5s flashes every 2s. The subjects viewed the display either passively or while performing a 2-back memory task. Thus, there were 12 (6 contrast levels X 2 viewing) conditions. Each of 4 runs contained 12 16s blocks separated with 20s rest periods. 8 subjects participated. The data were analyzed using a mixed effect analysis (FSL software). V1 was determined using standard retinotopic techniques (BrainVoyager).

Results: The response log contrast function of the BOLD activation at the visual cortex was approximately linear for both attention conditions. The BOLD signal from V1 was only slightly reduced under the 2-back condition. However, other brain regions including medial frontal gyrus, insula, higher visual cortex, and cuneus showed large differences between the two tasks. In particular an extensive negative BOLD response (NBR) was observed during the 2-back task. The NBR differed from the V1 positive response in two ways. First, it was not contrast dependent, i.e. the NBR was approximately the same for 0% and 100% contrast. Second, the NBR exhibited a different time course than the positive BOLD signal, ending slightly more abruptly.

Conclusion: Diverting visual attention while viewing a reversing dartboard display appears to exert a minimal affect on the contrast response function in V1. However, an extensive negative BOLD response was induced outside of V1 during the 2-back task suggesting a widely distributed task-dependent mechanism.

684 Differential visual cortex activity associated with common-onset and delayed-onset masks.

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When a masking stimulus is presented within 100 ms after a brief visual target, conscious recognition of the target is often impaired. Recent evidence suggests that in some cases, masks can interfere with re-entrant activity in visual cortex. We examined the effect of target-mask onset asynchrony on activity in cortical areas using event-related fMRI. Normal adults were asked to detect whether dotted squares (66 ms) followed by a surrounding mask (120 ms) contained 1 or 2 gaps. Masks were presented at one of 3 delays (SOA: 0, 100 or 220 ms). Both common-onset (SOA = 0 ms) and delayed-onset (SOA = 100 ms) masks increased target identification errors and fMRI activations in posterior parietal and frontal areas compared to the control condition (SOA = 220 ms). Activations in these areas were stronger during common onset masking and this condition also showed poorer performance. However, delayed-onset masking produced a stronger activation in occipital cortex than common-onset masking despite equivalent sensory stimulation. The results are compatible with the suggestion that delayed-onset masks can produce increased re-entrant activity in visual cortex.

685 Using Psilocybin to Investigate the Relationship Between Attention, Working Memory and the Serotonin 5-HT1A and 5-HT2A Receptors

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Increasing evidence suggests a link between attention, working memory, serotonin (5-HT) and prefrontal cortex activity. In an attempt to tease out the relationship between these elements, this study tested the effects of the hallucinogenic 5-HT1A/2A receptor agonist psilocybin alone and after pretreatment with the 5-HT2A antagonist ketanserin on multiple object tracking and spatial working memory, in eight healthy human volunteers.

Psilocybin significantly reduced attentional tracking ability, but had no significant effect on spatial working memory, suggesting a functional dissociation between the two tasks. In line with the 5-HT1A receptor's known role in modulating prefrontal activity, pretreatment with ketanserin did not attenuate the effect of psilocybin on attentional performance, suggesting a primary involvement of the 5-HT1A receptor in the observed deficit. Based on physiological and pharmacological data, we propose that this impaired attentional performance may reflect reduced ability to suppress or ignore distracting stimuli rather than reduced attentional capacity.

686 Temporary bilateral deficit of transient visual attention after right inferior parietal lobe surgery. A single case study.

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Purpose: We have previously shown that right parietal patients are impaired at performing attentive tasks of apparent motion and phase discrimination in both visual fields, not just the left field where they show other attention-related deficits. Left parietal patients performed normally in these tasks. We hypothesized that the right parietal lobe ought to play a selective role in tasks of visual timing. We studied a patient affected by medication-intractable, parietal lobe epilepsy, testing her before and immediately after her right inferior parietal lobe was removed in order to alleviate her seizure episodes. **Method:** We devised a battery of seven psychophysical experiments and tested the patient two days before and four days after surgery. We also did a follow-up testing at 9, 68 and 103 days post surgery. We tested her on low-level and high-level motion tasks such as apparent motion, visual tracking and biological motion. Furthermore we tested her on a phase discrimination experiment where six squares (three in each visual field) were flickering at the same temporal frequency and the target to be detected was flickering out of phase. The stimuli were reversed sinusoidally at temporal frequencies varying from 2-9 Hz. We used the method of adjustment and varied the temporal frequency progressively until the subject reported the target correctly. **Results:** The patient showed a severe loss in both hemifields in the phase discrimination task four days after surgery, while her low-level and high-level motion tasks were all within the normal limits immediately after surgery. She showed a significant improvement in the phase discrimination task 9 days post-surgery and she performed normally at 103 days post-surgery. Biological motion was mildly impaired at 4 days but recovered by 9 days post-surgery. **Conclusion:** Since the patient detected flicker normally, we conclude that the severe temporary deficit she showed immediately after surgery affects a higher level of processing possibly where attentional mechanisms assign transient onsets and offsets to the appearance and disappearance of objects.

687 Attention and Competitive Decision Making

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Aim: Does optimal decision-making depend on the availability of attention? When humans make decisions, their actions are a function not only of their current environment and present needs but also of historical variables such as their reward history. What role do attentional resources play in this process? Simple games are an excellent way to study the interface of attention and decision-making, because they are naturalistic and have explicit, well-defined ideal solutions. In this study we asked how humans process a visually presented reward signal and whether attentional manipulations would impact their performance. **Methods:** In the 'penalty kick' game, subjects play as either kicker or goalie, and the decisions are to jump/kick left or right. Goalies gain points by catching the ball and kickers gain points by getting the ball past the goalie. This game

was played repeatedly for many trials. On some blocks, we enforced completion of a secondary task (a tone-counting task) simultaneous with the game task. Sometimes only one player had to perform the secondary task, whereas at other times both or neither players were distracted. Players received monetary rewards based on their game performance, but also contingent upon performance in the tone-counting task. **Results:** A secondary task reduced the ability of players to play unpredictably. Players scored lower on the game if they were distracted by the secondary task. In addition, subjects produced sequences of responses that were more predictable when they were distracted than those produced when they were not distracted. **Conclusion:** Withdrawing attention from a competitive task reduces the ability to analyze patterns in opponent behavior and disrupts the ability to produce unpredictable behavior.

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688 Contrast gain vs. response gain: Do sustained and transient covert attention exhibit different signature responses?

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Background: We investigated the mechanisms underlying both sustained and transient covert attention. Two models have been proposed to explain how attention affects perception: contrast gain and response gain. Whereas contrast gain predicts a multiplicative increase in sensitivity (characterized by a threshold shift in the contrast response function), response gain predicts an additive increase in firing rate (characterized by a change in slope and asymptote).

Methods: Observers performed a 2AFC orientation discrimination task on a ± 48 tilted Gabor (4cpd), presented at one of eight iso-eccentric (48) locations. Psychometric functions were measured by presenting the target Gabor across a range of contrasts. In each block, either a neutral (baseline), transient (deploying attention exogenously), or sustained (deploying attention endogenously) cue preceded the target Gabor. Demands of the task were adjusted such that observers' psychometric functions did not asymptote at 100% accuracy, ensuring enough room at the upper bounds for response gain to manifest itself.

Results: For all observers, sustained attention caused a shift in threshold across the psychometric function, supporting a contrast gain model. However, with transient attention both a threshold shift and a change in asymptote were observed. These findings suggest that whereas sustained attention operates strictly via contrast gain, transient attention may be better described by a mixture of both contrast and response gain mechanisms.

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689 Is Stochastic Simulation a Suitable Geostatistical Method for the Study of Visual Attention?

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Visual attention has been the subject of different metaphors including a spotlight (Posner, 1980), a zoom lens (Ericksen and St.James, 1986), and a gradient field (LaBerge, 1995; Downing and Pinker, 1985). This study proposes a novel paradigm to investigate the spatial distribution of visual attention. Simple reaction times (SRTs) to dots presented over the visual field were used to assess attentional allocation in space. We analyzed the data with several geostatistical methods. One of these, stochastic simulation, has been used in various fields, such as petroleum geology, hydrogeology, meteorology, and oceanography and seems to be particularly suitable for our purposes because it emphasizes spatial

continuity patterns. Geostatistical stochastic simulation has the advantage of global precision, in other words it reproduces both the spatial variance and the statistical distribution characteristics of the phenomenon under study. As in any geostatistical method the basic tool is the variogram, which is used to predict data at any point within the domain. Simulations provide several different scenarios of equal probability, with the same spatial statistics of the original data. We used 5 different tasks and through SRTs we assessed attention (shorter or longer RTs were taken to indicate, respectively, higher or lower attentional focus). In experiment 1 participants were asked not to attend to any particular region, but rather try to spread their attention as uniformly as possible over the computer screen (diffuse attention). In the remaining experiments, subjects were instructed to direct their visual attention covertly to the center (experiment 2), to the left (experiment 3), to the right (experiment 4) or to both right and left, but not to the center, characterizing a divided attention situation (experiment 5).

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690 Characterizing Attention in terms of changes of Decision Criterion and Sensitivity

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Perceptual attentional effects have been characterized in terms of sensitivity or response time changes. Here we examine observers' decisional behavior in conditions thought to introduce attentional effects. We take advantage of a series of studies measuring changes of sensitivity (d') and decision criterion (zFA) between single and dual tasks (in standard detection and discrimination visual and auditory tasks) to reveal an unexpected relationship between the decisional behavior and sensitivity. Data show that while observers adopt a quasi-optimal decision criterion (in the Signal Detection Theory sense) in single tasks, they depart from it in dual tasks showing *criteria convergence*. In the extreme case, observers use a *unique criterion (uc)* in accordance with a model whereby decisions are based on a *unique internal representation*. Depending on the nature of the task and of the stimuli used, *uc* occurs in experiments showing no sensitivity drop, while separate criteria are used in experiments showing a sensitivity drop. Criteria ratio ($zFA2/zFA1$, where 1 and 2 refer to the less and more salient targets in a pair) in the dual task was found to be highly correlated with the d' reduction between the single and dual conditions (explaining more than 90% of the variance in the data). This correlation is accounted for by a model positing that observers always use a *uc* (Sagi & Gorea, VSS 2004) in the dual tasks and that the observed departures from it reflect an unequal increase of the internal noises related to the two targets. According to the model, the less salient stimulus yields a larger internal noise increment relative to the more salient one. Hence, both sensitivity losses and departures from optimality in dual tasks appear to be determined by the same process and can be used interchangeably as indices of attentional dispersal. This is the first demonstration of an attentional link between sensitivity and decisional impairments in dual tasks.

691 Multiplicative visual attention model can account for attentional modulation on STA power spectrum

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To examine the effect of attention on the synchronization of the LFP (local field potential) of V4 neurons, Fries et al. (2001) calculated STAs (spike triggered averages). The power spectra of the STAs show which frequency is dominant in the oscillation of the LFP. Attention increased and decreased STA power in the gamma-band (35-90Hz) and low-band (< 10Hz), respectively. Based on the evidence they concluded that attention modulates synchronization between V4 neurons. This study shows that

attentional modulation on STAs can be explained by a rate-based attentional modulation without directly controlling synchronization. Our model has a hierarchical structure corresponding to V1, V2 and V4. Each neuron has broadly tuned feature selectivity, and there is competition among neurons with different feature preference. The LFP is computed by summing the activity of neighboring V4 neurons, and the LFP shows oscillation because of overlapping receptive fields. The dominant frequency in the power spectrum of the STAs depends on spikes from V2 neurons. The components of the STAs in gamma- and low-band originate from spiking V2 neurons with identical and different feature preference, respectively. In our model, attention multiplicatively increases the feature selectivity of V2 neurons. When a high-contrast stimulus in the receptive field is attended, the rate of V2 neurons preferring the presented stimulus does not change compared to that without attention because of upper firing rate limit. On the contrary, attention increases the rate of V2 neurons with slightly different preferences than the presented stimulus up to gamma-frequency. As a result, V4 neurons receive more spikes in the gamma-band, and power spectra of STAs in the gamma-band are increased by attention. Our rate-based model simulated the attentional modulation on STAs power spectra. The result suggests that attentional modulation on STA power may not indicate the existence of synchronization-based attention.

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Orienting and Eye Movements

692 Goal-directed Attentional Orienting in Patients with Dorsal Parietal Lesions

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Over the past several years there has been a flurry of neuroimaging studies implicating a fronto-parietal network of areas as the neural mechanism subserving attentional orienting. In particular, it has been suggested that ventral parietal cortex including the temporo-parietal junction (TPJ) mediates stimulus-driven attentional orienting (i.e., attentional capture), while the dorsal parietal region, including the superior parietal lobule (SPL), subserves goal-directed orienting. In the present study, we investigated patients with deficits in attentional orienting who have acquired lesions to the dorsal part of the fronto-parietal attentional network. Patients were tested on three attentional tasks: the Posner covert attentional cuing task, a goal-directed attentional shifting task (cross-hemifield RSVP monitoring two targets and switching or maintaining attention as per cue), and a visual capture task (monitoring central target and inhibiting interference from salient distractors). Performance on the Posner task, which includes both elements of attentional orienting (goal-directed and stimulus-driven), was poor. Patients performed similarly to matched controls on the visual capture task but not on the goal-directed orienting task. Patients were particularly impaired on goal-directed attentional shifts to and away from the affected (i.e., neglected) hemifield. These results are consistent with the view that the dorsal part of the fronto-parietal network subserves goal-directed, and not stimulus-driven, attentional orienting.

693 A contrast polarity heterogeneity effect in infant visual orienting.

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Visual orienting in human infants has been modeled assuming dimensional switching across trials (Dannemiller, VSS, 2003). In displays with a single moving bar and 27 static bars, directional orienting is determined on some proportion of trials exclusively by the movement, but on the complementary proportion of trials, the stimulus dimensions that

comprise the static elements (e.g., contrast polarity, color, size) control orienting. The observed proportion of trials with orienting toward the moving bar then conforms to a mixture model of these two proportions. A further test of this model was conducted, and the results required modification of the model in a theoretically interesting way. Orienting was measured at two ages: 7-11 weeks and 17-21 weeks in two experiments with 129 infants. Bars of positive and negative contrast polarity relative to the background luminance were used. The dimensional switching model accounted well at both ages for the observed proportion of trials with orienting toward the moving bar but only if it was assumed in the model that the strength of the internal motion signal depended on the heterogeneity of the contrast polarities of the bars in the display. In homogenous displays with all of the bars having the same contrast polarity, orienting did not depend on the absolute polarity of the moving bar. However, in heterogeneous displays in which half of the bars had positive polarities and half of the bars had negative polarities, orienting toward the moving bar occurred more frequently when it had negative polarity than when it had positive polarity. This same asymmetry held regardless of how bars of the two contrast polarities were spatially distributed in the display. These results could be explained by assuming that a type of contrast gain mechanism enhances the perceived contrasts of the negative polarity bars only when bars of both polarities are present in the display simultaneously. This polarity heterogeneity effect was equally strong at both ages.

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694 Components of Bottom-Up Gaze Allocation in Natural Scenes

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A model of bottom-up visual attention ("baseline salience model", based on local detectors with coarse global surround inhibition) has been shown (Parkhurst et al., 2002) to account in part for the spatial locations fixated by people while free-viewing complex natural and artificial scenes. Here, we tested the additional roles in bottom-up gaze allocation played by several visual cortical mechanisms. In each case, we added a component to the salience model: non-linear interactions among orientation-tuned units both at short spatial ranges (for clutter reduction) and long ranges (for contour facilitation), and a detailed model of eccentricity-dependent changes in visual processing. Subjects free-viewed naturalistic and artificial images while their eye movements were recorded, and we used a metric called the Normalized Scanpath Salience (NSS) to compare the resulting fixation locations with the different models' predicted salience maps. NSS values indicate, on average, how many standard deviations above or below the mean salience was the model-predicted salience at human-fixated locations. Thus the minimum NSS value (when the model and human behavior are unrelated) is 0; the theoretical maximum NSS value is given by the ability of one observer's fixations to be predicted by the remaining observers' fixations, which in practice fell in the range 1.1--1.3 for different image categories. The baseline salience model predicted fixations at 39--57% of the maximum NSS level. Adding short-range orientation interactions increased this range to 50--65%, contour facilitation further increased it to 53--74%, and eccentricity-dependent processing increased it to 84--95%. Thus the proposed cortical interactions indeed appear to play a significant role in the spatiotemporal deployment of attention in natural scenes. This suggests that bottom-up attentional guidance does not depend solely on local visual features, but must also include the effects of non-local interactions.

<http://www.yale.edu/perception/>

695 Toward a method of objectively determining scanpath similarity

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The ability to objectively compare scanpaths enables researchers to study the adoption and evolution of visual search strategies within complex task environments. Current eye tracking technology is enhancing the researcher's ability to collect scanpaths. However, a drawback of using eye tracking technology is the difficulty in objectively analyzing portions of the obtained data. For example, the ability to compare two complete scanpaths, two subsections within the same scanpath, or two subsections of two different scanpaths has been elusive.

Recent research has applied objective measures to scanpaths (see Goldberg & Kotval, 1999; Ponsoda, Scott, & Findlay, 1995). However, such measures fail to utilize the temporal flow of dwells composing scanpaths (e.g., scanpath length or convex hull area). I present a novel method to objectively determine scanpath similarity that includes the temporal flow of dwells. A sequence alignment algorithm adopted from bioinformatics is used to determine whether areas of interest in a complex task environment are foveated in the same temporal order over repeated trials and between participants. The algorithm determines the minimum number of edits necessary to change one scanpath into another - the smaller the number of edits the greater the similarity between the compared scanpaths.

To demonstrate the usefulness of scanpath comparisons, all scanpaths from two conditions of an empirical study were compared for two participants (one per condition). Results demonstrate that prototypical scanpaths are determinable through sequence alignment, and represent search strategies. Results also demonstrate that such strategies are attained and settled on early in the task, and that two or more strategies likely compete over the course of the task. Furthermore, prototypical search strategies for the two subjects were similar, but differed systematically, suggesting that minute changes in task environments subtly change visual search strategies.

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696 Exogenous and Endogenous Attention Shifts during Smooth Pursuit Eye Movements

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Studies on the interaction of visual attention and saccadic eye movements argue in favor of an obligatory coupling of saccade goal and focus of visual attention (e.g., Deubel & Schneider, 1996). In a similar fashion, Khurana and Kowler (1987) proposed a coupling of visual attention and the target of smooth pursuit eye movements. The current study investigated whether exogenous and endogenous attention shifts (Posner, 1980) are possible during smooth pursuit eye movements. Subjects foveated a stationary fixation cross (fixation conditions) or a moving cross (smooth pursuit conditions). An exogenous or endogenous cue indicated the location of the upcoming discrimination target (symbols "E" and mirror "E") with a probability of 80%. The difference in discrimination performance between valid and invalid cue conditions was taken as a measure of visual attention. The discrimination target was either stationary or moved at the same velocity as the pursuit target. Stationary discrimination targets in space were stationary on the retina with eye fixation, but not with smooth pursuit and vice versa for moving targets. Effects of exogenous and endogenous cueing were about the same size for fixation and pursuit conditions. Further, it did not matter whether the discrimination target was stationary or moving. However, retinal motion of the discrimination target influenced smooth pursuit gain. Pursuit gain decreased when the discrimination target was stationary in space and moved across the retina, but not when it moved with the pursuit target and was approximately

stationary on the retina. The reduction of pursuit gain with the onset of the discrimination target was present for exogenous and endogenous cues, but it occurred earlier in the exogenous than in the endogenous condition (~150 ms vs. ~350 ms after discrimination target onset). The results suggest that the coupling of visual attention to the target of a smooth pursuit eye movement is not as strong as has been proposed.

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697 Can target selection for saccades use separate foci of attention in the two hemispheres?

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It is widely held that the targets of saccades (and perhaps of attention as well) are typically selected by a winner-take-all mechanism in which maximal neural activity on some brain map (perhaps in the superior colliculus or frontal eye field) converges on one location, inhibiting other locations. If circumstances permitted the brain regions in each hemisphere to separately process the candidate stimuli, might target selection for saccades occur more efficiently than if the alternatives were processed within the same hemisphere? In humans, there is some evidence that attention can be more easily split between the right and left hemifields than between two locations in the same hemifield (Sereno & Kosslyn, 1991; Awh & Pashler, 2000; McMains & Somers, 2004). We asked whether saccadic reaction times showed evidence of separate foci of attention.

Subjects were instructed to attend to two 5-deg stimulus patches 10 deg apart, and to make a saccade to the one that changed. The stimuli were a rotating colored grating, which changed from smooth rotation to rotation in 16 equal-angle steps, and a field of dots moving randomly, in which the lifetime of each dot changed from 75 msec to 375 msec. In different experimental blocks the two stimuli were the same or different, and were either located 3 deg below the fixation point, one to the left and one to the right, or 3 deg to the right of the fixation point, one above and one below. Across three subjects and four stimulus conditions, saccade latencies were shorter in 11 of 12 cases if the two stimulus patches were in opposite hemifields than if both stimuli were in the same hemifield, regardless of the nature of the stimuli (mean difference, 74 msec). This suggests that more attentional resources can be allocated to two locations if they are in different hemifields than if they are in the same hemifield.

698 Attention Modulates Saccade Latency but not Kinematics

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Previous studies have observed that similar brain areas are activated during covert shifts of attention and during the execution of saccades, leading to the suggestion that the brain systems controlling these functions share similar neural substrates. In the present study we tested the extent of the functional overlapping between the two systems.

In the first of two conditions (full attention) we instructed subjects ($n=6$) to make saccades from a central fixation point toward a target that appeared randomly at two different eccentricities (12, 24 degrees) to the left or to the right of the fixation point. The target could have six different contrast levels (0, 2, 4, 6 and 10%). In a second condition (divided attention) the subjects performed the same task but we additionally instructed them to signal the occurrence of a transient contrast change at the central fixation point.

We found that in the divided attention condition the saccade latency was increased relative to the full attention condition; however the kinematics of the saccades (peak velocity vs. saccade amplitude) was the same in both conditions. We additionally found that changing the saccade target

contrast in the full attention condition had a similar effect as in the divided attention condition, i.e., lowering saccade target contrast increased saccade latency but did not affect the kinematics. In general our results suggest that the level of attention directed to a stimulus influences visuomotor processing by modulating the relative saliency of that stimulus representation mainly during earlier stages of processing (similar to the effects of contrast), leaving the ultimate motor commands specifying the parameters for contracting the eye muscles relatively unchanged.

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699 Microsaccadic eye movements during ocular pursuit

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Recent studies (Hafed & Clark, VR 2002; Engbert & Kliegl, VR 2002) have shown that microsaccades can be taken as an overt measurement of covert attention shifts during fixation. It is unknown, however, if microsaccades also occur during pursuit and, if so, whether these microsaccades are related to covert attention shifts. We carried out an experiment to investigate this issue. In our study, subjects were asked to maintain pursuit of a horizontally moving cross. At the onset of every trial, a square cue appeared on the left or right side of the display and remained visible for a variable period between 700 and 1100 msec in duration. The pursuit target appeared at the location of the cue and began to move horizontally as soon as the cue disappeared. The total duration for each trial after cue onset was 3.5 sec. At a random time after pursuit initiation, a square shape briefly appeared at a distance of 11 degrees either to the left or right of the pursuit target. Subjects were instructed to report as soon as possible whether it had the same color as the pursuit target. The pursuit target changed its color randomly during the trial. We used four different pursuit velocities (1.6, 3.4, 5.0, 7.2 deg/sec) in the experiments, blocked into sets of 100 trials. Our results show that microsaccades did indeed occur during ocular pursuit and that they had similar characteristics to those occurring during fixation. An analysis of the directions and latencies of microsaccades found that they were correlated with both the flash directions and the pursuit velocities. In particular, it was observed that microsaccade directions were biased in the direction of pursuit and that this bias increased with increases in pursuit velocities. This result is in agreement with the finding of Van Donkelaar & Drew (PBR 2002), who found that covert attention leads pursuit targets, with a lead amount that increases with the pursuit velocity.

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700 Eye movement statistics for optimal, sub-optimal and human visual searchers

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In visual search, humans use eye movements to direct the fovea at potential target locations in the environment. Do humans employ rational eye movement strategies while searching for targets in cluttered environments? To answer this question, we derived the Bayesian ideal visual searcher for tasks where a known target is placed at an unknown location within a background of $1/f$ noise. We constrained the ideal searcher to have the same falloff in target detectability with eccentricity as humans. We find that humans achieve near-optimal performance in this search task, suggesting that humans must be selecting their fixation locations efficiently. To explore this further, we compared eye movement statistics of humans, ideal searchers, and suboptimal searchers that do not select fixation locations optimally but still integrate information perfectly across fixations. Remarkably, human search patterns match those of the parameter-free ideal searcher for most of the statistics we have examined, including: (1) the spatial distribution of fixation location, (2) the distribution of saccade lengths, (3) the change of mean distance of fixations from the center of the search area as search progresses, and (4) search time

as a function of target/noise contrast and target position. A particularly interesting suboptimal searcher is the MAP searcher (which always fixates the most likely target location) because the MAP fixation strategy is the basis for most existing models of eye movements in visual search. Although the MAP searcher shares many eye movement statistics with humans and ideal, and achieves near-optimal performance, it can be rejected as a model of human search because it distributes fixations across the search area in a spatial pattern that differs from human and ideal. Also, humans substantially outperform suboptimal searchers that select fixation locations at random (with or without replacement), allowing us to conclusively reject all possible random search models.

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701 Eye dominance effects in feature search

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The function of visual dominance is basically unknown. Mapp et al. (2003) argue that eye dominance does not play a role in vision, and eye dominance may be attributed differently when using different defining tests (Walls 1951, Friedlander 1971, Pointer 2001). It is well known that an element which differs significantly from surrounding elements in a single dimension, such as orientation, pops-out and search performance is independent of the number of distractors (Treisman & Gelade, 1980). We evaluated eye dominance effects on performance of a feature search task. 13 subjects participated in the experiment; each had similar visual acuities in their two eyes. Dominant eye was determined several times, using the Hole-in-the-Card test (Durand & Gould 1910). Subjects viewed through red-green glasses, an array of green and red lines oriented at 60° , followed by a masking stimulus after a variable Stimulus-to-mask Onset Asynchrony (SOA). On some trials, one element was replaced by a red or green line oriented at 40° - the target. The 8 nearest neighbors surrounding the target had the same color as the target, the opposite color, or a mixture of the two colors. Line colors were adjusted so that through the red-green glasses one eye saw only the red and the other the green lines - and both were perceived as black. In this way, we were able to test for differences in performance when subjects detected the target with the dominant vs. the non-dominant eye, and to test dependence on which eye viewed the surrounding elements.

We found significantly better performance when the target was seen by the dominant eye, especially when the surrounding elements were seen by the non-dominant eye. We conclude that there is an interaction between the salience arising from the pop-out and the dominance phenomenon. The advantage of the dominant eye may be in its perceiving items as if with more salience while items perceived by the non-dominant eye are relatively inhibited.

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702 Collaborative search using shared eye gaze

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Search need not be solitary. We explored the potential for people to collaborate during search, using only their gaze. Pairs of searchers (A, B), located in different rooms, jointly performed a difficult O in Qs search task. Searchers viewed identical displays and either participant could respond target present (TP) or absent (TA), with that response ending the trial for both. Collaboration was encouraged by instruction and payoff matrix. Both searchers wore ELII eyetrackers, which were interconnected via Ethernet. In the shared-gaze (SG) condition, a 1.7 deg yellow ring representing A's eye position was superimposed over B's search display, and vice versa. Each participant therefore knew where their partner was

looking during search by the position of this gaze cursor on their display. In the non-shared gaze (NG) condition, searchers performed the identical task but could no longer see their partner's gaze cursor (i.e., no potential for collaboration). We found that TP RTs averaged 448 ms faster in the SG compared to the NG condition, suggesting a gaze-related benefit from collaboration. No RT differences were found in the TA data. For each trial, we also analyzed: (1) the spatial overlap between A's and B's distributions of fixations by display quadrant, and (2) the proportion of display items fixated by both searchers. If searchers were able to use shared gaze to divide the labor of the task, we would expect minimal overlap in (1) and a small percentage of doubly inspected items in (2). Both predictions were confirmed. Mean quadrant overlap in the SG TP (.21) and TA (.42) conditions was less than half that of the TP (.46) and TA (.81) NG conditions (0 = no overlap, 1 = complete overlap). Similarly, the percentage of items fixated by both searchers was smaller in the SG (10% TP, 29% TA) compared to the NG conditions (16% TP, 55% TA). We conclude that communication is possible using only eye gaze and that this communication can produce collaborative benefits in a search task.

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Bistable Perception

703 Temporal Dynamics of Bistability in Motion Transparency

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Perceptual reversals occur when a given stimulus is consistent with more than one possible percept. When viewing motion transparent stimuli, observers experience reversals in depth. We are interested in the dynamics of these reversals, and particularly the role of segregation processes in determining biases and reversal rates. Random-dot kinematograms were generated and presented as two distinct surfaces moving at the same speed in opposite horizontal directions. We designed an experiment with two conditions varying the ease of segregation. In the first condition both surfaces were composed of only black dots, while in the other condition the two surfaces were distinguished using black and white dots. Critically, motion is necessary to perceive two surfaces in the same contrast condition since no other segregation cues are available. The task of the observers was to report the trajectory of the surface that appeared in front, by responding either left or right every two seconds. Consistent with previous studies (Mamassian and Wallace, VSS '03), directional biases varied across participants. In spite of these idiosyncrasies, the initial bias was stronger when the two surfaces had the same contrast. Observers were, however, more likely to experience depth reversals when the two surfaces had the same contrast. These results suggest that the role of segregation cues changes throughout a trial: segregation cues appear to accentuate directional biases initially, but then facilitate perceptual reversals.

704 Ambiguous Figures: Effects of ISIs in discontinuous stimulus presentation on EEG components

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Background. When observing an ambiguous figure, our percept suddenly changes while the figure stays unchanged. In previous EEG experiments we found an early occipital correlate of the perceptual reversal, suggesting that disambiguation is initiated during early visual processing. Orbach et al. (1963) showed that with discontinuous presentation of the Necker cube the duration of inter stimulus intervals (ISI) interacts with the reversal frequency. In the present experiment we investigated the effect of ISI duration on the associated EEG/ERP components.

Methods. An ambiguous 'Necker lattice' appeared repeatedly for 800 ms with 4 randomly changing ISIs (ms: 14; 43; 130; 390) between successive presentations. Subjects indicated whether they perceived a 'reversal' or two identically oriented Necker lattices ('stability'). EEG was recorded from 13 channels in 12 subjects; the difference traces between reported 'reversal' and 'stability' (reversal minus stability) were analyzed separately for each ISI.

Results. With all ISIs a highly significant parietal/central distributed ERP negativity ('Reversal Negativity', RN) occurred after a very early occipital positivity ('Reversal Positivity', RP, at 130 ms). Both components confirmed previous findings. The latency of the RN (ms: 370; 338; 298; 276) was negatively correlated with the ISI duration. The RP was independent of the ISIs except for the longest ISI, when the RP overlapped with the RN. **Discussion.** We interpret the early RP as a correlate of an initial transient bottom-up interaction of multiple neural representations preceding a perceptual reversal. The RN would indicate perceptual steps after ambiguity has been resolved. The negative correlation of the RN's latencies with ISIs suggests neural hysteresis accompanied with the reorganization of a biased perceptual system. This hysteresis may be stronger, the closer in time the previous percept was.

<http://eyelab.msu.edu/people/aaron/index.html>

705 When your brain decides what you see: grouping across monocular, binocular and stimulus rivalry

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Several studies suggest that the neural concomitants of visual rivalry are contingent on the stimulus parameters. This suggests the existence of at least three different types of rivalry. Binocular rivalry occurs when dissimilar patterns are presented one to each eye and is seemingly mediated by interactions between pools of monocular neurons. Monocular rivalry occurs when superimposed patterns are presented to the same eye(s) and is presumably the result of competition between neural representations of the patterns themselves without regard to their eye of origin. Stimulus rivalry occurs when dissimilar patterns are swapped rapidly between the two eyes and is thus also independent of the eye from which an image is sourced. Here we integrate these three different types of rivalry into one stimulus. We find that perceptual alternations span the three types of rivalry, demonstrating that the brain can produce a coherent percept sourced from three different types of visual conflict. This result is in agreement with recent cross paradigm work suggesting that competitive visual stimuli are mediated by a general mechanism spanning different levels of the visual processing hierarchy.

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706 The role of eye movements in bistability from perceptual and binocular rivalry and the role of voluntary control

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We exposed the visual system to four different stimuli that can induce bistable perception. The bistability paradigms that we used were slant rivalry, Necker cube rivalry, grating rivalry and house-face rivalry. For each of these stimuli we investigated the role of eye movements for perceptual alternations from one to the other representation. We compared results when subjects were trying to hold one of the two percepts with results when subjects did not try to actively influence the percept (natural viewing condition). The results show that, for each paradigm, saccades are suppressed just after a perceptual alternation occurs in the natural viewing condition. For slant rivalry, there is no positive correlation between saccades and a perceptual alternation before the perceptual alternation. For Necker cube rivalry and binocular grating rivalry, saccades sometimes occur before the perceptual alternation, but this positive correlation is relatively small. For house-face rivalry the

positive correlation between saccades and perceptual alternations before the alternations is more pronounced. When subjects are trying to hold a percept any correlation between saccades and perceptual alternations is reduced. Average gaze positions and average horizontal vergence do not change at the time of a flip for all stimuli in all viewing conditions. However different voluntary control conditions can lead to different average fixation positions or a wider scatter of fixations. We conclude that generally eye movements are not necessary to exert voluntary perceptual control.

707 Rapid plasticity determines the percept for a forthcoming bistable stimulus

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Visual neurons show fast adaptive behavior in response to brief visual input. However, the perceptual consequences of this rapid neural adaptation are not well known. Here, we show that brief exposure to a moving adaptation stimulus - ranging from tens to hundreds of milliseconds - influences the perception of a subsequently presented ambiguous motion test stimulus. Whether the ambiguous motion is perceived to move in the same direction (priming), or in the opposite direction (rapid motion aftereffect) varies systematically with the duration of the adaptation stimulus and the adaptation-test blank interval. These biases appear and decay rapidly. Moreover, when the adapting stimulus itself is ambiguous, these effects are not produced. Instead, the percept for the subsequent test stimulus is biased to the perceived direction of the adaptation stimulus. This effect (perceptual sensitization, or PS) builds gradually through longer adaptation-test intervals. The PS does not show any hint of decay as long as for 5 s - the longest interval tested. However, if a stationary pattern, instead of the blank, is viewed, the PS starts to decay after a few seconds. Our results suggest that in early motion processing, rapid adaptation serves as a rapid gain control. At a later stage, the slow potentiation controls the sensitivity depending on the past subjective perception, as opposed to input stimulus per se. This makes it tempting to suggest that this form of plasticity plays a critical role in rapid perceptual learning.

708 Mutual Information and Stochastic Resonance in Multistable Percept

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Bistable perception (binocular rivalry) occurs when one eye views dots moving upward while the other eye's dots move rightward. Perception switches between up and right. With ambiguous motion, dots moving on elliptical trajectories as a transparent sphere switch perceptually between opposite directions of motion (e.g., left and right). Multistable perception (switching among left, right, up or down) occurs when one eye views horizontal ambiguous motion while the other eye views vertical ambiguous motion. Most of the time, transition probabilities for switching among those states were similar; there was little mutual information in these particular switching time series. However, many observers had intermittent periods of highly predictable switching (high mutual information). Examples include: (1) long sequences switching between opposite directions on one axis (avoiding the other axis), (2) long sequences avoiding the opposite direction on the same axis (always switching axes), and (3) three-state sequences (vertical-horizontal-vertical and horizontal-vertical-horizontal) in which first and third directions were the same much more often than being opposite directions. Fluctuating mutual information characterizes certain nonlinear systems, and some nonlinear systems have a characteristic that adding the right amount of noise at the input will paradoxically reduce noise in the output (stochastic resonance). Adding zero-mean Gaussian velocity noise with standard deviations of 0.5%, 1%, \ddot{O} of mean stimulus velocity to the multistable display typically increased the variances of perceptual dominance times,

but not if the noise standard deviation was 1.5%. Perceptual dominance time variance was significantly smaller in the latter condition than when viewing stimuli with no added noise. The present findings extend previous work by Kim, Grabowecky & Suzuki (2003), Leopold, et al. (2002) and Suzuki & Grabowecky (2002).

709 Visual Awareness and Voluntary Control

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Visual awareness and voluntary control seem to be related: when we are confronted with ambiguous images we are in some cases and to some extent able to voluntarily select a percept. This provides the ideal opportunity to study neural underpinnings of voluntary control in relation to the percepts rather than to the stimulus. However, to date voluntary control has not been used in neurophysiological studies on the correlates of visual awareness, presumably because 1) the perceptual durations of rivaling ambiguous percepts were generally too short, and 2) the role of voluntary control was insignificant. We have recently developed a bistable slant rivalry paradigm that exhibits 1) long percept durations, 2) beneficial metrical (quantitative) aspects, and 3) perceptual durations that are under considerable voluntary control of the observer. We have examined the role of voluntary control for the perceptual reversals of slant rivalry and we compared these with orthogonal grating rivalry, house-face rivalry, and Necker cube rivalry. Here we report that we found qualitative similarities for the role of voluntary control, consistent with a shared underlying mechanism. But we also found quantitative differences that are inconsistent with one single underlying mechanism. Further, we found that perceptual flips were neither necessarily correlated with eye movements, nor with blinks. We found significant functional magnetic resonance imaging activation correlating with the instigation of awareness of stereopsis, and activation that increased metrically with increasing perceptual reversals.

Perceptual Learning 1

710 Training-Induced Improvements of Visual Motion Perception after V1 Cortical Damage in Humans

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Damage to the adult primary visual cortex (V1) causes largely permanent visual impairment. Visual motion perception is one of the main visual perceptual abilities affected by V1 lesions, yet it is critical for navigation and multiple other levels of interaction with our dynamic environment. Recent pilot studies on cats with damage to early visual cortex suggest that intensive visual discrimination training in the blind field can induce a localized recovery of motion thresholds. To assess whether improvements in visual motion perception can be elicited in adult humans with V1 damage, three patients were recruited one year after a stroke that induced homonymous visual field defects. They were taught to self-administer a two-alternative, forced-choice, global direction discrimination task within their blind fields. On a daily basis, they performed 300 trials of this task using random-dot stimuli that are optimally processed in higher-level visual areas such as the MT+ complex, which was intact in these patients. Slow but significant recovery of global motion sensitivity was observed that was highly specific to the visual field location(s) retrained. With discrimination retraining, all patients progressed from no conscious perception of the random dot stimulus and severely abnormal discrimination thresholds to conscious perception and near-normal thresholds at the retrained location(s). Patients also demonstrated enlargements of the usable field of vision using Humphrey perimetry and improved ability to detect and track moving objects in a realistic virtual environment. Thus, intensive direction discrimination retraining with

dynamic random dot stimuli in portions of the blind field improves visual motion perception after V1 damage in adult humans. Whether this recovery is mediated by spared primary visual cortex, extra-geniculostriate pathways or training-induced re-organization of intact, higher level visual cortical areas remains to be determined.

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711 Learned categorical perception specific to retinal location and orientation

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Although Categorical Perception (CP) can be acquired as a result of learning, the mechanisms involved remain unknown and there is debate about whether it is a perceptual phenomenon. In a previous experiment (Notman, Sowden & Ozgen, in press, *Cognition*), we showed that acquired CP for spatial phase defined categories was specific to orientation (tuned with a bandwidth of 6.5 deg.) supporting an early locus of the effect. Here, using the same stimulus set, we examined the perceptual nature further. In experiment 1, we examined retinal location specificity of learned CP. Observers were trained to categorise stimuli briefly presented to one retinal location. Following training, CP was apparent at the trained location but not at locations 3.3 deg. away. This supports the idea that CP is dependent on perceptual processing at relatively early stages of visual analysis where receptive fields (RFs) are smaller. In experiment 2, we examined a possible explanation for the narrow 6.5 deg. bandwidth found previously. The original stimuli (at 8 deg.) spanned the RFs of multiple interconnected units in V1 and it may be that perceptual learning modified the strengths of intra-cortical connections between cells tuned to the same (or similar) orientations. Here, stimuli were viewed through a narrow Gaussian aperture (20% of original) to reduce the impact of lateral interactions. Over the course of 3 days, observers were trained to categorise stimuli at a single orientation, before and after completing a same different judgement task at each of nine orientations. Whilst training led to improved categorisation performance, there was no measurable improvement in discrimination performance and therefore no learned CP effect. In combination, these experiments are consistent with the possibility that CP may be mediated by intra-cortical connections at early, retinotopically organised, stages of visual analysis.

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712 Identical Transfer of Perceptual Learning Following Easy and Difficult Task Training

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Perceptual learning improves performance in perceptual tasks due to experience with perceptual representations. One key attribute of perceptual learning is specificity of learning to the specific stimulus attributes. The degree of task and stimulus specificity shows considerable variability depending upon the nature of the task. One important proposal concerning stimulus specificity (Ahissar & Hochstein, *Nature*, 1997) is that the specificity of learned improvements to a stimulus may depend upon the difficulty of the task: that learning difficult tasks requires learning at lower, more specific, levels of the visual processing hierarchy. This conclusion was based on higher transfer from one easy visual search task to another, and lower transfer from one difficult task to another. In their analysis, task difficulty was controlled by the orientation angle. Here, we examined transfer to an easy Gabor orientation discrimination task (± 12 degrees from base angle) following practice on either an easy or difficult (\pm degrees) task at a different base angle and location, and similarly for transfer to the hard task following practice on an easy or hard task. Testing was carried out in either no-external noise or high noise displays, and adaptive methods were used to track 2AFC performance. This orientation discrimination task exhibited partial transfer to either an easy or a hard test condition in both high and no external noise, but the extent of this

transfer was identical regardless of the nature of the original training. Neither the initial level after transfer nor subsequent learning depended upon the difficulty of initial training. These results suggest a more complex view of the relation between task transfer and task difficulty.

713 Perceptual learning of motion discrimination with suppressed and un-suppressed MT

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Purpose:

Visual area MT has long been implicated in the perceptual learning of motion discrimination. However, it is not well understood whether learning is still possible without MT. We investigated psychophysically with normal participants the role of MT using paired-dots stimuli that suppress MT activity (Qian, Andersen, & Adelson 1994).

Method:

MT suppression was achieved because the dots in each pair moved counter-phase to one another so that the net motion directional signal was locally balanced. We further destroyed the Glass pattern per static frame so that the motion-axis information was available only via motion signals (Lu, Qian, & Liu 2004). In each trial, two stimuli were presented sequentially, participants decided whether the motion-axis changed clockwise or counter-clockwise. Psychometric functions of all participants were first measured. A threshold angle was then chosen per participant such that threshold angles at 60%, 65%, 70%, and 75% correct would be used for daily learning, with at least one pair of participants each. One of the two participants in a pair would be trained with counter-phase paired dots, the other with in-phase paired dots as a control.

Results:

Suppressed MT activity by counter-phase paired dots reduced or eliminated learning relative to non-suppressed MT by in-phase paired dots. This effect was more pronounced with reduced signal-noise-ratio (SNR) of the stimulus. Therefore, MT, whilst not necessarily essential for perceptual learning of motion discrimination with stimuli of substantial SNR, does facilitate learning particularly when stimulus SNR is low.

714 Learning to identify letters: Generalization in high-level perceptual learning

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Learning to identify letters is crucial to reading. The benefit of training on most perceptual tasks is highly task and location specific. However, unlike the specificity of perceptual learning, many studies of conceptual learning have found a great deal of generalization between related tasks and stimuli. Three new experiments explore the specificity of letter learning, assessing transfer across letters (Exp. 1), from part to whole (Exp. 2), and across the visual field (Exp. 3). In Experiment 1, observers learned to identify letters in one subset of a foreign alphabet (Chinese) before learning a second subset of that same alphabet. Observers are found to receive no benefit from having partially learned the alphabet, proving that letter learning is letter specific. In Experiment 2, observers trained on the components of Chinese characters (i.e. *brushstrokes*, specific combinations of features, and *radicals*, specific combinations of brushstrokes) before learning the characters themselves. The results show that observers learning to identify a new object need not relearn combinations of features with which they are already familiar; in fact, knowledge of an object's parts instills a more effective learning strategy in the observer. Experiment 3 explores the specificity of letter learning with regard to location in central and peripheral vision. Observers' efficiency for foreign letter identification (Armenian) is found to be highly dependent on eccentricity of training and testing. In sum, the results reveal two mechanisms that identify letters: a process in the central visual field that recognizes an object by parts and a ubiquitous process that recognizes objects holistically.

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715 Subliminal Perceptual Learning of Motion Results in Improvements of Critical Flicker Fusion Thresholds

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Critical flicker fusion threshold (CFFT) is the lowest level of continuous flicker that is perceived as a steady source of light and has historically been shown to be remarkably stable within and across multiple days of testing. The current study was designed to test the relationship between CFFT and subliminal learning. In two experimental groups, a total of seven participants were exposed to sub-contrast-threshold coherent dot motion occurring as a background feature of a rapid serial visual presentation (RSVP) task. Six other participants were recruited, and their CFFTs were recorded in the same manner as the experimental groups, either daily or during pre-test and post-test phases. Neural plasticity was instigated and measured with a Dynamic Random-Dot Display computer program. A Macular Pigment Densitometer was used to determine CFFT. Subjects reported the direction of coherent motion of random dot movement with 5% and 10% signal-to-noise ratio, and the direction of dot motion with 100% coherence of moving dots displayed at varying contrasts, sub-threshold through supra-threshold levels, in pre-test and post-test conditions. Herein we demonstrate that in subjects who underwent 1 hour of a subliminal motion training per day for nine days CFF thresholds increased significantly (by an average of 30%). This only occurred for subjects who experienced coherent motion paired with the targets of a task. Subjects who completed tasks without the motion pairing showed no improvement in CFFTs. These results demonstrate for the first time that the perceptual experience of subjects can dramatically alter CFFT and imply that CFFT is highly related to Dorsal Stream motion processing.

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716 Task specific disruption of perceptual learning

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For more than a century, the process of stabilization has been a central issue in the research of learning and memory (Miller and Pilzecker 1900). Namely, that after a skill or memory is acquired, it must be consolidated before it becomes resistant from disruption by subsequent learning of a similar task. While it is clear that there are many cases in which learning can be disrupted, it is unclear when learning something new disrupts what has already been learned. Herein we provide two answers to this question with the novel demonstration that perceptual learning of a visual stimulus disrupts, or interferes with, the consolidation of a previously learned visual stimulus. In this study we trained subjects on two different hyperacuity tasks and compared whether learning of the second task disrupted that of the first. We first show that disruption of learning occurs between visual stimuli presented in the same retinotopic location, but not for the same stimuli presented at retinotopically disparate locations. Second we show that disruption from stimuli in the same retinotopic location is ameliorated if the subjects wait for one hour before training on the second task. These studies demonstrate that disruption, at least in visual learning, occurs only between highly similar features that a temporal delay of 1 hour between the training sessions is sufficient to consolidate visual learning.

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Lateral Interactions and Filling-In

717 Filling-in of the blind spot: How much information is needed?

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The blind spot is a fairly large (58 x 78, centered 168 temporally) area of the retina that contains no photoreceptors. In binocular vision the absence of information is compensated by the other eye, which receives input from the corresponding region of the visual field, but even in monocular vision the blind spot is not subjectively noticeable as the color and texture of surrounding regions are perceptually filled in. It is debated whether this filling-in reflects higher-order cognitive processes or is generated by neural mechanisms at cortical areas where the retinal topography is preserved. We have obtained evidence for the latter hypothesis in a series of experiments on the minimum information required for filling-in. The blind spots of 6 trained observers were carefully mapped on a computer screen, and individually fitted frames of color or texture, having the same shape as the blind spot but varying in width, were generated in Adobe Photoshop. Frame and background luminances were 35.0 and 4.0 cd/m², respectively. With narrow frames, due to the influence of eye movements and Troxler fading, filling-in might be short-lived and partial, i.e. color or texture invaded part of the blind spot but left minor areas unfilled or "foggy". Observers rated the area subtended by the filling-in on a ten-step scale. With red, green and blue frames, frame widths broader than 0.268 produced complete filling-in (> 90%) on all trials, and complete filling-in was occasionally observed with frames as narrow as 0.068, the latter producing a mean filling-in of 80%. With texture, complete filling-in (> 90%) of dot patterns and horizontal as well as vertical gratings (1.5 and 2.3 c/deg) was observed with frame widths of 0.438 and broader, and occasionally with frames of 0.228, that produced a mean filling-in of about 70%. We suggest that filling-in is generated by local mechanisms of the cortex, analogous perhaps to the mechanisms generating the Craik-O'Brien-Cornsweet illusion.

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718 The primary visual cortex fills in color

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One of the most important goals of visual processing is to reconstruct adequate representations of surfaces in a scene. Surface representation is thought to be produced mainly in the mid-level vision and that V1 activity is solely due to feedback from the mid-level stage.

However, contradicting empirical and theoretical reports have also been proposed. One reason for this controversy may be due to the tacit assumption that surface representation is made by single processing rather than multiple processing. Surface representation could be a result of many different aspects of processing. Another reason for the controversy may be that most studies have not controlled effects of attention on a surface. Thus, it is necessary to examine how subcomponents of a surface contribute to surface representation with attentional effects controlled.

Here, we measured fMRI signals corresponding to 'neon color spreading' that is thought to be due to interactions between mechanisms for two surface subcomponents --- color filling-in and illusory contours. In the present study, we used 3T fMRI that provides a fine spatial resolution so that brain activity corresponding to illusory contours and filling-in both as surface subcomponents could be spatially dissociable if surface representation occurs in the retinotopic visual areas. To eliminate or decrease the attentional component of feedback signals, subjects performed an attentionally-challenging task unrelated to the surface perception.

Activity for filling-in was observed only in the primary visual cortex, whereas activity for illusory contours was observed in multiple visual areas. These findings indicate that surface representation is produced by multiple rather than single processing, and that V1 activity for surface representation is not solely from feedback from higher cortical stages.

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719 Facilitation of perceptual filling-in for spatio-temporal frequency of dynamic textures

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Purpose: The ultimate aim of this study is to elucidate the mechanism inducing perceptual filling-in from the viewpoint of spatio-temporal frequency characteristics in vision. Time to filling-in is not a suitable criterion for representing facilitation of filling-in because filling-in time does not distinguish among cases: filling-in is rapidly induced by a certain mechanism and a filling-in target is essentially difficult to distinguish from its surrounding. Therefore, we introduced a new criterion - the attenuation factor of distinguishability of a filling-in target from its surroundings - to represent facilitation of filling-in (Yokota, ARVO 2004). This study investigates the attenuation factor as a function of the spatio-temporal frequency of surrounding dynamic textures. Method: Filling-in time was measured for various dynamic textures characterized by different spatio-temporal frequencies (EX1). An annular filling-in target centered at a fixation point was adopted to stabilize the subject's fixation. The target was presented at 17 [deg] eccentricity of the subject's monocular visual field. We measured visual sensitivity for each dynamic texture used in EX1 (EX2). Results: The attenuation factor, which reflects facilitation of filling-in, was estimated using the measured filling-in time and visual sensitivity for each dynamic texture. The estimated attenuation factor, when represented as a function of spatio-temporal frequency, has a bimodal shape. Those peak frequencies correspond to those of sensitivity functions for M and P channels in LGN. Discussions: If neural activation in primary visual cortex propagates from the central visual field toward the peripheral filling-in target and if stronger activation propagates more quickly, a dynamic texture that induces stronger activation will greatly facilitate filling-in. For that reason, a dynamic texture having higher sensitive spatio-temporal frequency for M and P channels greatly facilitates filling-in.

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720 Ability of contours to block rapid color filling-in is dependent on global configuration

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If a thin luminance contour and a larger solid disk are dichoptically flashed to opposite eyes, a dark hole is seen in the disk. The contour masks the disk's interior by blocking brightness information which normally 'fills-in' from disk's edge (Paradiso and Nakayama, 1991). Using color versions of this paradigm, we find that a color contour mask can weaken if it is part of a larger global configuration. Here, adding to a mask decreases its blocking power, perhaps because the addition provides cues that the configuration is a separate, occluding surface. **Method:** A solid red disk (target) and thin green contour (mask) are flashed simultaneously to opposite eyes. The mask is either square or #-shaped (the same square with arms extending outside the target). The stimulus repeats until the subject responds. The task is to adjust the intensity of a peripheral color patch to match the redness perceived within the center of the mask. **Result:** subjects found the # to mask more weakly than the square, reporting the central redness to be significantly more intense in # trials. Some subjects reported that the # configuration often failed to mask the center at all, while the square configuration was a consistently strong mask. When the experiment was run using achromatic stimuli, subjects

saw no significant difference between masks, some found the # to be the stronger mask. **Discussion:** Previously, we showed that the slow color filling-in underlying Troxler fading can jump over luminance contours and fill discretely to remote areas. The ability of a contour to block filling-in is based not only on its local contrast properties, but also on global surface segregation. Here, we extend this finding to the rapid filling-in underlying normal perception. The #-shaped mask is seen to be separate from the disk's surface, which weakens the ability of the square portion of the # to block the filling-in of the disk. However, this does not seem to apply to the filling-in of achromatic brightness.

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721 Color assimilation: Dependence of watercolor spreading on contour luminance contrast and stimulus width

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The Watercolor Effect (WCE) is a long-range color assimilation effect. When a dark chromatic contour (e.g., purple) surrounds a lighter chromatic contour (e.g., orange), the lighter color will assimilate over the entire enclosed area. We performed two sets of experiments to measure the dependence of the WCE on: (1) the luminance contrast between the contours and the background, and (2) the width of the stimulus. The strength of the WCE was determined using a hue-cancellation technique. In the first set of experiments, we measured the color perceived in the enclosed area as a function of the luminance contrast between the orange contour and the background while the luminance contrast for the double contour was held constant. Using a variation of the minimally-distinct border technique, we determined an equiluminance level between the orange inner contour and the white background (CIE xy 0.30 0.33); then four luminance levels of the orange contour below the luminance background were chosen. The data showed that the chromaticity shift moves closer to the orange border when the luminance ratio between the background and the orange contour increased. In the second set of experiments, assimilation of the WCE was measured as a function of stimulus width (the part of the stimulus enclosed by the double contour). The contours had a luminance of 20 cd/m² (outer contour) and 55 cd/m² (inner contour) and the background was white with a luminance of 80 cd/m². Larger shifts in color appearance were observed for smaller stimulus widths (= 9.3 arcmin), with an exponential decrease in strength of assimilation as stimuli increased in width (up to 7.4 degrees). Correcting for chromatic aberration reduced the magnitude of color spreading for narrow stimulus widths (= 9.3 arcmin), but not for wide ones. Thus, the strength of the WCE depends on the luminance contrast between the inner contour and the background and also by the width of the stimuli.

722 Texture Fading Correlates With Neuronal Response Strength

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Single cell recordings in cat and monkey (e.g., Knierim & van Essen 1992) have shown that the response to an oriented line in the receptive field center of a neuron is strongest, when it is orthogonal to line elements in the receptive field surround. When the orientation is the same, the response is weak. We devised texture patterns to test whether there is a psychophysical correlate of this neuronal behavior when different orientations in the center are pitted against same orientations in the surround and vice versa. Two stimuli were used: one with randomly oriented bars in the center and vertical bars in the surround and a second that was its converse. The mean spacing of the bars was the same in center and surround, and stimuli were positioned at 8 deg from fixation. Fading time was measured. In 10 observers we found that the first stimulus was

not only perceptually more salient, but required also more time for the center to fade into the background ("filling-in"). This finding is consistent with the assumption that a random texture elicits activity in all orientation channels and thus produces a strong response, whereas a uniform texture elicits activity only in a single channel and therefore produces a weak response. As a consequence, the percept of a randomly oriented center would be sustained, while the percept of a uniformly oriented center would be suppressed. In a second experiment, we used dots, instead of bars, in the center and again found longer fading times for stimuli having uniformly oriented as opposed to randomly oriented bars in the surround. However, when we reduced the surround area while keeping the size of the center constant, we found no systematic change of fading time. Instead, fading increasingly occurred in the opposite direction ("filling-out"). The data suggest a correlation of fading time with perceptual salience and the presumed neuronal response, with a modulating influence by the relative size of center and surround.

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723 Collinear facilitation is largely due to uncertainty reduction

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Starting with Polat & Sagi (1993), several studies have shown that the presence of collinear flankers improves the detection of a central Gabor patch. This result has been interpreted as evidence for collinear facilitation. However, it is important to note that facilitation has been observed only for targets near detection threshold (Chen & Tyler, 2002), where observers act as if uncertain about the properties of the stimulus (Pelli, 1985). So the effect of the flankers may be to reduce the uncertainty about the target location and orientation. If this is true, then other cues to target location and orientation should give rise to a similar decrease in thresholds. To test this hypothesis, we measured contrast detection thresholds for a Gabor target under 3 conditions: (i) target alone, (ii) target surrounded by a low-contrast circle that served as a location cue and (iii) target flanked by two collinear Gabor patches. We also used an adaptive procedure to measure the slope of the psychometric function to determine whether the slopes were considerably lower in the presence of cues that reduced uncertainty, as predicted by signal detection theory. Our results show that the presence of collinear flankers improves detection thresholds by a factor of two. For three of our five observers, the circle alone improves thresholds as much as the collinear flankers. For the other two observers, the circle causes an intermediate improvement, suggesting that these observers also benefit from the orientation information provided by the collinear Gabors. More importantly, the slopes of the psychometric function are much shallower in the presence of the circle or the collinear flankers, indicating that the improved thresholds in these conditions are largely due to significant reductions in uncertainty.

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724 Transfer of noise over long distances

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If a homogeneous grey patch is surrounded by a dynamic noise background, observers report that the perceptual artificial scotoma fades and is filled in by the dynamic noise from the surround. When the background is switched off, observers report perception of a prolonged patch of twinkling noise in the non-stimulated area (Ramachandran & Gregory, *Nature*, 1991, 350, 699-702; Hardage & Tyler, *Vision Research*, 1995, 35, 757-766). These phenomena could be related to active neural processes induced by the surrounding stimulation, which increase the level of internal noise within the visual system. To test this suggestion, we

employed the equivalent noise approach in conjunction with the artificial scotoma paradigm.

Observers were presented with Gaussian dynamic noise and a grey patch of 1.5-deg radius centred at the fixation point. They detected a foveal Gabor patch of 4 c/deg (SD 15 min of arc) embedded in Gaussian dynamic noise. Using a 2 interval forced choice method and a staircase procedure, contrast thresholds for detecting the test stimulus were measured in filling-in and after filling-in conditions. The detection threshold increased as the scotoma noise density increased. These functions were shifted to higher contrast levels as the surrounding noise density increased. Observers' performance was analysed by a model for detecting visual patterns. This model took into account sampling efficiency, additive internal noise and multiplicative internal noise components due to the scotoma noise, signal energy and surrounding noise. The results show that in both filling-in and after filling-in conditions, the surrounding noise induces an internal noise component, which approaches the level of the additive internal noise. These findings suggest that dynamic noise may be transferred into internal noise over distances longer than the receptive field size. Thus, we have measured objectively the processes underlying our perception of twinkling noise in the non-stimulated area.

725 Asymmetrical long-range interaction reversed with adaptation to upside-down reversed optical transformation

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Long-range interaction was found to be extended and exaggerated at upper visual fields compared with lower visual fields (Tanaka et al, 2005; VSS, companion paper). Here we tested whether this asymmetry is reversed across upper and lower visual fields with prism adaptation to upside-down reversing retinal images. Experiments were carried out for 7 days. At the 1st day before adaptation, long-range interaction was tested both at the upper and the lower visual fields (eccentricity, 3.2 deg, 2 subjects). The asymmetry between upper and lower visual field was found with upper visual field 2.2 times extended (up to 20 lambda distance) to the horizontal direction with the overall magnitude of facilitation 94% more exaggerated (2 subjects). The asymmetry reversed between upper and lower visual fields at the 4th day; the long-range interaction became 1.7 times more extended (up to 17 lambda distance) and with overall facilitation 104% exaggerated at the upper visual field as compared with the lower visual field (2 subjects). This reversal lasted over the rest of adaptation period up to the 6th day, and persisted 1.5 hours after removing the prisms. No reversal was found for control experiments without adaptation (2 subjects). This is the first psychophysical demonstration of up-down perceptual reversal with prism adaptation. The asymmetry of long-range interaction and its reversal between the upper and lower visual fields suggest anisotropy of bilateral mirror symmetrical connection (Tanaka et al. 2003) between upper and lower visual fields.

726 Asymmetrical long-range interaction between upper and lower visual hemifields

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According to previous studies of lateral connection using the Gabor lateral masking paradigm, the long-range interaction was found with collinear configuration where target-flanker direction was co-axial and co-oriented. No asymmetry was found between horizontal and vertical axes in fovea (Polat and Sagi 1993). Here we show asymmetrical long-range interaction between upper and lower visual fields. Horizontally oriented Gabor target was presented on the vertical meridian either at the upper or lower visual field (3.2 deg eccentricity). Eyes were fixated at the central spot. Two collinearly configured (=horizontal) Gabor stimuli were flanked simultaneously at the left and right sides of the target

($\lambda = \sigma = 0.2$ deg, duration = 100 ms, $C = 0.4$) for each visual field. Contrast detection threshold for target was measured using the temporal 2AFC staircase method for different target-flanker distances ranging 3 to 24 λ . Normalized threshold (= comparison with no-flanker condition) facilitated up to 20 λ with magnitude of 0.14 + 0.04 log units (averaged over 3-20 λ , 4 observers) with the flanker-target presentation at the upper visual field. The facilitation was limited within the distance at 3 to 9 λ with the magnitude of 0.08 + 0.02 log units with the presentation at the lower visual field. Similar asymmetry was found with other target eccentricities (1.6 degrees and 4.8 degrees). These results demonstrate that long-range interaction is extended and exaggerated to horizontal peripheral direction at the upper visual hemifield compared with the lower visual field, suggesting the asymmetrical horizontal long-range interaction between upper and lower visual fields occurring at early stages of visual processing.

727 Contrast detection thresholds of Gabor strings: configuration dependency.

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Contrast detection thresholds improve with stimulus extent. This is often explained by statistical summation between independent spatial channels. Here we thought to test this hypothesis by comparing contrast detection thresholds for different configurations of Gabor quintets. Stimulus parameters were similar to those defined by the ModelFest group (<http://vision.arc.nasa.gov/modelfest/>) for Gabor Strings. These strings were generated from five horizontal collinear Gabor patches (8 cpd) with 0.358 inter-patch distance, arranged horizontally (= = = = =). In our experiments, there were also strings with parallel Gabor patches (| | | | |) and strings with alternating orientations (| = | = | and = | = | =). Thresholds were measured using a standard staircase procedure with a 2AFC method. Stimuli were presented within a Gaussian temporal envelope with $\sigma = 120$ or 60 ms. Results from 4 naive observers showed a significant improvement in threshold for all configurations relative to the threshold of the corresponding central patch. The collinear configuration showed the largest improvement, 0.17 log-units, in agreement with the 4th root summation law [$Ct(n) = Ct(1)/n^{1/4}$, here $n=5$], while the other 3 configurations improved by only 0.11 log-units. Stimulus duration had only a small effect on the collinear improvement (0.01 log-units difference) but a somewhat significant effect on the improvement of the non-collinear configurations (0.13 vs 0.08 for 120 and 60 ms respectively, $p=0.05$, paired t-test). The results do not agree with probability-summation across space as the assumption of channel independence predicts equal improvements in threshold for all configurations. It is possible that equality can be achieved with longer stimulus durations. The results with the shorter duration point to the existence of a neuronal mechanism that is specialized in detecting low contrast contours (Usher et al 1999, *Spatial Vision* 12, 187-210).

Motion in Depth 2

728 The Contribution of Disparity to Motion Contrast Segmentation

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The existence of center-surround organization in middle temporal area (MT) neurons suggests the utilization of motion contrast detectors. We presented a psychophysical test to human observers to investigate how motion contrast stimuli are processed when concentric apertures contain different depths. The stimulus was a stereo random dot kinematogram with an inner circle (diameter 1-10 deg) and outer aperture (2-20 deg)

moving independently. Observers made a 2-alternative forced choice indicating the direction of the center aperture. We tested 8 coherence levels ranging from 2-80% with surround dots (50% coherence) moving in either the same or opposite direction as center dots. Bias in the resulting psychometric functions reflected the modulatory effect of the surround on the perceived direction of center dots. This indicated a preference for reporting center motion in a direction either the same as (assimilation) or opposite to (contrast) the surround. When the inner and outer apertures had different luminances, we found a similar pattern of biases as Murakami and Shimojo (1996): assimilation bias for small apertures (This work was supported by NIH grant R01EY007861-15 to L.M.V.

729 Phenomena of the asymmetric process of visual perception for dilating and contracting size-changing objects in different time limited conditions

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Based on the general principles of Transcendental Psychology Methodology (TPM) and the introduced assumption (Mirakyan, 2004, *Outlines of Transcendental Psychology*, Book 2, Moscow, IP RAS) of the existence of size expansion or irradiation process at the initial stage of the form creation process (FCP) in human visual perception (HVP), it is possible to predict certain differences in HVP of rapidly dilating and contracting objects. In order to check this idea, we made an experimental investigation of anisotropic limits of HVP with short time (10-100 ms) presentations of size-changing objects - increased (A) and decreased (B) in size. High-contrast outline drawings of polygons were presented on a tachistoscope and the size was changed at 10-55 deg/s. Tasks included an object's type identification, movement tracking and size comparison. Objects were perceived with different clarity and line thickness depending on speed and other conditions. At longer presentation times, in the range of 40-10 deg/s, it is possible to perceive and to a certain extent track A and B movements without large visual differences but with predicted variance. It is impossible to see the start of A and B processes, while their other stages are well observed. In contrast, after further increases of size-changing speed up to 40-55 deg/s (i.e. coming out of the lower time boundary range of FCP functional limits), individual traces or 'clouds' are perceived, so that A and B processes have asymmetric visual appearance: for A - it is still impossible to perceive the start of the process, while for B - the start is well perceived and it is not possible to observe the end of the process. These phenomena of the process of asymmetric HVP for dilating and contracting size-changing objects in different time limited conditions, are consistent with a qualitative model based on general TPM principles.

730 Multiphasic Impulse Response for 2D Longitudinal Motion

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Collision avoidance requires that an observer accurately and continuously track the expansion of an approaching object's image. Based on an investigation of the visual system's dynamic response characteristics for this task, we derived a detection model consisting of a linear bandpass filter and a nonlinear criterion detector (presented at VSS 2004). The filter exhibited a biphasic impulse response. In a subsequent set of experiments this model was placed at risk by investigating the implications of the biphasic response characteristic. Experiments were performed in which a circle (representing the outline of a looming object) was presented on an x-y driven CRT. Its radius was subjected to either a pair of pulsed expansions ('PP Pulse'), or an expansion/contraction ('PC Pulse'). If the model is accurate, then the filter's response to two pulses of the circle's radius presented D sec apart will be the sum of the responses to each individual pulse. For certain values of D the individual responses of a PP pulse will reinforce one another, owing to the biphasic nature of the response, while for others they will cancel one another. Thus a PP pulse

should be easier to detect for some values of D and more difficult for others.

Three observers (all having normal vision) were tested at each of four different separation time intervals D. A two interval forced choice experiment was conducted in which the circle radius was subjected to either a PP or a PC pulse in one interval and left unchanged in the other. The observers' task was to detect which interval the circle radius was pulsed in. For each observer, threshold pulse amplitude as a function of separation time was obtained using an adaptive staircase algorithm. The experimental results were consistent with the model's predictions. Additional analysis indicated that criterion detection schemes based on either the peak output of the filter or its maximum peak-to-minimum peak output accurately predicted observer performance.

731 Depth perception from intermittent motion parallax stimuli

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Depth perception from motion parallax is based on relative motion. When object's depth changes, the change is immediately reflected in a change in relative motion as an input. However, the change is not necessarily reflected to a change in perceived depth. In this study, we examined the temporal characteristics of depth perception from motion parallax by using stimuli where relative motion was presented only a part of head movement period.

In the experiment, random-dot patterns moving with a sinusoidal velocity gradient were presented. Relative movements were presented only a part of the observers' head movement period, and stationary patterns were presented the rest of the period. Thus motion parallax changed abruptly in the middle of observers' head movement. The ratios of the moving part to the entire head movement period (motion ratios) were varied in five steps between 1/6 to 5/6. Equivalent disparities were 20, 40, and 60 min in motion period. These intermittent stimuli and those with constant parallax (constant stimuli) were presented side by side during a head movement and observers were asked to match the perceived depth of the two stimuli by adjusting parallax value of the constant stimuli to obtain the point of subjective equality (PSE). Observers' head movement was reciprocating, and traveling 20 cm in either direction. Head movements were cued by tones so that each one-way movement takes 1 second. The results indicated that there was no noticeable change in depth during each head movement regardless of the motion ratios, and that the perceived depth was proportional averaged parallax value during a head movement. There was no effect of parallax values on this relationship. The present results suggest that depth perception induced by motion parallax is averaged over a time period which is likely to be longer than a second.

732 The effect of luminance contrast and stroboscopic presentation on the threshold for the discrimination of approach from withdrawal

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In Minnesota last winter more than 70 vehicles crashed into the rear end of snowplows in daylight, while the frequency at night was lower. One explanation is that luminance contrast is lower in daylight when blowing snow matches the luminance of the snowplow. Low luminance contrast lowers motion sensitivity, which is vital because expansion of a retinal image specifies that approach is taking place and allows one to avoid collision. A second cause of collisions with snowplows is the use of bright, flashing, warning lights. While flashing lights increase the detectability of snowplows, they may reduce the ability to perceive optical expansion, increasing the likelihood of a collision. In this study we examined the effects of luminance contrast, duration of expansion or contraction patterns, and intermittent presentation of displays on the observer's ability to discriminate approach from withdrawal. The Quest procedure

estimated the lower velocity threshold for the discrimination of events in which a simulated vehicle (a square against a darker background) either approached (expanded) or withdrew (contracted) on a screen. During each presentation the square also translated in a random direction so that perception of global motion rather than motion of a single contour was required. When presented with lower contrast displays, observers easily detected the square on the computer screen. In contrast, lowering the luminance contrast between the display and background more than doubled the velocity threshold. Observers required twice the velocity to detect expansion when the display flashed 5 times, over a one second period, compared to a continuous display. Performance was much better when 3 flashes were presented than 5. Duration and amount of expansion were also varied. Sensitivity increased linearly as duration increased. Snowplows should be designed so that continuous optical change provides information that collision will occur if the driver does not slow down.

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<http://ilab.usc.edu/>

733 The Axis of an American Football Leads Observers to Misjudge Where it is Headed

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This study examines the influence of the axis of an American football on its perceived direction of motion. Experiment 1 was of a web survey examining beliefs of the behavior of an American football in flight. The results confirm that most people believe the ball travels with its axis essentially aligned with its trajectory both horizontally and vertically. Experiment 2 used an 8-Camera motion capture laboratory to determine the actual orientation of the axis of a thrown football relative to the direction of its trajectory. The results confirm that the axis consistently tilts horizontally toward the side of the throwing arm, while vertically maintaining a more constant orientation than the trajectory. Experiment 3 compared performance for observers estimating the final destination of thrown volleyballs versus footballs when viewed from the side. Observers were significantly more accurate with volleyballs [$F(1,9) = 17.82, p = 0.002$], and with footballs exhibited a significant bias to indicate balls were headed more in the direction that they were tilted [$r^2 = 0.53, p < 0.01$]. The results are consistent with work by Morikawa (*P&P*, 1999), which demonstrates a perceptual bias to perceive a symmetric shape that moves off-axis as traveling more than actual in the direction in which its axis is aligned. The current work confirms the existence of this bias in a real-world, 3-D setting. The findings support that observers maintain an expectation consistent with the regularity that symmetric objects, like life-forms, typically move along paths aligned with their axes of symmetry and elongation.

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734 Aftereffects of motion in depth based on binocular cues

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Purpose. Lateral motion aftereffects (MAEs) have been studied extensively. Less is known about MAEs in depth. We investigated whether adaptation to stimuli moving in depth induces MAEs in depth.

Methods. The adaptation stimulus consisted of two frontoparallel planes, depicted by random-element stereograms, one above and one below the fixation point. The two planes repeatedly moved in depth in opposite directions for 2 minutes. The motion-in-depth was specified by interocular velocity differences and/or changing disparity by using the random elements which were spatially and temporally correlated in the two eyes (RDS), those which were spatially uncorrelated but temporally correlated

(URDS), or those which were spatially correlated but temporally uncorrelated (DRDS). The test stimulus consisted of a RDS, URDS, DRDS or monocularly viewed random elements that did not move in depth. The subject pressed a key when any apparent motion in depth of the test stimulus ceased.

Results and discussion. Under some conditions the test stimulus appeared to move in depth in the direction opposite to that of the adaptation stimulus (negative MAE). Specifically, adaptation to motion-in-depth of RDS and URDS produced MAEs in many test stimuli, while adaptation to DRDS produced little or no MAE in most test stimuli. While further experimentation is required, this finding suggests that adaptation to interocular velocity differences produces substantial MAEs in depth, but that adaptation to changing disparity produces little or no MAE. Also, a monocular test stimulus showed a MAE in a diagonal direction in depth. The depth component of the MAE under monocular test conditions indicates that binocular processes are involved in generating MAEs in depth.

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735 Perceiving Time to Collision Activates Sensorimotor Cortex

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The survival of many animals hinges upon their ability to avoid collisions with other animals or objects, or to precisely control the timing of collisions. Judgements of time-to-collision (TTC) can be made using optical expansion information (Lee, 1976) and this may be combined with binocular information (Rushton & Wann, 1999). Neural systems underlying TTC judgement from optic expansion have been identified in pigeons (Wang & Frost, 1992) and houseflies (Wagner, 1982). In the case of humans, what cortical areas process judgments of TTC from optical expansion or how these are linked to co-ordinated action is unknown. We investigated this question using fMRI. Observers judged which of two approaching objects would strike them first (Todd, 1981), using optical expansion information. The main control task involved judgements of objects that inflated while remaining at a fixed perceived depth. A second control task utilised TTC judgements for objects translating in the frontoparallel plane. We identified areas of superior parietal and motor cortex, which are selectively active during perceptual judgments of TTC with the point of observation, some of which are normally involved in producing reach-to-grasp responses. These activations could not be attributed to actual movement of participants. We demonstrate that networks involved in the computational problem of extracting TTC from expansion information have close correspondence with the sensorimotor systems that would be involved in preparing a timed motor response, such as catching a ball.

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736 Walking and the Role of Speed in the Perception of Time to Contact

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Many analyses of time-to-contact (TTC) emphasize that retinal information, independent of distal distance and speed, is used to compute TTC (e.g., Tau). However, our research indicates that speed information is also used and that TTC judgments are influenced by extra-retinal self-motion information. A stereo HMD and a wide-area tracking system were used to present TTC stimuli in an immersive virtual environment. In Experiment 1, stimulus approach rate was independent of observer motion. TTC judgments were made by nine naïve observers, while walking and while standing, for object speeds that bracketed standard

walking speed (~ 0.5, 1, and 2 m/s). Displays lasted 3.5 s, with TTC varying from 4 to 6.5 s from onset. The visual environment was untextured, so that there was no visual information specifying the speed of self-motion. When standing, TTC judgments were fairly accurate (mean error = +169 ms), but were earlier for slow objects (49 ms) and later for fast (288 ms). This influence of object speed despite equivalence of Tau is consistent with a misperception of object speed (poorer speed differentiation than distance differentiation). When walking, all TTC estimates were earlier (M = -186 ms), and the differential between slow (-393 ms) and fast (25 ms) objects was increased (p < .05). The increased effect of perceived object speed might be a consequence of a greater misperception of speed. Extra-retinal information specifying self-motion speed might substitute for object speed. In Experiment 2, we studied TTC judgments while walking toward objects whose position was defined in absolute space, so that true TTC was a collision between the motion of the object and the observer. Stimuli were matched in initial retinal angle and approximate TTC, and drifted at varying rates. TTC judgments were again underestimated in all cases, but the estimates were most variable when the ratio of object approach speed to walking speed was most extreme.

Object Recognition

737 Numerical representation in four lemur species

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Although much is known about how some primates⁶ in particular, monkeys and humans⁶ visually represent, enumerate, and track different numbers of objects, very little is known about the numerical and cognitive processing of visual stimuli in prosimian primates. Here, we explore how four lemur species (Eulemur fulvus, Eulemur mongoz, Lemur catta, and Varecia rubra) visually represent small numbers of objects. Specifically, we presented lemurs with three expectancy violation looking time experiments aimed at exploring their expectations about a simple 1 + 1 addition event. In three experiments, we presented subjects with displays in which two lemons were sequentially added behind an occluder and then measured subjects' duration of looking to expected and unexpected visual outcomes. In Experiment 1, subjects looked reliably longer at an unexpected outcome of only one object than at an expected outcome of two objects. Similarly, subjects in Experiment 2 looked reliably longer at an unexpected outcome of three objects than at an expected outcome of two objects. In Experiment 3, subjects looked reliably longer at an unexpected outcome of one object twice the size of the original than at an expected outcome of two objects of the original size. These results suggest that some prosimian primates have the ability to track objects hidden behind occluders as well as the capacity to quantify these occluded objects across time and motion. In addition, since our looking tasks involve no training, our results necessarily tap into capacities that are naturally available to these animals without extensive preparation and suggest that the looking time paradigm may be used in future experiments assessing the visual processing abilities in a wide variety of primate species.

738 Evidence of kind representations in the absence of language from two monkey species

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How do we come to identify and individuate objects as members of different kinds? Some developmental psychologists have hypothesized that learning language plays a crucial role in the capacity to represent objects as different kinds of entities. If this hypothesis is correct, then non-linguistic animals should lack the capacity to represent objects as kinds. Previous research with rhesus monkeys (*Macaca mulatta*) and new data with capuchin monkeys (*Cebus apella*) shows that monkeys can individuate different kinds of objects. Using a searching time measure, we

* Student Travel Fellowship Recipient

found that monkeys who see one kind of object being hidden search longer when they find a different kind of object. But are monkeys in this task individuating objects as different "kinds", or simply representing objects with different properties? Here, we explore whether monkeys can individuate different kinds of objects in a task in which the visual properties of the objects don't vary. Again using a searching time measure, we found that capuchin and rhesus monkeys have different expectations about different kinds of objects even when the perceptual features of the objects are held constant. These data are the first of their kind to suggest that language is not necessary to represent kinds.

739 Project DYLAN: Modeling the development of visual object concepts

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Recently, we launched Project Prakash with the aim of experimentally exploring the development of visual object concepts in children, following sight onset (Sinha, VSS 2003). To complement these ongoing behavioral studies, we have embarked upon a computational project called Dylan (Dynamic input based Learning in Artificial and Natural systems). The goal of this project is to formulate a cascade of computational processes that together can discover objects in real-world video sequences without requiring pre-normalization of the inputs - a task that our human subjects are adept at performing with a few months of visual experience. While this is an extraordinarily difficult problem, and we are still far from a comprehensive solution, experimental data from infant studies and Project Prakash have allowed us to begin designing Dylan's basic computational architecture. The model comprises four stages: 1. Motion-guided orienting and region-trajectory analysis to determine which region assemblies to bind together, 2. Tracking assemblies to extract temporally extended appearance models (TEAMs) of dynamically transforming objects, 3. Statistical estimation of inter-TEAM correlations across time to infer their predictive dependencies, and 4. Object recognition in new inputs via TEAMs and their mutual correlational structure. This architecture emphasizes the role of dynamic information in the task of object learning, and is based on experimental data showing that motion cues are critical for accurate image parsing by infants as well as sight-restored children. The computations involved in motion-based region binding and tracking are detailed in presentations by Ostrovsky and Balas respectively. This presentation contextualizes all stages and describes the overall results, both successes and failures, of our current Dylan implementation.

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740 Invariant Object Learning and Recognition Using Active Eye Movements and Attentional Control

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Neural data and models have proposed that the brain achieves invariant object recognition by learning and combining several views of a three-dimensional object. How such invariant codes are learned when active eye movements scan a scene, given that the cortical magnification introduces a large source of variability in the visual representation even for the same view of the object? How does the brain avoid the problem of erroneously classifying together parts of different objects when an eye movement changes the cortical representation from one to the other? How does the brain differentiate between saccades on the same object and saccades between different objects? A biologically inspired ARTSCAN model of visual object learning and recognition with active eye movements proposes answers to these questions. The model explains how surface attention interacts with eye movement generating modules and object recognition modules so that the views that correspond to the same object are selectively clustered together. This interaction does not require prior knowledge of object identity. The modules in the model conform to brain

regions in the What and Where cortical streams of the visual system. The What stream learns a spatially-invariant and size-invariant representation of an object, using bottom-up filtering and top-down attentional mechanisms. The Where stream computes indices of object location and guides attentive eye movements. Preprocessing occurs in the primary visual areas, notably log-polar compression of the periphery, contrast enhancement, and parallel processing of boundary and surface properties. ARTSCAN was tested on a scene filled with letters of different sizes and orientations and performed above 95% correct in classification after real-time incremental learning controlled by attention shifts and active eye movements.

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741 Against Image-Based Theories of Shape Recognition

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Purpose:

To find a critical condition to test image-based theories, which predict that the more similar a query image is to a studied, the better recognition will be. By assuming that two identical images are more similar to each other than two different ones, we found that the latter could in fact yield better recognition.

Method:

In a same-different matching task, American subjects determined whether two images were of the same or different Chinese characters. A stimulus was created by randomly occluding with red pixels either 60%, or (by removing 10% of red pixels) 50%, or 20% area of a gray-level Chinese character. So when the two images were of the same character and percentage of occlusion, the two images were identical. No trials were repeated. When the first image was 60% occluded, the second image that was the same character but 40% occluded yielded higher hits (and accuracy) than that that was identical to the first.

Modeling:

All results of 25 conditions were explained by our model. We assumed that, due to limited capacity, up to a certain number of occluded pixels were recovered, each by the mean value of its neighboring unoccluded pixels. An unrecovered pixel was assigned a random value. In each of the 25 conditions, the model computed the following two distributions of pixel value differences between the two images: when the two images were of the same and different characters, respectively. The model's performance was assumed to be a monotonic function of the χ^2 measure between the two distributions, and was found to match that of subjects'.

Discussion:

In an experiment that favored template matching, we found that a different, but more structured image gives rise to better recognition. The results confirmed our earlier results with faces, which were explainable by the same model. We conclude that image-based theories cannot account for our results, and that structural organization is important in shape representations.

742 Differential fMRI activity produced by variation in parts and relations during object perception

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A key assumption of structural description accounts of object representation is that the representation of the relations among parts are distinguished from the representation of the shapes of parts themselves, e.g., by different units for the different kinds of information. Models that do not represent relations explicitly leave this distinction to some undefined, later cognitive process, an assumption somewhat at odds with recent results from selective attention tasks showing that parts are perceptually distinguishable (or analyzable) from relations (Hayworth &

Biederman, 2004). Subjects passively viewed four kinds of 'flip movies' (produced by rapidly cycling between two images) as well as an LO and an MT localizer. In Part Shape movies, the shape of a part of a two-part object cycled between two geons, say, a cylinder and a wedge, both on top of a brick for 3 s, with each frame being 250 msec. In Relation movies, the relation between the two parts changed with, for example, the cylinder shuffling back and forth over the surface of the brick. A control (Separate Parts) for the Relation condition separated the cylinder from the brick to assess whether activation produced by the Relation condition was reflecting within object-relations rather than activity from a large translation of a part. In View movies, the whole object either translated, changed size, or rotated in depth. The magnitude of motion energy was equated for the four conditions. All four types of movies activated MT equally, confirming the motion energy calculations. Part changes produced greater activation in area LO than any of the other conditions whereas the Relation changes produced the greatest activation in a region in the parietal cortex.

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743 fMRIa to complementary, contour-deleted images of objects

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Brief presentations of feature-deleted images of line drawings of objects, in which every other edge and vertex are deleted from each part, prime their complements (comprised of the deleted features) as well as they do themselves (Biederman & Cooper, 1991). This result suggests that the representation mediating visual priming of the facilitation in the speed and accuracy in the naming of the identical image over a same name, different-shaped exemplar (presented 7 min later) does not specify local features but, instead, simple object parts. Presumably once the representation of these parts is activated (by either member of a complementary pair) the memorial representation is of the parts rather than the local features. We assessed whether these priming results would be reflected in fMRIa (a for adaptation), in which the second presentation of a repeated stimulus 400 ms later, results in a reduced BOLD response compared to the presentation of a different object (e.g., Grill-Spector, Kurtzi, & Kanwisher, 2001). A contour-deleted image of an object was followed 400 msec later by the Identical image, its Complement, or a same-name Different-shaped Exemplar. The second presentation was always a mirror reversal of the first to reduce the potential role of local spatial or completion processes. Subjects passively viewed the sequences but were instructed to identify/silently name the objects to themselves. If fMRIa in area LO provides an index of priming, a reduced BOLD response for Identical compared to Different Exemplar images would be expected in that area. Preliminary results are consistent with such an effect, suggesting that the reduction in the BOLD response cannot be attributed to reduced activation from repetition of the name or basic-level concept of the object. Moreover, the BOLD response for Complementary images is equivalent to that for Identical images, a result parallel to that found in the behavioral experiments.

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744 Standard Model v2.0: How Visual Cortex Might Learn a Universal Dictionary of Shape Components

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The tuning properties of neurons in inferotemporal (IT) cortex are likely to play a key role for visual perception in primates and in particular for their object recognition abilities. The tuning of specific neurons probably depends, at least in part, on visual experience.

We describe a model of plasticity and learning in V4 and IT extending the initial version of the standard model of object recognition in cortex [Riesenhuber and Poggio, *Nat. Neurosci.* 1999] -- that accounts for known physiological data. When exposed to many natural images the model generates a large set of shape-tuned units which support robust recognition performance and which can be interpreted as a universal dictionary of shapes with the properties of overcompleteness and non-uniqueness. Preliminary results suggest that the set of shape-tuned units obtained is consistent with recent physiological data collected in V4, see abstract by [Cadieu et al, *VSS* 2005]. We also show that the model can handle the recognition of different object-categories in natural images at the level of the best existing computer vision recognition systems.

745 Mixture of view-invariant and view-dependent representations in human object-selective cortex

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Humans recognize familiar objects from almost any viewpoint (i.e., view-invariance). However, behavioral invariance need not imply that underlying neural representations are also invariant. Indeed, the nature of object representation is under heavy debate. We used fMRI-adaptation to investigate sensitivity to changes in viewpoint using a parametric manipulation of in-depth rotation from an initial adapting view. Critically, this method allowed us to determine the degree of invariance as a function of rotation and adapting view.

Eight participants completed ten runs of adaptation and test in a 3T scanner. During adaptation, participants viewed 10 line-drawings of animals and vehicles repeated six times while performing a 1-back matching task. For five runs participants were adapted with front views of objects, and for the other five they were adapted with rear views. At test, they viewed objects rotated in-depth 0 (identical), 60, 120, and 180 degrees, as well as new objects. Participants categorized each image as animal or vehicle.

Surprisingly, responses in object-selective cortex were largely invariant (i.e. remained adapted) to changes in viewpoint when adapted with front views of animals, but were view-dependent (i.e., showed a systematic recovery from adaptation with increased rotation) when adapted with rear views of the same animals. In contrast, responses in these regions were view-dependent when adapted with vehicles, regardless of the adapting view.

These results suggest that representations in object-selective cortex are largely view-dependent, but the information available in a particular view affects the level of invariance. Responses to informative views (e.g., front views of animals) are more invariant than less-informative views (e.g., rear views of animals). These findings suggest a mixture of view-invariant and view-dependent representations exists within object-selective cortex, and provide critical constraints for theories of object recognition.

746 The emergence of object size invariance in the human visual cortex

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Changes in the image size of an object occur routinely and result in massive changes in neural activity at early stages of the visual system. For example, reducing the viewing distance between an observer and an object (i.e., increasing its retinal size) can produce a very different pattern of activity in early retinotopic cortical areas. However, changing image size has little consequence on our ability to recognize an object. Using fMRI adaptation in a rapid event-related design, we measured neural sensitivity to changes in object shape and image size in the human visual cortex. We show that size invariance - that is, a single neural population coding for multiple image sizes - is evident as early as dorsal retinotopic visual area V3. In ventral visual areas, size invariance is not apparent until the lateral occipital (LO) region. Both dorsal and ventral areas, however, were limited

in their size invariance; a doubling of image size resulted in a signal equivalent to a change in shape indicating that large size changes are represented by a different neural population. Directing attention towards or away from the shape of the objects did not qualitatively change the pattern of results in any area examined, suggesting that limited, size-invariant representations are formed automatically by the human visual system. Finally, we address the role of perceived object size constancy on fMRI adaptation by associating changes in perceived depth with image size changes.

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747 The Role of Polar Features in Visual Object Constancy

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Previous research has shown that object recognition may be either orientation-dependent, or orientation-invariant, depending on a variety of stimulus and task variables. This study investigated the role of polar features (i.e., stimulus features that may serve to define the directionality of an object-based spatial reference frame) to the computation of orientation-invariant shape representations. A recognition memory paradigm was used to examine the effects of stimulus orientation on the recognition of previously memorised 2D novel shapes. The salience of the internal shape axes and polar features were manipulated. The results of Experiment 1 confirmed that orientation-invariant recognition can be found from the outset of testing with objects containing a salient internal axis of symmetry. In Experiments 2 and 3 it was found that the removal of a single salient polar feature, whilst preserving the axis of elongation, was sufficient to increase stimulus orientation effects. This finding suggests that polar features may play an important role in object constancy. It is suggested that polar features act by facilitating the assignment of consistent coordinate values to the spatial locations of features in shape representations encoded within object-based reference frames.

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748 Paying Attention to Orientation: A Two-Stage Framework of Familiar Object Recognition

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Recognition costs incurred by rotated objects have usually been interpreted as evidence for viewpoint-dependent recognition. However, recent findings from repetition blindness and attentional blink experiments (Harris & Dux, in press; Dux & Harris, VSS 2004) suggest that initial recognition is actually mediated by orientation-invariant representations and that the orientation effects arise during a later stage of processing which enables conscious recognition and report. We detail a two-stage framework of familiar object recognition which accounts for these results and other findings in the object recognition literature. In stage 1, the object's identity is recovered from memory via an orientation-invariant representation. However, before the object can be consolidated, a second attention-demanding stage of processing is required, in which the object's identity and its orientation at a particular moment are integrated, in order to give rise to a conscious percept anchored in space and time. According to the model, orientation effects on recognition arise during the second stage, because of a discrepancy between the spatial orientation of the stimulus and the expected orientation retrieved from memory. This discrepancy has to be resolved before an episodic representation of the object can be consolidated and reported.

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Sensory Integration: Vision and Touch

749 Effects of effort and reduced visual cue information on perceived walking speed

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Previous studies have shown that people can estimate walking speed from the rate of optic flow (Banton et al., in press). However, it is unclear whether these estimates are driven solely by the optical properties of the flow field or by additional factors. For example, Bhalla & Proffitt (1999) and Proffitt et al. (2003) showed that an observer's physiological potential for action can alter his or her perception of the slant of hills and of extents along the ground. Building on these findings, we hypothesized that perceived walking speed might also be affected by manipulations of physiological potential, specifically, effort for walking.

Participants walked on a treadmill while wearing a virtual-reality headset. The virtual environment (VE) consisted of an infinitely long moving walkway running through an airport concourse. As participants walked along the walkway through the world the rate of optic flow was varied randomly between 3 and 8 mph in 1 mph increments. The actual walking speed on the treadmill remained constant at 3 mph. For each trial, participants were asked whether the speed of the world matched their walking speed and perceived walking speed was determined by averaging speeds at which the participant responded, 'yes'.

To manipulate walking effort physiological potential was changed by having participants walk with a heavy backpack or without a backpack in one of two VEs, which contained rich or impoverished optic flow cues. The rich optic flow VE contained detailed textures and objects and the impoverished VE had minimal textures and objects.

With impoverished optic flow the estimated walking speed was significantly higher for participants wearing a backpack versus participants that did not wear a backpack. Speed estimation was not affected by wearing the backpack in the rich optic flow condition. This finding suggests physiological potential is given greater weight in speed estimation as the availability of optical cues decreases.

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750 A hand in sight: How blindsight is improved by hand location.

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Bimodal visual-tactile neurons, located in the putamen, ventral premotor cortex, and posterior parietal cortex, respond both to visual and tactile stimuli presented near the hands, arms, and face. Single-cell recordings have shown that hand proximity to the visual stimulus determines the degree to which bimodal cells respond. We tested the hypothesis that hand proximity to a visually-presented target object may influence residual vision in the blind visual field of an individual with a lesion in the geniculostriate pathway. MB is a 26-year-old man with a dense upper-left quadrantanopia. He fixated one of 4 randomly-presented LEDs shown 408 to the upper-left, lower-left, upper-right, and lower-right of a central target location. One of 3 (small, medium, large) objects was presented for 150 ms, and MB responded in two ways with his right hand. For the action task, he reached for and grasped the target. For the perception task, he estimated target height by adjusting thumb-finger separation. Hand position was crossed with response type and both were randomly presented in blocks. In the hand-present condition, MB's left hand was placed just to the left of the target object. This placement ensured that this hand was always in the same visual field as the target. In the hand-absent condition, MB's left hand was placed out of view on his lap. Hand position had a significant effect on performance in MB's blind field. In the hand-absent condition, he showed little or no scaling of either peak grip aperture (PGA) or size-

estimation aperture (SEA) to object size. In the hand-present condition, however, scaling of both PGA and SEA improved significantly. We saw no improvement in performance with hand-presence in his non-blind visual fields. The results imply that recruitment of bimodal cells can do more than simply improve visual detection in the blind field, they can also contribute to size perception. Potential mechanisms for this improvement will be presented.

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751 Visuo-Spatial Alignment Produces an Instant Rubber Hand Illusion

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In the rubber hand illusion (RHI -- Botvinick & Cohen, 1998), one's hand is occluded, and a rubber hand is placed in view nearby. If the real and rubber hands are then touched in synchrony, one comes to experience the tactile sensations as occurring at the surface of the rubber hand. Like prism adaptation, this results in a shift in the felt position of the hand. We wondered whether visuo-tactile synchrony is a direct source of information about localization of the body schema, or if the RHI is primarily mediated by visuo-spatial identification. To test this hypothesis, a mirror box was constructed that allowed a rubber hand to visually replace the left hand of an observer. A first-surface mirror served to occlude the hand while simultaneously providing illusory visual access to the expected visual location of the real hand. Whether the rubber hand was placed (via the mirror) in the visual space of the real hand or displaced by 15 cm, the rubber hand illusion was immediate. To test whether synchronous touching added any additional spatial shift to the illusion we measured shifts in the felt position of the unseen hand after approximately two minutes of exposure to the optically displaced rubber hand while (1) real and rubber hand were touched synchronously, (2) the rubber hand was "stroked" with the light of a 'laser,' or (3) the real hand was touched while the rubber hand was not. In all three conditions, a displaced rubber hand produced shifts in felt position of the real hand (3 cm) that were statistically equivalent. Similarly, electrodermal responses to threats to the RH were indistinguishable in the three conditions (see Armel & Ramachandran, 2003). Visuo-tactile synchrony added nothing to the visual identification of the rubber hand when plausible alternative locations of the real hand (occluders) were not visually available. When the spatial location of the real hand is rendered visually empty, or is filled by the rubber hand, the RHI is instant.

752 Looking in the Mirror Does Not Prevent Multimodal Integration

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Ernst & Banks (2002) showed that humans integrate visual and haptic signals in a statistically optimal way if they are derived from the same spatial location. Integration seems to be broken if there is a spatial discrepancy between the signals (Gepshtein et al., VSS 04).

Can cognitive factors facilitate integration even when the signals are presented at two spatial locations? We conducted two experiments, one in which visual and haptic information was presented at the same location. In the second experiment, subject looked at the object through a mirror while touching it. This way there was a spatial offset between the two information sources. If cognitive factors are sufficient for integration to occur, i.e. knowledge that the object seen in the mirror is the same as the one touched, we expect no difference between the two experimental results. If integration breaks due to the spatial discrepancy we expect subjects' percept to be less biased by multimodal information.

To study integration participants looked at an object through a distortion lens. This way, for both the 'mirrored' and 'direct vision' conditions there

was a slight shape conflict between the visual and haptic modalities. After looking at and feeling the object simultaneously participants reported the perceived shape by either visually or haptically matching it to a reference object.

Both experiments revealed that the shape percept was in-between the haptically and visually specified shapes. Importantly, there was no significant difference between the two experimental results regardless of whether subjects matched the shape visually or haptically. However, we found a significant difference between matching by touch and matching by vision. Haptic judgments are biased towards the haptic input and vice versa.

In conclusion, multimodal signals seem to be combined if observers have high-level cognitive knowledge about the signals belonging to the same object, even when there is a spatial discrepancy.

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753 Visual and Vestibular Factors in the Perception of Bodily Tilt

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When supine subjects are at rest, the degree of bodily tilt should theoretically be communicated by the static effect of gravity upon the otolithic sensors. This experiment was carried out to determine whether visual inputs enhance or degrade this ability in male and female observers. Male and female subjects reclined in a supine position face-up and directed an experimenter to make adjustments to an inversion table to achieve a specified target angle of bodily tilt (758, 908 or 1058 from vertical). Subjects delayed their directions for 3 seconds so that their judgments would not be influenced by the acceleration of the adjustments. Prior to each trial the experimenter would adjust the table to the target angle and then offset it to provide an ascending or descending trial type. When the subjects felt they had achieved the target angle, the experimenter would record the absolute discrepancy from the target angle. Half the trials were performed with the eyes open and half were performed while blindfolded. For the 908 target angle with the blindfold, the mean discrepancy scores for men and women were about 18, but with eyes open, discrepancy scores declined for men and increased significantly for women. For the 758 and 1058 angles, discrepancy score increased for both men and women (to about 3-48), but increased more for women than men. Discrepancy scores for women were less without, than with the blindfold at the 758 target angle. These results indicate that female subjects are more influenced by visual inputs when making judgments of bodily tilt.

754 Effects of response type on visuotactile congruency effects

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Does the brain have common representations of external space across different sensory modalities? This question was examined by Spence and his colleagues who reported the crossmodal congruency effects (CCE); subject's speeded elevation discrimination responses on tactile stimuli were much better when both tactile and light stimuli were presented in congruent elevation in hands rather than in incongruent elevation. We tested whether the CCE were the artifacts caused by the type of response. In the typical crossmodal congruency task, the target tactile stimuli that subjects had to discriminate were presented to fingers while subjects had to respond via foot pedals. The different body parts involved in tactile stimulus reception and discrimination response might have affected the response difficulty asymmetrically for the congruent and the incongruent conditions. We examined this possibility by comparing the CCE measured with two types of responses; finger response and foot response. The experimental equipments were specially designed in order to allow subjects to respond via the fingers receiving the tactile stimuli. The

experimental stimuli were quite similar to those used in the typical crossmodal congruency task. The distance between left and right hands was manipulated in three levels (i.e., 7 cm, 13 cm, and 25 cm) while the distance between an index finger and a thumb was fixed at 13 cm. The typical CCE were found when measured with foot response. When measured with finger response, however, the CCE were found only when the visual distracters were presented to the same hand side with respect to the tactile targets. The effects of response type on CCE were consistently obtained over the three levels of hand distance. This result suggests that the CCE depends on response type and its implication should be revisited.

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755 Combining multi-modal information of a deformation of an object

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Recently, it has been shown that humans could efficiently combine multi-modal information to estimate an environment. In most research, however, information to be processed was temporally static. We conducted two experiments to investigate the process of combining dynamic multi-modal information. Participants estimated the amount of compressive deformation of a virtual cylinder through only haptic or visual (uni-modal trials) or both haptic and visual (multi-modal trials) cues. There was inconsistency between the amount or the timing of visual and haptic deformations in some of the multi-modal trials. The virtual surface of the cylinder was presented haptically to the index finger using a force-feedback device (PHANTOMTM). The visual stimulus was a cylinder-shaped white random patched texture on black background without shading nor stereo projection. The task was to identify the odd stimulus among three sequentially presented deformations (experiment 1), or to identify which was the larger between two deformations (experiment 2). The threshold of multi-modal estimation was lower than uni-modal estimation if there was no inconsistency between modalities. In addition, in experiment 1, in multi-modal trials where participants could use only haptic information to identify the odd stimulus because visual deformation of it was identical with the other stimuli due to inconsistencies, the estimation threshold was higher than in uni-modal haptic trials. However, the threshold in multi-modal trials where only visual information could be used was almost the same as in uni-modal visual trials. This suggested that there was a bias toward visual information. Experiment 2 showed that the performance drastically fell if the timing of deformations was inconsistent, even when the difference was only 125ms. Humans can efficiently combine not only static but also dynamic multi-modal information, and geometrical and temporal consistencies between modalities are important for efficient combination.

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756 Touch-induced Visual Illusion

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Although vision is considered the dominant modality, recent studies demonstrate the influence of other modalities on visual perception (Shams et al. 2000, Sekuler et al., 1999, Ernst et al., 2000). We report an extension of the 'sound-induced flash illusion,' (Shams et al., 2000) to the tactile-visual domain, yielding the 'touch-induced flash illusion.' Methods: Visual stimulus consisted of a uniform grey disk presented at 7 degree eccentricity below the fixation point for 10 ms. Tactile stimulation was provided by a refreshable Braille cell consisting of a 2x4 array of plastic

pins which were raised simultaneously for 34 ms and provided a salient stimulation to the tip of the left index finger. A factorial design was used with two factors: the number of flashes (1 or 2), and number of taps (0, 1, 2). Thirty trials of each condition were presented in random order to nine naïve subjects. The task was to judge the number of flashes seen on the screen. Results: On average, observers reported seeing two flashes on 63% of trials when a single flash was accompanied by two taps, compared to 15% of trials when it was presented in the absence of taps. Furthermore, signal detection theory analysis indicated that double taps caused a change in sensitivity in visual discrimination. This radical change in perception was consistent across all subjects tested. Conclusion: These findings provide further evidence challenging the notion that visual perception is independent of activity in other modalities.

757 Aging and the Cross Modal Perception of Natural Object Shape

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Previous research on visual-haptic cross-modal shape matching has typically investigated the abilities of younger adults (e.g., Gibson, 1962, 1963; Norman, Norman, Clayton, Lianekhammy, & Zielke, 2004). Aging is known to lead to deteriorations in both tactile acuity (e.g., Stevens, 1992) and the visual ability to detect and discriminate 3-D shape (e.g., Andersen & Atchley, 1995; Norman, Dawson, & Butler, 2000; Norman, Clayton, Shular, & Thompson, 2004). The purpose of our study was to evaluate whether and to what extent these visual and tactile deteriorations compromise older observers' abilities to cross-modally compare 3-D shape across vision and haptics. Ten younger (≤ 22 years) and ten older (64-81 years) observers participated in the experiment. On each trial, the observers haptically explored one of 12 naturally-shaped objects for 7 seconds; they were then required to indicate which of the 12 simultaneously visible objects possessed the same shape as the one they had haptically explored. Each observer performed a total of 96 cross-modal shape comparisons (8 repetitions for each of the 12 objects). Observers in both age groups performed well above chance levels, but made systematic errors that suggested that their matches were based upon similarities in the objects' global shapes. The performance levels of the younger observers were about 60 percent higher than those of the older observers (the mean performance of the younger observers was 67.6 percent correct, while that obtained for the older observers was 42.4 percent). In addition to their overall better performance, the younger observers also exhibited higher rates of improvement over time with the task than did the older observers. The reduced performance of the older observers did not correlate with the reductions observed in their visual and tactual acuities. The results thus suggest that the age-related deficit in cross-modal shape matching is caused by central rather than peripheral factors.

758 Blind Patients 'See' Their Moving Hand In Darkness (Synesthesia)

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A patient who is blind because of damage to the visual pathways was asked to move his hand in front of his eyes in complete darkness. Amazingly he not only felt, but literally saw his hand moving; the converse of experienced movement of phantom limbs induced by visual feedback in mirrors. Normals don't see this because the top-down signals to the visual centers from polymodal cells in parietal and frontal lobes is vetoed by bottom-up nulling signals from the intact visual pathway.

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759 Gravitational signals contribute to visuospatial updating in humans

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Primates can update, and thus keep track of, the locations of objects in space. Specifically, they can accurately look to the remembered location of a flashed target even if the eyes/head are subsequently moved from their initial location. To do this, the brain requires information about the amplitude and direction of the intervening movement. Such information can be provided either by motor signals (i.e., efference copies) or by sensory signals. These sensory cues include proprioception and vestibular (i.e., canal and otolith) signals that also provide information on the body's orientation relative to gravity.

To determine if efference copy signals are necessary for spatial updating, we had subjects sit, with their heads and bodies fixed, on a three-dimensional turntable. In complete darkness, subjects were passively rotated torsionally (left ear down or right ear down) to a new orientation, briefly shown an eccentric target, returned to upright, and then asked to make a saccade to the remembered target. Using this paradigm, we tested subjects' abilities to update from 7 tilt angles to 8 target directions and 2 target amplitudes.

We found that subjects were able to update remembered target locations from all tilt angles and all amplitudes. Slopes of directional errors vs. tilt angle ranged from -0.01 to 0.15, were similar to a slope of 0 (perfect updating) and significantly different from a slope of 1 (no compensation for head torsion). Since the head and body were fixed throughout these rotations, efference copies were not required for updating.

To investigate the contribution of canal vs. gravitational signals, we repeated the above experiment with subjects supine. This time the slopes of directional errors vs. tilt angle ranged from 0.60 to 0.82, indicating poor updating performance. Thus, we conclude that information specifying the body's orientation relative to gravity is critical for maintaining spatial constancy and for distinguishing space-fixed vs. body-fixed targets.

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Temporal Processing

760 Temporal resolution of the human visual system for processing color, orientation, and color/orientation conjunctions

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Holcombe and Cavanagh (2001) introduced a psychophysical method that enabled them to place an upper bound on the speed at which the human visual system can integrate color and orientation. They concluded that the visual system requires, at most, 25 milliseconds to determine how color and orientation are conjoined. However this method does not quantify the temporal resolution of color and of orientation, and thus it does not place a lower bound on the time required for feature integration. Indeed, if 25 milliseconds were required to process either feature, this would rule out a time-consuming integration computation. Here we introduce a psychophysical method that provides comparable measures of temporal resolution for color, orientation and color/orientation conjunctions. Since all measures are derived based on judgments of the same stimuli, the method is robust with respect to changes in arousal and adaptation state. Preliminary results from three subjects suggest that the temporal resolution for color/orientation conjunctions is slower than temporal

resolution of either feature, providing evidence for a non-instantaneous integration computation.

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761 Nonlinear Neural Processing of Temporally Modulated Inducing Light

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BACKGROUND & PURPOSE A uniform surround can induce changes in the brightness or color of a test region. A surround sinusoidally varied in time in luminance or chromaticity induces perceived temporal variation in a physically constant test field. DeValois et al. (*Vision Research* 1986) reported strong induction in a test field at inducing-field temporal frequencies below ~3 Hz but not at higher frequencies. Here we investigated whether nonlinear neural processing occurs prior to the site of neural filtering of temporally-varying induction. If so, simultaneous modulation of two different temporal frequencies above 3 Hz may induce perceptual modulation in the test. For example, a nonlinear process may produce a lower-frequency neural response at the difference (beat) frequency of two simultaneously presented inducing frequencies. **METHODS** A steady EEW annular test ring (0.5 deg wide) was embedded in a larger circular surround (6 deg diameter). Test and surround were separated by a thin (3 min) dark gap. The surround was modulated (i) sinusoidally at various single temporal frequencies or (ii) with the superposition of two temporal frequencies. The induced temporal modulation in the test ring was matched by adjusting the modulation amplitude of a separate annular 'matching ring' varied sinusoidally at 2 Hz. **RESULTS** As reported previously, temporal induction from sinusoidal surround modulation was severely attenuated above ~3 Hz. The superposition of two higher temporal frequencies (e.g. 4.17 & 5 Hz), however, induced substantially more temporal variation in the test than either temporal frequency presented alone. **CONCLUSION** Induced temporal modulation can result from higher temporal inducing frequencies than reported previously. This can be explained by a nonlinearity, which precedes a neural low-pass temporal filter and which produces a neural response at a lower temporal frequency than either inducing stimulus. This lower frequency alone survives a subsequent low-pass filter.

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762 Dynamics of contrast-gain controls in pattern vision

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Introduction. We are studying the dynamics of *contrast-gain* controls psychophysically using a probed-sinewave paradigm. In this probed-sinewave paradigm a background pattern's contrast is flickering sinusoidally over time. Threshold is measured for a short-duration probe-pattern superimposed at various phases with respect to the background flicker. The patterns are element-arrangement textures made of Gabor (2nd-order) or blob (1st-order) elements. Effects demonstrated with *static* versions of these patterns are consistent with a contrast-gain control produced by inhibition among channels in a normalization network (and are *not* consistent with a number of other models).

The Past. We and others have previously studied *luminance-gain* controls using a probed-sinewave paradigm with spatially homogenous background and probe. Probe thresholds at all phases increased with the frequency of the flickering background up to about 8 to 16 Hz. These results were very useful in distinguishing among models of light adaptation. These results show little interocular transfer, indicating that the luminance-gain control is very likely to be predominantly retinal.

The Present. In our current contrast-gain-control experiments -- using element-arrangement textures in the probed-sinewave paradigm -- we are

seeing qualitatively different results. We think these new results will have a similar ability to distinguish among models. This time the models are of the *dynamics* of contrast-gain-controlling processes, e.g., inhibition among cortical cells, synaptic depression at LGN to V1 synapses, long-range horizontal connections, and so on.

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763 Feature Integration is Determined by the Temporal Order of Events

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How features of an object are bound into a unique percept is one of the puzzling problems in the cognitive and neurosciences. In order to investigate the temporal dynamics of feature binding, we used a feature fusion paradigm: a vernier (V) was immediately followed by a vernier with opposite offset direction (AntiV). Because of the very short presentation times of V and AntiV, feature fusion occurs, i.e. only one vernier is perceived. We presented various sequences of Vs and AntiVs while keeping their total physical energy (duration x luminance) constant. Surprisingly, the contribution of each vernier to the fused percept depends not only on its energy but also on the temporal order of the elements. If, for example, a V was followed by an AntiV, the AntiV dominated the perceived offset (condition V - AntiV). This changed when the V was subdivided into two equal parts, of which one was presented before and the other after the AntiV (condition ?V - AntiV - ?V): none of the verniers dominated. In general, our results show that any level of performance can be achieved by arranging sequences of Vs and AntiVs appropriately - even though the total physical energy of V and AntiV is identical.

We conclude that for a given physical energy of V and AntiV the temporal order of presentation determines the integration of features. Different positions within the temporal sequence of events are of different importance. It seems that later elements of the sequence influence the perceived offset more than earlier ones.

Our findings provide evidence that the temporal order of elements is crucial for the integration of features. These results pose serious challenges for most models of feature processing, since they are mainly energy-based while ignoring temporal aspects.

764 The role of temporal integration in backward masking

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Visibility of a brief target is reduced by the appearance of a mask 50 ms after target onset. At shorter or longer SOAs masking is weaker, which produces a u-shaped masking function of target percept against SOA. Many quantitative theories have explained why backward masking has this property, but as we reported last year, all of the quantitative theories predict that the shape of the masking function is related to the overall strength of masking. We reported data inconsistent with this prediction. One alternative theory that might account for the results hypothesizes that when the target and mask are presented with a short SOA they temporally integrate to form a single percept. In this percept, the target may be identified and thus lead to weak masking at short SOAs (Navon & Purcell, 1981). Here, we report a conceptual replication of a study by Reeves (1982) to explore the role of integration in a u-shaped masking function. Observers were asked to identify the location of a target (rectangle) among three distracter squares arranged on a virtual square around a fixation point. The target frame was followed by a mask frame (both 27 ms duration) of outline squares around each element in the target frame. The SOAs between target and mask frames were 0, 13, 27, 40, 53, 67, 133 or 267 ms. On each trial an observer was asked to identify the location of the target element and then to judge whether the target and mask elements were presented simultaneously or consecutively. Regardless of the temporal alignment report, a u-shaped masking function was found. This

finding deviates from Reeves (1982), which found different monotonic shaped curves for reports of perceived simultaneous and consecutive target and mask frames. The new result suggests that temporal integration of the target and mask is not necessary to produce a u-shaped masking function. We discuss the differences between the present study and Reeves' and what kinds of models might account for the results.

765 The highs and lows of temporal integration in backward masking

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It has long been known that a brief target can be rendered invisible if followed by a brief mask. Two general patterns of backward masking have been observed when the strength of the target percept is plotted against the SOA between the target and mask (a masking function). For some kinds of masks, the masking function increases monotonically as the SOA increases from zero. For other kinds of masks, the masking function is u-shaped, with a bottom at around 50 ms. We now propose that there is a more general principle than type of mask that describes whether a monotonic or u-shaped masking function appears. Namely, at the shortest SOAs the target and mask integrate into a single percept and the visibility of the target features in the integrated percept determines performance in the masking task. A monotonic or u-shaped masking function occurs when the integrated percept hides or facilitates the target's features, respectively. We tested this hypothesis by running a backward masking experiment with four types of targets and five types of masks. On each trial the observer identified the location of a known target in a field of three distracters. Some target/mask combinations produced monotonic masking functions, while others produce u-shaped masking functions. A second experiment verified that target identification at the shortest SOAs was related to the visibility of the target in the integrated target/mask percept. The target and mask stimuli were presented together in a visual search experiment, which measured RT for detecting the presence or absence of the target among the distracters. Across the different target/mask combinations RT correlated strongly with percent correct identification of the target at the shortest SOAs in the masking experiment ($r = -0.90, -0.87, -0.87$) for each of the three observers. This relationship suggests that the shape of the masking function is determined by the effect of temporal integration of the target and mask.

766 Visual Backward Masking: Feed-forward or Recurrent?

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In the past years there has been a renewed debate on the mechanisms of backward masking. Some of the existing models assumed that masking occurs by the interactions between two feed-forward processing streams (e.g. Breitmeyer, 1984). The recently introduced object substitution model assumes that masking occurs in recurrent architectures in which the mask replaces the target representation (Di Lollo et al., 2000). Here we show that a 2-dimensional, one-layer Wilson-Cowan type model, which relies on lateral connections only, is able to describe a broad range of masking effects. These effects include masking by light, noise, pattern, and shine-through masks. The model mimics processing in the visual area V1 and comprises an excitatory and an inhibitory layer only. Neural activities corresponding to the edges of an object are dynamically enhanced while inner elements are suppressed. In the model, masking occurs when edge and target activity interfere with each other. When homogeneous structures of the mask are filtered out before corresponding neural activities can interfere with the target activity, masking is diminished. On the basis of our model simulations we propose that masking effects occurs during basic early visual information processing such as object contour detection. At least some masking phenomena can be described by a single

layer network without the need for interactions between feed-forward processing stages or between higher and lower-level areas.

767 Spatially localised distortions of perceived duration

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We investigated whether the apparent duration of a flickering test pattern can be modified locally through adaptation to flicker (Johnston, Arnold & Nishida (2003) Perception, 32, Suppl. 46-47). Subjects judged the durations of intervals containing 10 Hz sinusoidal modulation of spatially localised 2D Gaussian profile luminance blobs (s.d.: 1.15 deg of visual angle). The adaptation stimulus was either 5Hz or 20Hz Gaussian flicker, centred 9.2 deg to the left or right of fixation. Adaptation was followed by two consecutive test intervals with test stimuli being shown on both the adapted and unadapted side. The order of presentation was randomised. Subjects reported which of the two appeared to last longer. The duration for one 10Hz stimulus was fixed (250, 500 or 750ms) while the other was varied systematically (Standard duration +/- 60%) to measure a psychometric function. The point of subjective equality provided a measure of perceived duration after adaptation. We found that perceived duration decreased after 20Hz with little change after 5Hz adaptation. The duration aftereffect was not a consequence of changes in apparent temporal frequency as it remained when test and standard were matched in temporal frequency. Adaptation to oscillating motion of drifting (20 Hz) sine gratings also reduced apparent duration for test gratings (10 Hz) that were either parallel or orthogonal to the adapting grating and consequently less subject to contrast adaptation. The findings implicate the spatially localised temporal mechanisms of early visual processing in duration encoding for the subsecond range.

768 Detection of dual flashing lights

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Flashing lights are often employed to increase visibility and safety. In the transportation industries and aviation there has been great effort invested in improving safety lights. Among the proposed design innovations is one in which lights appear to move (phi motion). There has been evidence that phi motion increases the salience of warning lights particularly for vehicle brake lights. Phi motion may also improve detection of warning lights at a greater distance such as with aircraft wingtip strobe lights. We tested the effect of phi motion on detection of small targets.

The intensity-thresholds of dual flashing lights were tested. A target with dual flashing lights was shown on a 1/f noise background generated on a 17 inch CRT monitor. The sizes of the target (distance of two lights) were over the range of 0.5 to 3 degree. The duration of light was 100 ms and different flicker rates were tested (10-20 Hz). The target was randomly presented in one of 4 quadrants, at 10 degree in the periphery. Subjects fixated a point on the center of monitor and judged in which quadrant the target appeared. A 4 AFC and two-staircase method was used to obtain thresholds. We compared in-phase flashing, out-of-phase flashing conditions and a steady lighting condition as a control.

Our results indicate that detection of dual flashing lights in the near periphery is not improved by a 180 degree temporal phase shift that induces phi motion over the range of conditions that we tested.

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769 How Do Motor Acts Change Time Perception?

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Traditional psychophysical studies deliver stimuli to a subject at a time of the experimenter's choosing, not the subject's. But critically different results emerge when a participant's motor act is involved - especially as regards the perception of time. We here report results on motor and sensory integration using a novel psychophysics, fMRI, and modeling. Consistent with previous studies, we found that simultaneity judgments for 2 intra-sensory stimuli (e.g., 2 flashes) were more precise than for cross-sensory stimuli (e.g. a flash and a bang). In both cases the window of simultaneity is symmetric: a flash coming within ~100 ms of a bang - in either order - will be judged simultaneous. But the story changes when motor acts are involved. When participants judged their keypress against flashes, simultaneity judgments were asymmetrical: participants were extremely sensitive to stimuli that preceded their keypress, but called stimuli up to 120 ms after their keypress simultaneous. This finding is consistent with the precision of operant learning mechanisms that are optimized for causality. Next, participants reported how much before or after their keypress a flash occurred. Although these intervals were judged accurately if the flash came from -200 to 0 ms before their keypress, interval determination of a flash from 0 to 120 ms after their keypress was impaired: all intervals in this region were reported to be close to 0 ms. Our psychophysical data can be captured by a model involving neural pooling and opponent-processing. This model also explains what happens during temporal adaptation (e.g., injected delays between action and sensation), which represents a temporal analogue to the motion aftereffect. We thus hypothesize that identical neural mechanisms underlie judgments of both time and space, allowing analogous illusions in both domains. Including motor acts in time perception informs related issues of prediction, prior expectation, and internal models.

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770 Neural correlates of conscious flicker perception

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Beyond the Critical Flicker Fusion (CFF) threshold, flickering light is perceived as fused, so multiple physical events are perceived as a single, continuous event. Little is known about the brain mechanisms underlying such temporal parsing of perception; and many previous studies of flicker perception have compared frequencies above and below threshold, thus confounding physical stimulation with perceptual outcome. Here, we used event-related functional MRI to measure brain activity in response to a single LED flickering at or around the individually adjusted CFF threshold in thirteen participants. Conscious perception (flickering or fused light) therefore varied while physical stimulus parameters were kept constant. On each trial participants reported whether they perceived the light emitted by the LED to be flickering or fused, with catch trials controlling for response bias. Behaviorally, an equal number of trials were perceived to be flickering and fused. For physically identical stimuli, greater brain activation was observed on flicker (versus fused) trials in regions of left parietal and prefrontal cortex previously associated with psychological processes of time estimation. In contrast, greater activation was observed on fused (versus flicker) trials in occipital extrastriate areas. Our findings indicate that the integration of temporally discrete visual events may occur relatively early in the visual pathway, while the activity of higher-level cortical mechanisms may be important in separating such events into distinct percepts in time.

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771 Illusory reversal of action and sensation elicits neural conflict response

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After participants adapted to a delay between their keypress and a flash, they experienced the illusory perception the flashes appearing at shorter delays preceded their keypress. When participants perceived these illusory reversals, BOLD signal increased in the dorsal anterior cingulate cortex, as compared to trials in which the participants perceived the veridical timing. This activation suggests conflict between two timing representation in the brain - one which adapts to the delay between action and effect, and one which does not. Other areas activated in this task - including the insula, inferior frontal gyrus and supramarginal gyrus - may be locations involved in time perception. We show that these areas may relate to a new psychophysical finding: humans have poor interval determination between action and effect up to 120 ms after they perform an action. That is, although motor-sensory intervals were judged accurately if the flash came from -200 to 0 ms before their keypress, interval determination of a flash from 0 to 120 ms after their keypress was impaired: all intervals in this region were reported to be close to 0 ms. The onset and offset of this 120 ms period could be shifted by adapting participants to a frequent 100 ms delay between their keypress and a flash. Collectively, these results indicate a plastic mechanism by which organisms can quickly recalibrate motor-sensory timing.

Talk Sessions

May 10, 2005 – Tuesday AM

3D Visual Processing (772-777), Visual Search (779-784), Color, Lighting, and Objects (785-790), Scene Perception and Inattentive Blindness (791-797)

3D Visual Processing

8:30 - 10:00 am

Hyatt North Hall

Moderator: Laurie Wilcox

772 D-max for stereopsis in human infants.

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Infants can perceive 3D shape from horizontal binocular stereo cues only after age 264 months. Is this late emergence because of an overall immaturity of the spatial aspects of early visual processing? If infant receptive fields are uniformly extra-large (under a phase-based model), or if infant vision compares visual information over large distances within the visual field (under a position-based model), d-max is predicted to be larger for infants than for adults.

We studied the stereoptic detection of large values of binocular disparity by infants aged 12-20 wks, using forced-choice preferential looking. We measured detection of a 3-D target portrayed by horizontal binocular disparity (crossed or uncrossed, 0.2 deg/0.3 deg) within a random texture, compared to a 'catch trial' stimulus portrayed by an equal value of vertical binocular disparity. We used 2AFC to collect control data on adults. 12-wk-olds showed no evidence of binocular stereopsis at any disparity value. Stereopsis emerged as infant performance improved over the range 0.5 deg/0.1 deg, and infants over age 13 wks generally had stereopsis. Infant and adult performance was remarkably similar for binocular disparities of 1deg, 2 deg and 3 deg. Neither infants nor adults correctly detected a horizontal binocular disparity of 3 deg.

The d-max for stereopsis is 2 deg/0.3 deg, and is about the same for infants and adults, starting as soon as binocular stereopsis can be measured. Under a phase-based model of stereopsis, we find no evidence of uniformly larger receptive fields serving as the basis of binocular stereopsis in infants. Under a position-based model, we find no evidence that infants compare binocular information over larger distances than adults. Our experiment provides no evidence of any immaturity in the purely spatial aspects of early visual processing in infants. Some other immaturity, for instance insensitivity to contrast, especially at high spatial frequencies, must explain their poor stereopsis.

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773 Random-dot stereopsis is highly immature in infants

Anthony M. M. Norcia (amn@ski.org), Chuan Hou¹; The Smith-Kettlewell Eye Research Institute

The visual cortex contains cells that are selective for both horizontal and vertical binocular disparity, but only horizontal disparities give rise to a sense of depth in the central visual field. Here we used Visual Evoked Potentials (VEPs) and dynamic random dot stereograms to study disparity processing in adults and in 63 infants between 2 and 6 months of age.

METHODS. We compared VEP disparity response functions for horizontal and vertical disparities. The use of dynamic random dot patterns ensured that no monocular cues were visible. Disparities were modulated sinusoidally across a 50 deg field over a wide range of disparities (0.25-64 arcmin). In the case of horizontal disparity, a corrugated depth surface was visible binocularly. No depth was seen with vertical disparities, rather a weak sense of banding was present for disparities larger than about 5 arcmin. The disparity corrugations were presented either in appearance/disappearance mode or in disparity reversal mode where the disparity sign of the corrugation was inverted.

RESULTS. In adults, the response to the appearance of a horizontal-disparity corrugation was much larger than to its disappearance or to the reversal of disparity. In infants these responses were all comparable in amplitude. In adults the threshold for horizontal disparity was about 0.25-0.5 arc min, but infant thresholds were much higher (4-10 arcmin). Critically, infant disparity response functions for vertical disparities were very similar to those for horizontal disparities. In adults, there was no measurable response to vertical disparities smaller than about 5 arcmin, but horizontal disparities produced a robust response that extended down to 0.25-0.5 arcmin.

CONCLUSIONS: Infants are sensitive to horizontal and vertical disparity, but we find no evidence for the greater sensitivity to horizontal disparity that is characteristic of adults. On this criterion, infants lack stereopsis, suggesting that they may perceive depth on the basis of other cues.

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774 The contribution of binocular and monocular texture elements to depth ordering

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While once considered simply a source of noise in binocular images, recent experiments show that monocularly visible elements that are consistent with the sign of a depth discontinuity improve depth perception (Gillam & Borsting, Perception, 1988; Nakayama & Shimojo, VR, 1989). This improvement is evident in simple (Pianta & Gillam, VR, 2002) and complex (Wilcox

et al. JOV suppl, 2003) stereoscopic displays. However, we do not know how this monocular signal is combined with other cues. To this end, the experiments described here evaluate the relative contribution of monocular elements and disparity to depth perception. We used random dot stereograms and a 2AFC paradigm to assess the contribution of monocular elements and disparity to ordinal depth judgments. Experiments 1 and 2 used suprathreshold stimuli and demonstrated that when monocular elements alone signalled a discontinuity depth perception was poorer than in conditions where disparity was presented alone or conflicted with the monocular cue. We posited that the monocular signal is used when disparity is unreliable. In Experiment 3 we measured the minimum amount of contrast needed to see depth via disparity and then measured percent correct in a depth ordering task at threshold and at 1.5 times threshold. At threshold, performance was the same in the monocular and the disparity alone conditions. When contrast was increased slightly, performance improved in the monocular conditions (with or without disparity) relative to the disparity only condition. We conclude that if a reliable disparity signal is present it will be used to make depth ordering judgments; the presence or absence of a valid monocular signal does not influence performance. However, if the disparity signal is weak, then the monocular information is exploited to make depth judgments. Significantly, we have found no evidence of summation of disparity and monocular signals suggesting that this process cannot be modeled as a weighted average of the two cues.

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775 Distance judgements based on Rayleigh Scattering: The detection of color changes with distance in blue-yellow opponent channels.

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Rayleigh scattering causes distant objects to appear bluer than their nearer counterparts. The phenomenon is exploited by landscape painters who add a blue tint to representations of more distant objects. Using calibrated cameras (Parraga, Troscianko and Tolhurst, 2002, *Current Biology*, 12, 483-487) we measured the chromatic properties of near and far surfaces in natural images of mountains, hills, meadows and railway tracks. RGB values for pixels were translated into cone-activity values and in turn these were translated into values in Blue-Yellow opponent space ($BY = (S-Lum/2)/(S+Lum/2)$). Regressions were calculated for each category of natural scene and the mean slope was derived ($\Delta BY = 0.000068 \cdot \text{meters}$) revealing an increase in blue pixel activity of approximately 235% over 4000 meters. In a psychophysical study the sensitivity of observers ($n = 3$) to these color changes was measured. The results confirmed that observers could detect changes in color caused by shifts in distance of as little as 200 meters. We conclude that while L and M cones have wavelength sensitivities optimised for the detection of fruit and for the removal of shadows (Parraga et al 2002), the relative wavelength sensitivity of the S cone results in a BY opponent system that is efficient at the discrimination of distance, even when all other cues are removed. This may be related to the benefits, on an evolutionary timescale, gained from having the ability to discriminate distances where other cues are removed, for example in savannah and desert.

776 Disparity and texture gradients are combined in a slant estimate and a homogeneity estimate

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Different combinations of depth cues are relevant for different perceptual judgments. For judgments of slant, disparity and texture gradients should be combined in a weighted sum. For judgments of texture homogeneity, the slants specified by disparity and texture should be compared; this can

be accomplished by subtracting one from the other. An analogous transformation occurs in color vision where L- and M-cone signals are added in luminance channels and subtracted in color-opponent channels. We asked whether the same occurs with disparity and texture signals. Specifically, are disparity and texture actually combined in a weighted sum for slant estimation and in a subtraction for judging texture homogeneity? And is access to the disparity and texture signals themselves lost in the process? To answer these questions, we presented planes whose slants were defined by disparity and texture gradients. There were three types of trials (conducted in different sessions). 1) 3-interval "oddy", in which three stimuli were presented, one (or two) at a base slant with no conflict between disparity and texture, and two (or one) with a conflict between disparity and texture (but the same values). Observers indicated the interval containing the 'odd' stimulus. 2) 2-interval "slant", in which two stimuli were presented, one with conflict and one without. Observers indicated the interval containing the greater slant. 3) 2-interval "homogeneity", in which two stimuli were again presented, one with conflict and one without. Observers indicated the interval containing the texture that was more compressed on one side. The slant and homogeneity thresholds predicted the oddity thresholds. This is consistent with the hypothesis that disparity and texture cues are indeed added to estimate slant and subtracted to estimate texture homogeneity, and that access to the disparity and texture signals themselves is lost in the process

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777 Functional Neuroanatomy for the Processing of 3D Shape from Shading and Texture in Humans

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Using the same set of 3D objects defined either by texture or shading we investigated whether the 3D shape is extracted from shading and texture in the same or different cortical areas. The 3D visual stimuli depicted randomly shaped roughly spherical objects. Functional images of the whole brain of twelve human subjects were obtained with a 3T MR scanner (Philips).

In the shading experiment the surfaces of the visual stimuli were based on Lambertian shading. One set of 3D shapes and five sets of matched control stimuli that appeared perceptually as a 2D luminance patterns were created. Random effect analysis was applied to compare 3D to all 2D conditions and masked inclusively by 3D versus each of the 2D conditions from the group (fixed effect). We found bilateral activation in the posterior inferior temporal gyrus (post-ITG) and right middle fusiform gyrus (mid-FG). In the second experiment the object surfaces were filled with random dot patterns. Two types of 3D surfaces and four 2D controls were used. In analyzing the results of this experiment, we performed the same analysis as in the shading test. Within this activation pattern, only 6 regions reached the strict significance criterion: LOS and post ITG, symmetrically in the two hemispheres, and two dorsal parietal regions: DIPSM and DIPSA activated only in the right hemisphere.

There was a more extensive activation when subjects viewed 3D objects defined by texture in comparison with viewing 3D shapes based on shading. The activation patterns overlap however in post ITG, completely in the left hemisphere and partially in the right hemisphere. These results underscore the importance of the posterior part of the LOC complex for the extraction of 3D shape information, in agreement with earlier studies (Orban et al 99, Amedi et al 2001 and James et al 2002).

Visual Search

8:30 - 10:00 am

Hyatt South Hall

Moderator: Ruth Rosenholz

779 A Surprise Theory of Early Attention

Laurent Itti (itti@usc.edu)¹, Pierre Baldi²; ¹University of Southern California, Departments of Computer Science, Psychology and Neuroscience Graduate Program, ²University of California, Irvine, School of Information and Computer Science and Department of Biological Chemistry, College of Medicine

Attention in biological and artificial systems rapidly selects important information from within massive sensory inputs, a process key to survival. When time lacks for detailed sensory analysis, finding important information must rely on heuristic or approximate computations. To quantitatively characterize these computations, we propose a Bayesian definition of important information we call surprise. Surprise quantifies how data affects a natural or artificial observer, by measuring the difference between prior and posterior beliefs of the observer. We argue that surprise subsumes and extends previous often ad-hoc notions of stimulus saliency and novelty, casting them into a single theoretical framework derived from first principles. To test this, we measure the extent to which ten image-based metrics that highlight different facets of important information may predict gaze recordings of four human observers watching 50 complex videoclip stimuli, including television broadcast and video games (about 30 minutes in total). At the target location of each of the 10,192 saccadic gaze shifts recorded, compared to at random locations, we evaluate intrinsic visual properties of the video clips using the ten computational metrics, including a surprise metric. Extending previous findings, but for dynamic scenes, we find that humans preferentially gaze towards locations where local entropy, contrast, information, color, intensity and orientation responses are higher than expected by chance (sign tests, $p < 1.0E-100$ or better). Furthermore, metrics computing dynamic image features like flicker, motion, saliency and surprise correlate even better with human eye movements. Out of all metrics, surprise significantly stands out as best-scoring (t-tests, $p < 1.0E-100$ or better). Our data shows that guiding attention towards intrinsically surprising stimuli is an efficient shortcut to important information.

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780 A Computational Form of the Statistical Saliency Model for Visual Search

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Previously (Rosenholtz, Vis. Research, 1999; Perception & Psychophysics, 2001), we have presented the Statistical Saliency Model for visual search. This model says that an item in a display is salient if its feature vector is an outlier to the local distribution of feature vectors, according to a parametric statistical test for outliers. In particular, saliency is given by essentially the number of standard deviations between a given feature vector and the local mean. A simple model -- that visual search is easier the greater the saliency of the target -- has been shown to qualitatively predict the results of a number of search experiments involving low level features such as color, motion, and orientation.

We will present a computational form of the Statistical Saliency Model, which operates on arbitrary images, and consists of biologically inspired mechanisms. As with preattentive texture segmentation (Rosenholtz, Proc. ECCV, 2000) there need not be a dichotomy between models that are statistically inspired and those that are biologically inspired, nor between models based upon the desired *function* of a saliency computation, as opposed to its implementation in neural hardware. Where statistical models of perceptual phenomena are appropriate, as, we argue, in visual search, deriv-

ing models based upon what the brain tries to do, and why, as opposed to how it might do it, can lead to fewer free parameters, with more intuitive interpretations, and easier design of experiments to determine those parameters. The Statistical Saliency Model was designed with an eye towards the brain's purpose (detect outliers or unusual items) as opposed to its possible neurocomputational mechanisms, yet its statistical test may be implemented using such mechanisms.

781 Human and optimal eye movement strategies in visual search

Wilson S. Geisler (geisler@psy.utexas.edu), Jiri Najemnik; University of Texas at Austin

To perform visual search, the primate visual system uses eye movements to direct the fovea at potential target locations in the environment. What are the rational eye movement strategies for a foveated visual system faced with the task of finding a target in a cluttered environment? Do humans employ rational eye movement strategies while searching? To answer these questions, we derived the Bayesian ideal visual searcher for tasks where a known target is embedded at an unknown location within a background of 1/f noise. Next, we measured the detectability (d') of our target across the human retina, and constrained the ideal searcher with the same d' map. We find that this ideal searcher displays many properties of human fixation patterns during search. For example, both the spatial distribution of human fixation locations and the distribution of human saccade lengths are similar to the ideal. We also find that humans achieve nearly optimal performance in our task, even though humans cannot integrate information perfectly across fixations. By analyzing the performance of the ideal searcher we show that, in fact, there is only a small benefit from integrating information perfectly across fixations--much more important is efficient parallel processing of information on each fixation and efficient selection of fixation locations. To test the importance of fixation selection we simulated searchers that do not select fixation locations optimally, but are otherwise ideal. We find that humans substantially outperform the searchers that select fixation locations at random (with or without replacement), allowing us to conclusively reject all possible random search models. The searcher that always fixates the most likely target location achieves near-optimal performance, but distributes its fixations across the search area in a spatial pattern that differs from human and ideal (which are very similar).

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782 Visual search: The perils of rare targets

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In laboratory visual search tasks, targets are typically presented on 50% of trials. However, in many important real-world search tasks (e.g X-ray screening at airports, surveillance, routine screening in radiology), target-present trials are rare. Miss errors on these tasks can have serious consequences. We mimicked this situation in the laboratory by having Os search for targets (tools) amongst other objects (not tools) and varying the percentage of target-present trials. When targets were present on only 1% of 2000 trials, Os missed 42% of targets, far more than the 6% missed when the same targets were present on 50% of trials. In order to help real-world searchers avoid these catastrophic miss rates, we need to understand how the structure of the task influences error rates. Models of target-absent trials propose that that Os set quitting criteria based on implicit and explicit feedback about their performance. They search longer after an error and terminate unsuccessful searches more quickly after accurate responses. These adaptive search termination rules become maladaptive when targets are rare. In our experiments, Os came to terminate target absent trials with average RTs that were shorter than the average time needed to find targets on target-present trials. Can we ameliorate this situation? Again, we asked Os to search for tools among other objects. As in the first experiment, the

critical target tool (for example, a drill) only appeared on 1% of the trials. Other tools were targets on 49% of the trials. Under these conditions, in which Os were responding "yes" about as often as "no", the error rate for critical rare targets dropped to 21% - a substantial improvement though far from ideal. Keeping Os' search termination criteria properly calibrated may lead to major increases in accuracy on tasks where accuracy really counts.

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http://www.ski.org/Verghese_Lab/laura/

783 Features underlying visual search asymmetry revealed by classification images

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The underlying mechanism of visual search asymmetry remains unclear. Many accounts attribute the asymmetry to features used in visual search, but features are usually not clearly defined. For example, in a case of O and Q, asymmetry may reflect different target-defining features (e.g., circle and crossing), or asymmetry in search for presence and absence of a common feature. To overcome this limitation, classification image technique was employed to estimate which visual features were used in searching for O and Q. Three observers viewed displays with 1 target and 3 distractors, either O (1.9 degree diameter ring) or Q (O plus 0.9 degree vertical bar), embedded in white Gaussian noise, each located on a corner of an imaginary diamond at 3.8 degree eccentricity, and were asked to localize the target. Classification images were constructed from error trials, where the target and selected distractor images were treated as miss and false alarm images, respectively. Both Q- and O-target conditions revealed the same feature, the vertical bar, and the asymmetry reflects the amplitude of the feature, which is larger for O-target than for Q-target. This amplitude difference reflects the strength of noise canceling the bar feature. Regardless of the target, only noises in Q stimuli were correlated with response. Thus, 3 Q's in O-target condition is more likely to have a noise strong enough to lead to an error, than a single Q in Q-target condition. Furthermore, singleton search task showed results similar to the target defined version, suggesting stimulus-driven mechanisms. Search asymmetry between O and Q does not reflect different target-defining features. Also, contrary to the idea that search for feature absence is more difficult than search for its presence, the presence of a feature is more vulnerable to noise than its absence. Difficulty in search for O is not due to search for feature-absence itself, but due to many error-prone feature-present distractors.

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784 Top-down Inhibition of the Response to an Irrelevant Popout Stimulus in Monkey Parietal Cortex

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Salient stimuli usually capture attention and the eyes in a stimulus driven manner. However, subjects can withhold saccades to such stimuli, especially when they are irrelevant to the task at hand. We have shown that activity in monkey LIP correlates with saccadic behavior during free visual search (Gee et al., VSS2005). We now show that after a monkey has learnt that a popout stimulus is irrelevant, the response in LIP is reduced. We recorded from LIP neurons while monkeys performed a visual search task in which they reported the orientation of a target by making a non-spatial manual response. The target was embedded in a radial array of 7 distractors that closely resembled the target, one of which popped out by virtue of color and luminance. The monkeys were free to move their eyes in any direction throughout the trial. We have previously shown that after a block of trials in which the target pops out, the monkeys adapt to a block

in which a distractor, but never the target, pops out by greatly reducing the number of saccades to the now irrelevant popout. In about 95% of the current trials, the monkeys directed their first saccade away from the popout distractor and to the target or to one of the non-popout distractors. When the first saccade was made to a non-popout distractor the next saccade rarely if ever went to the popout. We found that the activity in LIP discriminated early between the popout and non-popout distractor in the receptive field, with the popout evoking a smaller response than the non-popout distractor. This discrimination occurred both when the monkey made a saccade to the receptive field and when it made a saccade away from the receptive field. These data suggest that an early top down mechanism suppresses LIP's response to a salient stimulus which the monkey has learned is task-irrelevant, and is therefore less likely to be the target of the next saccade.

Acknowledgment: National Eye Institute, James S. McDonnell Foundation, Whitehall Foundation

Color, Lighting, and Objects

10:30 - 12:00 pm

Hyatt North Hall

Moderator: Anya Hurlbert

785 Color appearance and the material properties of three-dimensional objects

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Purpose. What determines the color appearance of real objects viewed under natural conditions? The light reflected from different locations on a single object can vary enormously, even when the object is made of a uniform material. One source of variation is inhomogeneity in illumination; another is that the relative contributions of diffuse and specular reflectance change across the object. Yet humans have no trouble assigning color names to most things. We have begun to study how this works. Methods. Subjects viewed a graphics simulation of a three-dimensional scene containing two spheres, test and match. The subject's task was to adjust the match sphere until its color appearance was the same as the test sphere. The match sphere was always matte, and subjects varied its color by changing the simulated diffuse spectral reflectance function. A variety of test sphere materials were simulated by varying the strength and roughness of the specular reflectance component. This was done using Ward's parametric BRDF model. The test sphere's diffuse reflectance component ('body color') was also varied. Scenes were rendered as stereo pairs using RADIANCE, combined with custom software that ensured spectral accuracy. Subjects viewed the stereo pairs on a calibrated computer-controlled haploscope. To date, data have been collected from two non-naïve observers. Results & Conclusion. For fixed test sphere body color, observers' matches depend on the simulated test sphere material. The data thus reject the hypothesis that perceived object color depends only on the object's diffuse reflectance. A successful theory of object color appearance will need to account for the interaction between material properties and perceived color. One plausible conjecture is that the matches depend only on the spatial average of the light reflected from the test sphere. The data reject this simple possibility. Indeed, the diffuse reflectance of the test predicts matches better than the spatial average.

Acknowledgment: Supported by: NIH Grant #EY10016

786 Spatiochromatic statistics of natural scenes: First- and second-order information and their correlational structure.

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Few studies have investigated the structural relationships between modeled neural images of the luminance, red-green and blue-yellow post-receptoral channels in response to natural scenes. Here we examine these relationships for both first-order, i.e. luminance and color, and second-order, i.e. texture and contrast, variations in a set of natural color images.

Images collected using a calibrated digital camera were transformed into LMS cone responses for each pixel, which were then converted into luminance, red-green, and blue-yellow channel images. Simulated responses of cortical first- and second-order operators were produced by convolution with linear filters (Gabor functions) or filter-rectify-filter operators, respectively, for a wide range of filter orientations and spatial frequencies. Filter response amplitudes and image statistics (kurtosis and entropy) were examined, as well as 'signed' and 'unsigned' cross-correlations between the three first-order channel images and between the first- and second-order channel images.

The results demonstrate that first-order red-green has a higher kurtosis/entropy than blue-yellow, which in turn has higher values than luminance. Correlations between first-order luminance and first-order color information are surprisingly high. Additionally, first-order luminance and color are strongly correlated with second-order luminance, but not second-order color. These results suggest that higher-order chromatic statistics play a distinct role in natural images.

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787 Color Discrimination of Natural Objects

Thorsten Hansen (Thorsten.Hansen@psychol.uni-giessen.de), Karl R. Gegenfurtner, Dept. of Psychology, University of Giessen

Discrimination of different chromatic hues is a fundamental visual capability. Traditional measurements of color discrimination have used patches of a single homogeneous color. Everyday color vision however is based on natural objects which contain a distribution of different chromatic hues. Here we study chromatic discrimination using photographs of various natural fruit objects

In a 4AFC experiment, four stimuli were briefly presented on a CRT monitor in a 2x2 arrangement. Three of the stimuli were identical (test stimuli) and the fourth one (comparison stimulus) differed. The stimuli were either homogeneous patches of light, or digital photographs of fruit objects (banana, orange, etc), and were displayed on top of a homogeneous background whose chromaticity was also systematically varied. The mean color of the comparison stimulus was varied along 8 different directions in color space from the test stimulus. Discrimination thresholds were measured along these 8 directions and ellipses were fitted to the resulting threshold contours.

In agreement with earlier studies, we found that discriminability was best when the test stimuli had the same average color as the adapting background. However, when fruit objects were used as stimuli thresholds were elevated and threshold contours were elongated in a way that reflected the distribution of hues in the image. For test stimuli that had an average color different from the background, threshold contours for fruit objects and homogeneous patches were identical.

We conclude that the distribution of hues within natural objects can have a profound effect on color discrimination and needs to be taken into account when predicting discriminability.

788 Representing Spatially and Chromatically Varying Illumination Using Spherical Harmonics in Human Vision

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When light sources are distant, they can be represented as a spectral power distribution on a Debevec sphere (DS; Debevec & Malik, SIGGRAPH, 1997). In natural scenes, this distribution can be complex, and the light absorbed by a matte surface can vary with surface orientation. We previously reported that observers discount orientation changes in 3D scenes lit by a diffuse blue and a punctate yellow source (Boyaci et al, JOV, 4, 664-679). Observers effectively estimated at least some aspects of the DS.

In a spherical harmonics expansion of the DS, only the first nine low-pass components contribute appreciable light to matte surfaces (Basri & Jacobs, IEEE/PAMI, 2003). Here we examine whether the visual system makes use of this physical constraint to simplify representation of illumination. We asked observers to carry out an achromatic setting task for matte patches varying in orientation with full-pass and matched low-pass DSs. If performance were the same in full-pass and matched low-pass scenes, we could conclude that the visual system uses only the low-pass.

Methods: Stimuli were binocularly-viewed rendered 3D scenes. We chose four DSs, two full-pass consisting of two yellow punctate light sources and a blue diffuse source, and two corresponding low-pass approximations with nine components. Test patch orientation was varied and observers adjusted the color of the test until it was perceived to be achromatic; 7 naive observers repeated 9 orientations and 4 DS conditions 20 times.

Results: Under the low pass approximations observers did not compensate as well for changes in orientation. We conclude that the visual system makes use of high-pass information in estimating the DS. We propose a two-stage model: the visual system estimates the illumination using its full spatial spectrum, and then at a second stage retains only the low-pass representation for the illumination in estimating the surface color of matte surfaces.

Acknowledgment: Grant EY08266 from the National Institute of Health; Grant RG0109/1999-B from the Human Frontiers Science Program

789 Representing the spatial and chromatic distribution of the illuminant in scenes with multiple punctate chromatic light sources

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Introduction: In previous work, we demonstrated that observers, making achromatic settings for a lambertian surface patch at different orientations, systematically discount the relative contributions of a yellow punctate light and a blue diffuse light as patch orientation changes (Boyaci et al. JOV, 4, 664-679, 2004). We concluded that the observer's visual system effectively estimated a representation of the spatial and chromatic distribution of the illuminant. In this study, we investigate whether the visual system can represent and discount more complex spatial and chromatic distributions of illumination.

Methods: The stimuli were computer-rendered 3D scenes, containing a rectangular test patch at the center. Observers viewed stimuli in a stereoscope. Scenes were illuminated by a composition of a diffuse blue and two yellow punctate sources placed symmetrically about the observer's line of site and either 90 degrees apart or 160 degrees apart. A blue diffuse and single yellow punctate source condition was included as a control. The orientation of the test patch was randomly varied among 9 orientations from -60 deg to 60 deg. On each trial the observer adjusted the color of the test patch until it was perceived to be achromatic. We analyzed the amount of relative blue in the observers' achromatic setting as a function of test patch orientation. Six naive observers repeated each orientation x light condition

20 times. We fit a generalization of the equivalent lighting model (ELM) developed in Boyaci et al. to predict settings at each test patch orientation for an ideal observer with imperfect knowledge of the spatial and chromatic distribution of illuminants.

Results: Observers systematically discounted the relative contribution of diffuse and punctate light sources at the various test patch orientations for all illuminants. We conclude that the visual system effectively represents complex lighting models that include multiple punctate sources.

Acknowledgment: Grant EY08266 from the National Institute of Health; Grant RG0109/1999-B from the Human Frontiers Science Program

790 If it's a banana, it must be yellow: The role of memory colors in color constancy

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Color constancy is a robust phenomenon most likely mediated by multiple mechanisms, operating at different levels in the visual system. Hering (1874) suggested that in the natural world, the memory colors of familiar objects may influence the extent to which their colors remain constant under changes in illumination. Here we test this hypothesis using a setup which preserves the natural binocular and monocular cues to 3D shape, while allowing us to adjust the apparent color of real objects. **Method.** The objects were solid, matt-white-painted styrofoam fruits and vegetables arrayed on a white board (70cm x 50cm) contained within a black box (100cm x 80cm x 60cm) and illuminated by a hidden data projector. Each trial consisted of two phases, separated by a 10-sec blank interval. In the test phase, observers briefly viewed an array containing a test object (either a generic dome or familiar fruit - here, a banana) and a reference disk, under the reference illuminant (D65). In the matching phase, the observers viewed an array of 5 colored flat disks, from which they selected the best match to the remembered test object's color. The illuminant in the matching phase was either D65 (memory task), D40 or D145 (constancy tasks). The test object's color varied between trials. 4 observers took part.

Results. In the memory and constancy tasks for the banana, matches for yellow test colors were shifted toward more saturated yellows, while matches to bluish and purplish test colors were shifted towards blue. The matches to identical test colors for the generic dome showed no such shifts, but instead were almost perfectly color-constant. **Conclusion.** The results are consistent with the notion that the banana's 'canonical' yellow memory color interferes both with immediate perception of its real color, and with the constancy of that real color under changing illumination. Color constancy does not depend solely on sensory mechanisms.

Acknowledgment: Unilever plc

Scene Perception and Inattentional Blindness

10:30 - 12:15 pm

Hyatt South Hall

Moderator: Dan Simons

791 Attentional set as a contributing factor in virtual traffic accidents

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Attention research has revealed powerful effects of preparatory attentional set. For example, when people seek targets containing certain properties, other stimuli containing those properties are particularly likely to capture attention (Folk et al., 1992). Similarly, unexpected stimuli matching a person's 'set' are particularly likely to be noticed (Most et al., 2005). To date,

however, the real-world generalizability of such laboratory findings has rarely been explored. We introduce a program of research using a virtual reality driving simulator to explore the potential role of attentional set in traffic accidents. In driving situations, even small delays in response time can have drastic consequences. Participants navigated at a constant speed through a virtual cityscape, where each intersection contained a sign with arrows indicating the route to be followed. One group of participants was instructed to follow blue arrows while ignoring yellow arrows, and another group was instructed to follow yellow arrows while ignoring blue arrows. At a critical intersection, an oncoming yellow motorcycle veered into the participants' lane and stopped suddenly in their path. Consistent with our hypothesis, participants attending to yellow arrows were substantially faster to brake to avoid the yellow motorcycle than were those attending to blue arrows, demonstrating a role for attentional set in the processing of unexpected obstacles while driving. We discuss these findings within the context of an ongoing program of research, as well as the importance of such paradigms for underscoring the relevance of attention research to everyday real-world concerns.

792 The roles of attention, memory, comparison failures, and decision making in top-down influences on change detection

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Beck, Angelone, & Levin (2004) demonstrated that changes that are likely to occur in the real world (probable changes: e.g., a lamp changing from off to on) are detected more frequently than changes that are unlikely to occur in the real world (improbable changes; e.g., a blue lamp changing into a green lamp). Top-down knowledge may influence CD performance by directing attention to some aspects of the scene over others. Alternatively, top-down knowledge may influence the memory representations, the probability of comparing representations, and/or the probability that a change signal will be discounted during a post-perceptual decision process. We examined these possible explanations using the same stimuli from Beck, et al., (2004). Participants' eye movements were monitored during a CD task for probable and improbable changes and during a memory test for the scenes. Eye movement data revealed that when a change was detected, more time was spent looking at the change area of the scene prior to the change than when the change was not detected. However, selective attention does not appear to be the cause of the change probability effect, because probable and improbable change areas were examined equally often even though probable changes were detected more frequently than improbable changes. Memory performance revealed equivalent memory representations for both types of changes, and explanations of false alarms to no-change scenes were no more likely to be descriptions of probable changes than improbable changes. Therefore, it appears that both types of changes are attended and represented equally and that a post-perceptual decision process is not the cause of the effect. In support of these findings we found implicit CD (longer fixation durations on the change area when the change was not explicitly detected) for only the probable changes. Therefore the change probability effect results from a failure to compare the pre- and post-change representations for improbable changes.

793 Robust Inattentional Blindness

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Inattentional Blindness (IB) is the failure to see the presence of an item when it is not attended. Previous studies (e.g., Neisser & Becklen, 1975; Mack & Rock, 1998) relied on having the observer attend to one part of a visual display and then presenting an unexpected--and thus unattended--part that the observer is subsequently queried about. But the need for an unexpected stimulus creates problems. For example, the test stimulus is unexpected only the first time it appears, making extensive exploration of IB difficult. And at the theoretical level, it leaves open the possibility that

IB is not really a failure to see the stimulus, but rather is a failure to remember it long enough to be queried about it (Wolfe, 1999).

To address these concerns, a 'locked onset' technique was developed in which a test stimulus appeared the moment the observer attended to some other part of the display. In each trial, observers viewed a set of items that briefly appeared and then made a sudden change; a test stimulus then appeared in the center of this display on half the trials. Observers were asked to report whether the monitored items did or did not change uniformly, and whether the test stimulus appeared. The onset of this stimulus was locked to the moment the monitored changes occurred, so that attention could not be easily given to it. Detection rates therefore indicate whether or not observers are blind to an unattended stimulus even when it is expected.

Results showed blindness rates comparable to those reported in previous studies, even when there were 192 trials per observer, and test stimuli were displayed for 400 ms. Since observers were prepared to respond to the test stimulus, this shows that IB is due to a failure to see rather than a failure to remember. These results also suggest that the locked onset technique may form a simple and practical basis for the exploration of IB.

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794 Undetected Transformation of One Scene Into Another of the Same Gist

Anthony C Sampanes (bruceb@ucsc.edu), Bruce Bridgeman¹; Department of Psychology, University of California, Santa Cruz

Change blindness experiments suggest that rather than integrating the information in one visual fixation with the next fixation, only a few attended objects and a general gist are carried over from one fixation to the next. This result leads to a startling prediction: if perception of attended objects can be suppressed, it should be possible to exchange one image for a completely different one of the same gist without an observer noticing the change. We test this prediction with a new change blindness paradigm; rather than alternating back and forth from one image to another in the flicker paradigm, we progressively alter segments of an image until one image is completely changed into another, a 'progressive transformation paradigm'. To avoid misalignments of parts of the old and the new images we superimpose a checkerboard of white squares on the image, then swap old image segments for new ones within each checker, so that the changed area is completely surrounded by white. It is possible to swap several checkers at a time without subjects detecting the change, with a complete swap in about 12 steps. Each stage is presented for 1 sec, with a 60 msec blank between images. We suppress detection of changes in details with a fixation target on the left of odd-numbered images in the sequence, and on the right in even-numbered images, while monitoring eye movements. We apply this technique with several pairs of same-gist images, such as two different beaches, two different bus stops, two different white cars parked in different lots, etc. In half the trials, the image is not changed. Subjects fail to detect the image swap in about 1/3 of change trials; when detection occurs, it tends to occur late in the sequence. Control change trials, transforming to an image of different gist, are detected at a 98% rate. We conclude that gist is stored as a general description, not as a detailed image.

795 Induced Fading of Natural Scenes

Daniel J Simons (dsimons@uiuc.edu)¹, David P Slichter², Alejandro Lleras¹, Susana Martinez-Conde³, Gabriel Nevarez¹, Eamon Caddigan¹; ¹University of Illinois, ²Harvard University, ³Barrow Neurological Institute

Prolonged fixation leads to fading of a peripheral target (Troxler, 1804). Moreover, fading can be induced more rapidly in other contexts: yellow disks disappear when presented against dynamic background elements (Bonneh et al., 2001), colored circles disappear as a function of attentional modulation (Lou, 1999), and display transients near a target induce fading (Kanai & Kamitani, 2003). We have found that full-color, low-pass filtered photographs of natural scenes fade to a uniform hue and luminance in less

than 30 seconds when observers maintain fixation. Moreover, fading is more complete and more rapid when transient high-contrast splotches flashed repeatedly on the display. Here we show that perceived fading of scenes is induced by the offset of high-contrast splotches superimposed on the scene but not by the onset of such splotches. Given that the appearance of splotches does not induce fading, our results are not readily explained by transient-induced fading. Because the fading can be induced nearly instantaneously in some conditions, it does not appear to reflect a slow adaptation process such as Troxler fading. Finally, we find that the presence of static splotches does not facilitate fading, suggesting that the results are not readily attributable to contrast gain-control settings. Instead, building on May et al (2003), we argue that the fading of entire scenes can be induced by a contrast decrement. Most of our induced scene fading effects are sufficiently robust that they can be experienced in a single trial.

796 Forgetting visual versus conceptual information about pictures

Mary C Potter (mpotter@mit.edu), Laura F Fox¹; Massachusetts Institute of Technology

When photographs of natural scenes are shown in a rapid serial visual presentation at 6/s, more than half can be recognized if tested immediately, but over the next few seconds of the test many are forgotten (Potter, Staub, Rado, & O'Connor, 2002). When the test consists of titles of the pictures (e.g., "cut up fruit") performance is similar to tests using pictures, except that at the beginning of the test performance with pictures is significantly better than with titles (Potter, Staub, & O'Connor, 2004). Could this be because visual information (as cued by a picture test but not by a title) is forgotten more rapidly than conceptual information (as tested by titles and pictures)? Subjects viewed five pictures plus a mask at 6/s and were tested with titles. Either early or later in the test, after deciding whether a given title corresponded with a presented picture, the subject was given a forced-choice test of some visual property of the picture. In Experiment 1 the test was a question such as "What color was the flower?" (purple, orange white). In a second experiment the test required a choice between two versions of the picture, one identical to the original and one altered by changing a color, left-right orientation, or the like. In neither experiment was there a significant effect of test position on accuracy, contrary to the prediction that visual information would be remembered better when the test came early. Implications for the abstract nature of picture memory will be discussed.

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797 The depth of distractor processing in search through clutter

Mary J Bravo (mbravo@crab.rutgers.edu)¹, Hany Farid²; ¹Psychology, Rutgers Camden, ²Computer Science & Cognitive Neuroscience, Dartmouth College

Background clutter can make it difficult to segment whole objects. This is especially true for compound objects, which have parts made from different materials (e.g., a table lamp). We reported earlier that when observers search for a category target in dense clutter, search is slower when the distractors are compound objects rather than simple objects. This result is consistent with two interpretations. In the first, observers reject distractor parts, and this process is slow for compound objects because they have multiple parts. In the second, observers reject whole distractor objects, and this process is slow for compound objects because they are difficult to segment. In the present search experiment, we used familiar and chimerical distractors to distinguish between these alternatives. Familiar distractors were drawn from a set of 100 color photographs of everyday objects. Each of these objects had at least two clearly delineated parts. Chimerical distractors were created by exchanging parts between objects. Observers searched for a target defined by its membership in a broad category (e.g., animal) or categories (e.g., animal or vehicle). We found that when target uncertainty was high and target recognition was difficult (e.g. the target was partially occluded, randomly rotated or drawn from two categories),

search times were significantly slower for chimerical distractors than for normal distractors. This difference suggests that for some search tasks, observers recognize and reject whole objects. This difference was greatly reduced, however, when the target was unoccluded, upright and drawn from a single category. For this simpler search task, observers may reject object parts. In sum, the demands of the search task determine the depth of distractor processing required, and this determines whether observers recognize and reject whole distractor objects.

<http://vision.arc.nasa.gov/personnel/al/talks/04vss/>

Poster Session G

May 10, 2005 – Tuesday AM

Binocular Vision/Eye Movements (798 - 805), Reading and Print (806-820), Faces 2 (821-836), Motion 3 (837-853), Object Recognition in Context (854-862) Perceptual Learning 2 (863-874), Sensory Integration: Vision and Hearing (875-890), Visual Cortical Organization (891-909)

8:30 am - 1:30 pm (Authors present 12:00 - 1:30 pm)

Municipal Auditorium

Binocular Vision/Eye Movements

798 Binocular summation of color and luminance contrast gratings

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Binocular luminance contrast thresholds for stimuli with the same spatial configuration are lower than monocular thresholds. Binocular color contrast thresholds follow a similar pattern but have not been studied in great detail. The current experiment measured binocular summation for luminance gratings that modulate the L and M cones together (L+M gratings), and color gratings that modulate the L and M cones with opposite sign (L-M gratings).

Five subjects used the method of adjustment to determine monocular and binocular detection thresholds for contrast reversed (at 4 Hz) 1 cycle per degree gabor patches (with a 1 degree space constant). Thresholds were determined for horizontal and vertical gratings, with dichoptic cone contrast modulated either in-phase or out-of-phase. Thresholds were also determined for gratings with crossed orientations in the two eyes. A binocular summation index was computed from the ratio of monocular thresholds to binocular thresholds (a value > 1 indicates binocular summation).

Summation patterns were similar for color and luminance gratings when averaged across observers. The binocular summation index was 1.80 for in-phase gratings; greater than the 1.41 value expected for probability summation. Crossed orientation gratings showed only small levels of binocular summation (a binocular summation index of 1.16). The binocular summation index for out-of-phase gratings was 0.76, indicating that binocular out-of-phase gratings were less visible than the monocular components. This effect was only evident for color gratings in two observers.

The results suggest there is binocular neural summation for dichoptic luminance and color gratings with the same orientation and spatial phase. Luminance and color gratings show destructive binocular interactions for dichoptic gratings with opposite phase in the two eyes. The pattern of binocular summation is consistent with the existence of spatially selective binocular mechanisms for luminance and color.

799 Empirical horizontal horopter determined by fusion time

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We determined the empirical horizontal horopter. The criterion is the position in depth of a test patch of random-dot at which a binocular image is fused most quickly. It is assumed that a binocular test object is fused most quickly after exposure when the object is on the horopter, and that

the method maps corresponding points in the two retina. In our experiment the subject converged on a fixed point at a given distance and made judgements about a test object at each of several directions on either side of fixation point, i.e. peripheral vision. The test object was a flat patch of random-dot consists of a pair of stimuli presented in a stereoscope. The test object was exposed at each of several depths. Depth of the test object was simulated by varying the horizontal disparity between the dichoptic stimuli relative to the fixated object. After each pair of stereograms was exposed, the subject was required to press a switch to indicate fusion. Fusion was described at a state in which the subject could see a clear and single image without fuzziness. The result confirms that the empirically determined horopter deviates from the theoretical ideal.

800 Binocular summation, dichoptic masking and contrast gain control

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We consider a classical question - how signals from the two eyes are combined - in the context of contemporary models of contrast gain control. In 2AFC experiments, observers had to detect the presence of a test grating (1 c/deg, 200 ms) in one or both eyes, in the presence or absence of a similar masking ('pedestal') grating in one or both eyes. We found a high degree of binocular summation when pedestal contrast was low or zero, while at higher contrasts we confirmed Legge's (1984) paradoxical finding that there was no advantage for detecting binocular contrast increments over purely monocular ones. In a new variant, however, we found that, on a binocular pedestal, binocular increments were better detected than monocular ones. This implies that there is binocular summation of test signals even in the suprathreshold task. Importantly, there is also binocular summation of suppressive (gain control) signals: monocular increments were harder to detect on a binocular pedestal than on a monocular one. The pattern of results can be largely, but not completely, understood through a binocular version of the standard gain control equation: $\text{Resp}(\text{binoc}) = (L^p + R^p) / (s^q + L^q + R^q)$, expressing the output of a binocular channel to contrasts L,R in the left and right eyes, with p,q,s constant (p~2.4, q~2). With additive noise, this mechanism correctly predicts the high thresholds and unusually steep, step-like psychometric functions that we observed in dichoptic masking (test in one eye, pedestal in the other). But this mechanism under-estimates both facilitation and binocular summation at low contrasts, so we shall consider what modifications are needed. Viable options include more than one output channel, and more than one stage at which nonlinear transduction and gain control operate.

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801 Two eyes: Twice as good as one?

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In a classic experiment on the detection of simple patterns, Campbell & Green (1965) showed that for both humans and an ideal signal detector, two eyes are only $\sqrt{2}$ better than one eye. If the ideal observer shows only a $\sqrt{2}$ improvement, then how can binocular simple cells (Ohzawa & Freeman, 1986; Smith, Chino, Ni, & Cheng, 1997) show a doubling in contrast sensitivity when given binocular input? We resolve this puzzle by showing that the ideal observer may differ from the Campbell & Green model, and we find that the binocular improvement for detection increases with spatial frequency to a level well above $\sqrt{2}$.

802 Binocular interactions of spatial visual signals in children

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Stereoacuity, an index of binocularity, is almost adult-like by five years of age (Fox et al., IOVS, 1986). The purpose of this study was to determine whether binocular summation, another index of binocularity, is mature in children older than five years of age. Binocular summation refers to the superior visual performance with two eyes when compared to one eye alone, and is usually expressed as the ratio of binocular sensitivity to best monocular sensitivity. We assessed monocular and binocular performance for letter acuity, contrast sensitivity and spatial localization tasks in 10 children between 6-13 years of age and 10 adult subjects with normal vision and binocularity. For all tasks, the stimulus duration was 100ms. Letter acuity was assessed using a computer generated E target. The subjects had to identify the orientation of the letter E (four-alternative forced-choice). In the contrast sensitivity task, a Gabor patch was presented in one of two temporal intervals. The task was to identify the interval in which the Gabor patch was presented (two-alternative forced-choice). In the alignment task, we used three vertically oriented gabor patches. The task was to report whether the middle patch was located to the right or left of the two fixed peripheral patches. Our results demonstrate binocular summation in both letter acuity and contrast sensitivity irrespective of the age groups. Summation ratios did not vary with age in children aged 6-13 years for all three visual functions. The magnitude of binocular enhancement in acuity and contrast sensitivity was similar in children and adults. There was no summation in the alignment task in either age group. Taken together, our results suggest that binocular neural summation of spatial signals mature before six years of age.

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803 Binocular vision and the correspondence problem

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Depth perception is fundamental to vision. It can be achieved by comparing the left and right retinal images, an ability known as stereopsis. To do this the brain must first determine for each point in one retinal image which point in the other originated from the same part of the same object. This issue, known as the correspondence problem, is central to binocular vision since without its solution the input from the two eyes cannot be combined. Despite engendering considerable interest, its resolution by the visual system has remained enigmatic. Here we show that for a scene consisting of a single, long binocular bar some cells in the primary visual cortex (V1) solve this problem. We present evidence that such cells are always endstopped but although endstopping is clearly necessary, on its own it is insufficient to ensure a cell solves the correspondence problem. Furthermore the cells that do match

corresponding points in the two retinal images respond to visual stimuli with a characteristic timecourse. Initially the cells do not solve the correspondence problem and so their initial responses are uninformative but after approximately 120ms a suppressive mechanism develops that ensures that the cells respond only to the horizontal disparity between elements that originated from the same point in the visual environment. Clearly such cells have solved a form of the correspondence problem and so would appear to play a crucial role in binocular vision.

Acknowledgment: We thank Tamara Chuprina and David Freeman for technical assistance, and Bevil Conway, Christopher Pack and Doris Tsao for comments and discussion. This work was supported by a Helen Hay Whitney Foundation grant to P.H. and NIH grant EY 13135 to M.L.

<http://www.psy.vanderbilt.edu/faculty/seiffert/presentations>

804 The Role of Luminance Polarity in Vergence Control

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Background:

In order to understand binocular vision it is important to recognize what features in the stimulus are matched between the 2 eyes. One issue in matching that is of interest is the luminance polarity of the elements—whether a dark line in one eye can match a bright line in the other eye. Helmholtz (1909) showed that line stereograms with opposite luminance polarity can be fused, but Julesz (1971) reported that random dot patterns with opposite dot polarity could not be fused. Masson et al. (1997) reported the vergence system responds to spots with opposite polarity by going the wrong way. Howard (1997) has suggested that the polarity of edges, rather than spots, may be the key feature. In this study we have measured vergence responses to both lines and edges of matched and mismatched polarity in an effort to clarify this issue.

Methods:

A dual-Purkinje eye tracker was used to measure vergence movements to dichoptic targets with same and opposite luminance polarity. The targets were: randomly placed line segments; a single black/white edge; a single Gaussian spot whose luminance was reversed in one half to form a sharp edge; or multiple such Gaussians. Disparity was changed either sinusoidally with 0.50° amplitude at 0.25 Hz, or in a random, jittery fashion. We stimulated horizontal and vertical vergence in separate recordings, and recorded both matched and mismatched target polarities.

Results:

The targets with opposite polarity showed vergence responses that were reliable, but weaker than targets with same luminance polarity. When present, the vergence response was always in the correct direction. This was true even for a single edge with opposite luminance polarity driving vertical vergence.

Conclusions:

Our results show that vergence responses do occur to targets of opposite polarity under conditions in which they cannot be attributed to matching of same-polarity edges or to voluntary control of vergence.

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805 Vertical disparity vergence eye movements: Evidence for spatial filtering of the monocular visual inputs prior to binocular matching

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Vertical vergence eye movements (Vg) were elicited in 3 human subjects by applying vertical disparities to horizontal square-wave gratings lacking the fundamental ('Missing Fundamental' stimulus, MF). Viewing was dichoptic by Wheatstone stereoscope and eye movements were recorded

with the search coil. Stimuli were large (46 deg wide x 30 deg high; spatial frequency: 0.04-1 c/deg) and presented only briefly (200ms). To avoid spatial aliasing, stimuli were synthesized by summing the odd harmonics only up to the Nyquist Frequency (16 c/deg for our display). Disparities were ° of the fundamental wavelength so that the overall pattern and its luminance features (peaks, troughs), together with the 4n+1 harmonics (n=integer), had left-hyper (or right-hyper) disparity, whereas the 4n-1 harmonics, including the strongest Fourier component (3rd harmonic), had the reverse disparity. The earliest Vg had short latency (70-80ms) and were always in the direction of the 3rd harmonic, but their magnitude fell short of those that were elicited when the same disparities were applied to pure sinusoids whose spatial frequency and contrast (32%) matched those of the 3rd harmonic. This shortfall (on average, about 20%) was approximately halved when the MF stimulus lacked the 5th harmonic ('MF-5' stimulus)-indicating a contribution from the next most powerful harmonic-and was completely eliminated when the contrast of the MF-5 stimulus was reduced so that its 3rd harmonic had a contrast of 16% or less-consistent with a contribution from distortion products, which are dominated by the even harmonics (2nd, 4th, 6th, etc) that have zero disparity. In sum, the direction and magnitude of the earliest vertical disparity vergence responses could be attributed entirely to the major Fourier components of the binocular image, consistent with current disparity-energy models in which the monocular visual inputs undergo spatial filtering prior to their binocular matching.

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Reading and Print

806 Memory for Words From Fictional Text Read on Computer Screens and Paper, in Four Polarities

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Does our ability to remember text that we read on a computer differ from our ability to remember text on paper? We examined memory for text read on paper vs. text read on a computer screen. A passage of 380 words of text was read silently for three minutes (black text on white background or white text on black background). Then participants worked on a distractor task (a set of multiplication problems) for four minutes. Following the distractor task, subjects participated in a 20 word memory test (explicit or implicit) for three minutes (black text on white background or white text on black background). We failed to replicate last year's finding (which used a one-minute distractor task) that subjects recall more words when the background for text of passages and word stems are white rather than black. We found no difference between the four polarity conditions, $F(3, 105) = 0.52, p > .05$. We found that subjects remembered fewer words on computer than on paper, 21 vs. 27 percent correct, $F(1, 35) = 6.42, p < .05$. There was no interaction, $F(3, 105) = 0.31, p > .05$. For four polarities and two memory tests, subjects remembered fewer words on computer than paper. We discuss the implications of these findings in context of roles that familiarity of media, distractor time, and polarity have on implicit and explicit memory.

807 Changes in the Visual Span May Explain the Effect of Letter Spacing on Reading Speed

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Purpose: Chung (IOVS, 43, 2002, 1270-1276) has shown that RSVP (Rapid Serial Visual Presentation) reading speed varies with letter spacing, peaking near the standard letter spacing and decreasing rapidly at smaller spacing. This pattern was linked to the crowding effect which refers to the

interference in letter recognition from adjacent letters. It has been proposed that the size of the visual span - the number of letters recognized with high accuracy in a single fixation - is a visual factor limiting reading speed. We predict that the size of the visual span and reading speed will show a similar dependence on letter spacing. We tested this prediction for RSVP reading, and asked whether it generalizes to the reading of flashcards composed of blocks of text.

Methods: Five normally sighted adults participated. Visual span profiles, measured with trigrams (strings of 3 random letters with designated spacing), are plots of letter-recognition accuracy as a function of letter position left or right of the midline. Size of the visual span was defined as the area under this profile, converted to bits of information transmitted. Reading performance was measured using 2 presentation methods: RSVP and flashcard (a 56 character long sentence arranged in 4 lines). Four letter spacings (0.5x, 0.707x, 1x, 2x 'standard spacing') and two print sizes (0.088 and 0.158) were used.

Results: Sizes of the visual span and reading speeds measured by the two presentation methods showed a qualitatively similar dependence on letter spacing for the two print sizes, and were highly correlated (correlation coefficient ranges from 0.710 to 0.999 and the median is 0.908) across 5 subjects.

Conclusions: The high correlation between reading speed and size of the visual span is consistent with the view that spacing effects on reading speed are due to changes in the size of the visual span.

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808 Multi-word buffering during bilingual bidirectional reading as evidenced by saccade direction reversals

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The study of eye movements in reading is among the earliest field of oculomotor research. During reading, the text is scanned by means of saccades separated by periods of fixation during which the information is acquired. The saccades are several letter-lengths long, and at each fixation several characters are acquired. English is read from left-to-right thus most of the saccades are rightward and the perceptual span is asymmetric to the right. Hebrew is read from right to left and thus the saccades are leftward and the asymmetric span is asymmetric to the left of the fixation point.

In modern Israeli society numerous English words are embedded within Hebrew text, especially in scientific and technical texts. In addition, in Israel the same numerals are used as in the West, and are read from left to right. Herein we present the results of a study of eye movement during the reading of Hebrew texts in which English words, phrases, and/or numbers are embedded within Hebrew sentences.

Subjects included both native English speakers and native Hebrew speakers and were instructed to read once silently the text presented. Subjects sat 70 cm in front of a 19" monitor on which were displayed 2 or 3 lines of text, with the "X" character subtending 0.43 deg. Eye movements were recorded monocularly at 120 Hz using the ISCAN video based system.

Results show that when subjects encountered a left-to-right phrase, they reversed directions and read from left to right only for unfamiliar terms. A familiar multi-word term is acquired backwards. The later, indicates the existence of a low level buffer that can store and reverse words within a single phrase.

809 Crowding, shuffling, and capitalizing reveal three processes in reading

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Meshing ideas from the reading literature with our work on crowding, we present a three-process model of reading to account for reading rate in word/min. We use crowding to distinguish holistic vs by-parts recognition. In crowding there is a *critical spacing* beyond which neighbors no longer interfere. If the object is recognized *holistically*, then it can be identified even when the whole object lies within a critical spacing, without isolating any part (Martelli, Majaj, and Pelli, 2004, *Journal of Vision*, in press). If recognition is *by parts* then object identification will be possible only when each part is isolated from the rest of the object by the critical spacing. Words are recognized in three ways: by parts, holistically, and through context. Stimulus degradations - shuffling, capitalizing, and scrambling - each knock out one of the three processes. We call the processes L, W, and S, which stand for Letter, Word, and Sentence. We characterize reading as identifying words, one after another. All three processes - L, W, and S - identify words. They differ in what part of the stimulus they use to identify the word. L does it on the basis of word content (i.e. the letters), W does it on the basis of word shape (i.e. holistic), and S does it on the basis of word context (i.e. the rest of the sentence). We have measured the contributions of these three recognition processes to RSVP reading as a function of location in the visual field. Preliminary results find that the W process contributes 50 word/min everywhere, the S process contributes 100 word/min everywhere, and the L process contributes 210 word/min centrally, but only 5 word/min in the periphery. These numbers make sense. The letter-decoding process (L) makes the biggest contribution, as expected from the learning-to-read literature, and is available only in central vision, as expected from crowding. Peripheral reading is much slower because only W and S contribute.

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810 Developmental Changes in the Visual Span for Reading

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Purpose: Previous research has suggested that the size of the visual span—the number of letters recognizable in a glance—imposes a fundamental limit on reading speed (Legge, Mansfield, & Chung, *Vision Research*, 41, 725-734, 2001). The present study investigates developmental changes in the size of the visual span in school-age children, and the potential impact on children's reading speed. **Method:** The study design includes groups of 10 children in 3rd, 5th, and 7th grade, and 10 adults. Two print sizes (0.258, 1.08) and two exposure times (100ms, 200ms) were used. To measure visual spans, participants were presented with trigrams (random strings of three letters) flashed briefly at varying letter positions (0 to 5) left and right of the fixation point. Over a block of trials, a profile was built up showing letter recognition accuracy (% correct) versus letter position. This profile was fit by a split Gaussian model, and the results were used to estimate the size of the visual span (area under the profile) for the four combinations of print size and exposure time. For each participant, visual acuity and reading acuity were assessed with the Lighthouse Near Acuity Test and MNREAD chart respectively. **Results:** Preliminary findings indicate that children have significantly smaller visual spans than adults ($F(1, 72) = 14.66, p < 0.05$). There was also evidence for increasing visual-span size across increasing grade level. We also found that 200ms exposure time yielded a larger visual span than 100ms. However, no significant print size effects or interactions among age, print size, and exposure time were found. **Conclusion:** These results show that there are significant developmental changes in the size of the visual span from grade school to adulthood. The findings are consistent with the view that the growth of the visual span plays a role in the development of reading speed in children.

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811 Deficits in Forming Perceptual Templates May Underlie the Etiology of Developmental Dyslexia

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Formation of optimal phonological and orthographical templates is critical for speech perception and reading. A general deficit in forming perceptual templates distorts speech perception in infancy, retarding development of phonological categories. It can also affect letter recognition and encoding of letter patterns and sequential redundancies. The behavioral signature for non-optimal perceptual templates is reduced ability in processing information embedded in high external noise ("TV snow"), compared to normal behavior in processing clean signals without added external noise (1). In this study, we compared contrast sensitivity of dyslexic and non-dyslexic children using sine wave gratings designed to activate either magnocellular (M) or parvocellular (P) processing. The gratings were either displayed without noise, or embedded in a noise patch. Dyslexics had higher contrast thresholds than non-dyslexics when the gratings were displayed in high noise, in both the M and P versions. Dyslexics performed as well as non-dyslexics, however, when the gratings were displayed without noise, again in both M and P versions. In addition, contrast thresholds in high external noise conditions correlated with language measures, as well as word reading and orthographic measures. Dyslexics with language impairments tended to have the highest thresholds. The same pattern of results was obtained in several related studies using different tasks. Our results suggest that dyslexic children may have a general deficit in forming perceptual templates instead of having just magnocellular deficits. The inability to form optimal perceptual templates primarily impairs language development, which may in itself contribute to deficits in phonological processing.

¹Lu, Z.-L., & Doshier, B. (1998), *Vision Research* 38, 1183-1198.

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812 Preventing Dyslexia? Early Enhanced Hand-Eye Coordination Activities Reduces Reading Difficulties

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Persons with developmental dyslexia were shown to have wider visual perceptual strategy (recognition of letters) than ordinary readers (e.g. Geiger et al. 1992, Lorusso et al. 2004). Dyslexic children and adults who practiced a regimen comprising hand-eye coordination activities and reading with a mask, improved reading dramatically while their perceptual strategy narrowed (Geiger et al. 1994, Geiger et al. VSS 2001).

Given that this practice alleviates dyslexia, we asked: would small-scale hand-eye coordination activities, given to all the children at early stages of learning to read, reduce the number of those with severe reading difficulties? Would it impart to them the right perceptual strategy for reading?

We conducted a study in a Boston public school during the last three years with 188 students from K-2, first and second grades. Students in each grade level were randomly assigned to two groups: experimental and control. The experimental groups started every school day with 40 minutes of hand-eye coordination activities in the form of arts and craft. At the same time the control groups performed general school activities. The reading assessments were made with the Developmental Reading Assessment (DRA) test that the teachers administered three times each year. At the end of the second grade the students were also measured for their strategy of visual perception.

For the K-2 the DRA is not sensitive enough to indicate differences. In three consecutive years, the experimental groups of the first grade had

significantly fewer students at risk for reading compared with the control groups (19% to 29%; $p < 0.04$). In the second grades the differences were larger.

These results suggest that early practice of hand-eye coordination activities reduces the risk for reading difficulties. The results also support the notion that neural tuning can be narrowed by practice (Geiger et al. VSS, 2004) thus providing the students with an effective perceptual strategy for reading

813 Isolating the Role of Visual Perception in Dyslexia

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Despite the current prevalence of phonological theory of dyslexia, there are several theories (e.g. the magnocellular hypothesis) that attribute an important role to visual deficits as a basis for dyslexia. These theories stem from introspective reports of many dyslexics of visual discomfort while reading and are further supported by findings of various visual deficits in dyslexic subjects. However, these findings were argued against and largely explained as resulting from impaired perceptual memory rather than poor immediate perception. To assess the role of (possibly impaired) visual perception in dyslexics' reading, we composed a task that was as similar as possible to normal reading in all its visual characteristics, but lacked all the other aspects of reading (phonological, semantic etc.), and compared performance of dyslexics and controls on it under several paradigms. The task was to identify a letter of an alphabet unknown to subjects, but similar to Hebrew and English in all graphical details (10 similar Georgian letters). Eight different conditions were assessed, measuring threshold duration of presentation (SOA) and threshold contrast levels for identification of small and large letters, with and without flanker letters, with and without white noise. Twenty adult native-Hebrew speaking dyslexics, mainly students, and 20 controls, matched for gender, age, and general cognitive abilities, participated in this study. We found all the predicted effects in both groups. Namely, adding flankers and decreasing letter size increased threshold SOAs, and adding white noise increased contrast thresholds. However, there was no difference between the experiment group and the controls, neither in single-set comparison, nor in effect magnitude, nor in an all-inclusive analysis of variance (MANOVA $d=0$; $p>0.9$). We conclude that the visual processing deficits found among dyslexic individuals by other researchers do not affect reading performance, and that therefore, the cause of their reading deficit resides elsewhere.

814 Use of spatial frequencies information in normal readers and a letter-by-letter dyslexic patient.

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We employed the Bubbles technique (Gosselin & Schyns, 2001) to examine the use of spatial frequencies in normal ($N = 10$) and letter-by-letter ($N = 1$) reading. Each stimulus sampled either an individual letter, or one of 2,000 four-to-seven-letter words (one letter spanned 0.38 deg of visual angle \times 0.6 deg of visual angle) by dot multiplying their Fourier spectrum with white Gaussian noise convolved with a Gaussian function (Std = 0.156 of the Nyquist frequency). Accuracy was 97% on average for normal readers and of 71 % for LH, a so-called letter-by-letter dyslexic. Multiple linear regression was performed on reading latency and sampling noise. We found that normal letter identification is mediated by a single frequency band centered at 3 cycles per letter (see also Solomon & Pelli, 1994), and normal word reading, by another, partly overlapping, frequency band peaking at 1.6 cycles per letter. We found a different pattern of results for LH: in letter recognition, he uses a frequency band centered at 1.9 cycles

per letter and, in word recognition, a somewhat narrower frequency band centered at 1.6 cycles per letter. Our results suggest that letter-by-letter reading is caused by a deficit in using the spatial frequencies normally associated with letter recognition and that this deficit is exacerbated in word recognition. We will argue that spatial frequencies around 3 cycles per letter are necessary for the explicit word identification, and that lower spatial frequencies are responsible for the implicit effects found in normal and pathological reading.

815 Why is light text harder to read than dark text?

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Scharff and Ahumada (2002, 2003) measured text legibility for light text and dark text. For paragraph readability and letter identification, responses to light text were slower and less accurate for a given contrast. Was this polarity effect (1) an artifact of our apparatus, (2) a physiological difference in the separate pathways for positive and negative contrast or (3) the result of increased experience with dark text on light backgrounds? To rule out the apparatus-artifact hypothesis, all data were collected on one monitor. Its luminance was measured at all levels used, and the spatial effects of the monitor were reduced by pixel doubling and quadrupling (increasing the viewing distance to maintain constant angular size). Luminances of vertical and horizontal square-wave gratings were compared to assess display speed effects. They existed, even for 4-pixel-wide bars. Tests for polarity asymmetries in display speed were negative. Increased experience might develop full letter templates for dark text, while recognition of light letters is based on component features. Earlier, an observer ran all conditions at one polarity and then switched. If dark and light letters were intermixed, the observer might use component features on all trials and do worse on the dark letters, reducing the polarity effect. We varied polarity blocking (completely blocked, alternating smaller blocks, and intermixed blocks). Letter identification responses times showed polarity effects at all contrasts and display resolution levels. Observers were also more accurate with higher contrasts and more pixels per degree. Intermixed blocks increased the polarity effect by reducing performance on the light letters, but only if the randomized block occurred prior to the nonrandomized block. Perhaps observers tried to use poorly developed templates, or they did not work as hard on the more difficult items. The experience hypothesis and the physiological gain hypothesis remain viable explanations.

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816 The effective use of spatial frequencies through time in reading

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We used the Bubbles method (Gosselin & Schyns, 2001) to examine the effective use of spatial frequencies through time in a reading task. Ten participants viewed a total of 2600 dynamic stimuli. Each stimulus sampled one of 2,000 four-to-seven-letter words (one letter spanned 0.38 \times 0.61 deg of visual angle \times 180 ms) by dot multiplying their Fourier spectrum with a 2D white Gaussian noise field convolved with a Gaussian function (Std's = 0.156 of the Nyquist frequency and 25 ms). The subjects' accuracy was maintained at 50% correct by adjusting, on a trial by trial basis, the surface under the sampling noise. Multiple linear regression was performed on response accuracy and sampling noise. Subjects showed an early use of a narrow band of spatial frequencies centered at 1.6 cycles per letter. Around 40 ms following the stimulus onset, another band of spatial frequencies centered at 3.0 cycles per letter became useful. These results show that two bands of spatial frequencies are important for visual word identification and suggest a two-step process: low spatial frequencies

would activate a subset of word attractors and mid-spatial frequencies, known to be useful for letter recognition (Solomon & Pelli, 1994; see Fiset, Chauvin, Dupuis-Roy, Blais, Arguin & Gosselin, VSS, 2005), would add fine grain letter information to complete word recognition.

817 Critical role of phonological encoding in midstream order deficit

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The midstream order deficit (MOD) is a phenomenon that accuracy in recalling the relative order in a cycling visual sequence is much lower than when the sequence is presented just once (Holcombe, Kanwisher, & Treisman, 2001). The occurrence of MOD interested in how the relative order is encoded. Chiba & Yokosawa (2003) reported that phonological and visual codes played different roles in order encoding. In this study, to prevent phonological encoding of relative order, four characters with the same pronunciation were used within each target set. By this manipulation, we were able to examine whether MOD would need for phonological encoding. Japanese Kanji characters were used as stimuli, because they have many homophones. Participants were required to report the relative order by connecting the printed characters on the response sheet using arrows. In both experiments, MOD disappeared when the Kanji characters had the same pronunciation, suggesting a critical role for phonological encoding in MOD. In experiment 1, when the stimulus sequence was presented after memorization of the four Kanji characters, the accuracy of the recall of order in both the single and cycling conditions was higher. However there was not the MOD effect. In experiment 2, it is also examined whether MOD would occur when performance improved. It takes longer processing time for a complex character like a Kanji character than for a simple character. A slow final item duration was used in experiment 2. However MOD still was not found. The results contradict the explanation that the disappearance of MOD was related to task difficulty. It is summarized that MOD disappeared when the Kanji characters had the same pronunciation, suggesting an important role for phonological encoding in MOD. The robust MOD effects found with the verbal reports in Chiba & Yokosawa (2003) support this suggestion.

818 Recognition of Chinese Characters: The Effects of Stroke Frequency and Critical Band Masking

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Purpose: Many studies of reading and visual recognition of familiar figures have used Roman-alphabetic letters. While conclusions drawn from such studies have practical value, their theoretical application may be limited due to the uniform complexity of the stimulus set. Hieroglyphic script elements such as Chinese characters (CC) have a wide range of complexity and thus elicit more informative data. In this study a standard CC battery was built. Acuity and critical band noise masking were measured using CC and English Sloan letters (SL) and results were compared. **Methods:** The 500 most frequently used CC were divided into 6 groups by the number of strokes. From each group, 10 CC with uniform inter-character Euclidian distances were chosen. Acuity thresholds for the 60 CC and 10 SL were obtained from young, native Chinese readers who had at least 10 years of education in reading English. Recognition contrast thresholds for CC in the 2-4, 10-12, and 16-18 stroke groups as well as for SL were measured in band-passed white noise of various peak spatial frequencies and 1-octave bandwidth. **Results:** Acuity character size for CC increases linearly but slowly with stroke frequency (stroke/char). Mean acuity sizes for the 2-4 stroke and the 16-18 stroke groups are 4.4 and 6.5 arcmin. Acuity sizes for the 2-4 stroke group are similar to those for SL if the stroke width is matched (otherwise, are about 30% larger). Noise masking results suggest that critical bands for the 2-4 stroke group and SL are similar, but the peak spatial frequency of the critical band increases

with increasing CC stroke frequency, and the bandwidth tends to broaden. **Conclusions:** Recognition of CC near acuity thresholds is only partially dependent on stroke frequency; other information such as the globe shape of characters may be utilized. While a single spatial frequency band may suffice for recognition of simple CC, multiple frequency bands are critical for the recognition of more complex CC.

819 Enhancing fonts

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We present a novel method for automatically enhancing (or diminishing) the legibility of typefaces without altering grapheme size or energy. Just as caricature generators enhance those features which most distinguish a targeted face from the average face, we generate an enhanced grapheme by exaggerating those aspects which distinguish that grapheme from an average grapheme. More particularly, we model letter perception with a multidimensional activation-space with each dimension measuring the activity of a unit jointly tuned to a spatial frequency and an orientation. Every grapheme corresponds to a point in the space, and the point is determined by the grapheme's 2D Fourier power spectrum modified to reflect the gain filters found to mediate letter identification in critical bandmasking studies (Solomon and Pelli 1994; Majaj et.al.2002). In this activation-space, points corresponding to frequently confused graphemes are nearby, while those corresponding to graphemes which are easily distinguished are further apart. To enhance the legibility of a single grapheme, say, the numeral '2', we produce a new grapheme which corresponds to an activation-space point roughly along the trajectory passing through the points corresponding to the average numeral and '2', but further from the average numeral than '2'. Thus, our enhanced '2' differs from the other numerals along the same lines as '2', but more-so. The graphemes this process generates are grey scaled, and so, even if for convenience's sake, we 'cookie-cut' an enhanced grapheme so it has the same shape as the original, the new grapheme has a different spatial-frequency profile. To enhance the legibility of a font, we enhance each grapheme in it, and consequently spread the activation-space points associated with the font's graphemes apart, and succeed in generating fonts that are more discriminable in noise.

820 What matters in the matter of variable message sign intelligibility

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The question that we tried to answer is how best to construct a visual message to be seen by passing motorists, albeit briefly, on the so-called 'variable message sign' (VMS). Optimizing the manner in which information is presented would seem to be useful to ensure that a driver is capable of reading and remembering the details within the brief time window during which the sign is readable. (An alternative strategy, forcing the driver to slow to increase that time, tends to increase congestion). Ten observers (Os) were asked to recall the information presented on a series of computer-simulated CMS signs (each of a total possible three lines of 16 characters) displaying unpredictable but comprehensible messages (e.g. 1-800-CALL-CHP; BLK HONDA SUV; LIC 4KGE268). Computer generated movies containing a simulated CMS sign were presented on a computer monitor as if it were being approached, then passed, at 96 KPH. Simultaneously, Os were engaged in a task to load attention as required in driving. They monitored 3 distinct eccentric loci on the same monitor and were asked to indicate when a target letter occurred at one. Independent CMS message variables included modifications in the justification of the text, the presentation of license plate information and notification phone number, the number of frames used, and the length of

time each frame of multiple frame messages was presented. Accuracy of recall upon message extinction was scored (e.g. vehicle type, color, each character of a license plate number, etc. were assigned points). Displaying the information with left-justified text was best ($p = 0.04$, t-test). Characters 'CA' in advance of the license numbers made the license number harder to recall ($p = 0.03$; t-test). Messages are most effective when limited to a single frame. The second frame substantially reduced the observer's ability to reproduce information ($p = 0.01$; t-test). Little things seem to matter.

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Faces 2

821 The role of sleep in perceptual learning of face-identification

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Several reports suggest that perceptual learning derives critically from consolidation processes that are sleep-dependent. We examined the extent to which the performance gains that are typically evidenced with practice on a 10-AFC face-identification task depend on sleep between sessions. The stimuli were faces embedded in one of three levels of external noise, and presented at one of seven different contrasts using the method of constant stimuli. Two separate groups of observers performed the task on a training and test session that was separated by a 12-hour interval. The 'No sleep' group performed the training (9am) and test (9pm) session on the same day, and did not nap between sessions. The 'Sleep' group performed the training session at 9pm and rested overnight before performing the test session at 9am the next day. We assessed the time-course of learning by splitting the sessions into quartiles and estimating proportion correct at each quarter within each session. Both groups performed comparably on the training session and evidenced substantial within-session gains in performance that did not differ as a function of time of day. There was a slight but significant advantage for the 'sleep' group relative to the 'no sleep' group on the test session, but the time-course of learning reveals that gains from within the first session account for a larger proportion of the total improvement found in both groups. Thus, we find that perceptual learning occurs in the absence of sleep and conclude that sleep-related consolidation processes comprise only a small component of learning to identify faces.

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822 200 ms of controversies: a high-density ERP study of face processing

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Most ERP studies of face perception have focused on the N170, an ERP component that is systematically larger for faces compared to objects in the time window 140-200 ms, however, some studies have reported face-specific ERP differences as early as 80-120 ms after stimulus onset. Moreover, the N170 itself remains poorly defined, both in terms of stimulus-specificity and cortical origin. We further examine these issues in a new study, where 16 observers discriminated briefly flashed (80 ms) upright and inverted faces, houses and textures (240 trials per condition), while high-density EEG (256 electrodes) recordings were collected. All stimuli had identical amplitude spectra. To examine the stimulus-differences in ERP across time, a spatiotemporal analysis was performed. Within the time window of the classically defined N170, the N170 was larger to faces than to houses, which was in turn larger compared to textures. Surprisingly, the topographic maps during this time window show a different pattern. Although the topography for faces differed

significantly from that of textures (suggesting the involvement of different cortical sources), it did not differ significantly from houses, a result at odds with recent reports of face specific N170 topographies (Itier & Taylor, 2004; Rousselet et al. 2004). Further, there was no significant difference between topographic maps obtained with upright and inverted stimuli. A significant effect of inversion on face ERP topography does emerge during the earlier time window of 80-150ms, providing evidence for face-specific processing prior to the N170. Finally, preliminary results from source analyses on individual data using a linear distributed model suggests that from 80 to 280 ms, ERPs to faces and houses are generated by a network of cortical areas including ventral and lateral occipital-temporal areas as well as parietal areas.

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823 Eccentricity effects on the N170 face ERP component can be eliminated by size scaling

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The N170 is a posterior negative event-related component that is particularly pronounced for human faces. Earlier studies indicated that the N170 is stronger when faces are presented foveally than when presented peripherally (Jeffreys, 1992; Eimer, 2000). We previously reported that the difference between the N170 evoked by faces and houses diminishes with stimulus eccentricity, and becomes only marginally significant at 108 of eccentricity (Rousselet et al., VSS 2003). Following Jeffreys (1992) this result might indicate that the N170 is a response to fixated faces, involving a foveal bias in the generators of the N170. To more rigorously examine the possibility of a foveal bias in face processing, it is necessary to rule out the possibility that eccentricity based effects may be a simple consequence of the reduced cortical representation of peripherally presented stimuli. Thus, we have re-examined the effect of eccentricity on the N170, controlling for the effect of cortical magnification. We tested 15 observers. Faces and houses (matched for spatial frequency content) were presented for 80ms, either centrally, or at 58 or 108 to the left or right of fixation. Peripherally presented stimuli were presented at one of two sizes (either matched to the central presentation size, or scaled to compensate for differences in V1 cortical representation). There were a total of 18 conditions with 120 trials per condition. As found previously, the N170 was larger in amplitude for faces than for houses, and this difference decreased with eccentricity. However, when faces and houses were enlarged to compensate for cortical magnification differences, the difference in N170 strength between faces and houses re-emerged. Thus, we find no evidence that there is a foveal bias for face processing per se. Rather, eccentricity-based differences in face processing appear to be largely attributable to simple differences in cortical magnification.

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824 Upright & inverted face recognition relies on the same, narrow band of spatial frequencies

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How does information processing differ between upright and inverted face recognition? Previous research from our lab suggests that, in the spatial domain, the differences in processing are quantitative rather than qualitative (Sekuler et al., 2004). Here we ask whether differences exist in the Fourier domain. Previous studies suggest that observers rely on frequency information centered around 9 cyc/face when recognizing upright faces (Nasanen 1999; Gold et al., 1998; Gold et al., 1999). Observers might be worse at inverted face recognition because they rely on a different, or broader range, of spatial frequencies for inverted face

recognition than for upright face recognition. A recent study by Nakayama (VSS 2003) suggests that inverted face recognition might be less selective for frequency than upright face recognition, however spatial frequency tuning was not measured directly. We re-examined the issue using critical-band masking to measure spatial frequency tuning in a 10-alternative face recognition task, for both upright and inverted faces. In agreement with past results, upright face recognition relied on a narrow band channel, ~1.4 octaves, centered at ~8 cyc/face. However, despite the fact that observers required significantly more contrast to discriminate upside-down faces than upright faces, observers used a similar narrow band of spatial frequencies regardless of face orientation. Because our stimuli and task differed considerably from those of Nakayama, additional research is needed to elucidate the nature of spatial frequency selectivity under various conditions. Regardless, our results place strong constraints on how the strategies for upright and inverted face recognition might differ. We propose that the critical difference lies not in which frequencies are used, but in how information is used within a narrow band of frequencies.

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825 The Stickiness of Face Adaptation Aftereffects

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Face adaptation aftereffects have been assumed to disappear rapidly with time and/or interference, as do standard adaptation effects in low-level vision. Our results challenge this assumption. We considered two adapter duration procedures: a 160 s adapter period with separate pre- and post-adaptation phases; and a 5 s adapter period intermixed with post-adaptation trials. Each of these is similar to procedures used in previous studies. Our distortion types involved either radially compressing-expanding a face (where adaptation to a compressed face makes a normal face look expanded), or altering only the spacing between features so that the eyes were shifted up or down the head (where adapting to an eyes-down face makes a normal face appear to have its eyes shifted up). Results showed that, following a 160 s adapter period, significant adaptation survived a 15 min delay filled with visual stimulation; moreover, this occurred when the visual input involved only words and objects, and when many normal undistorted faces were included. For the 160 s adapter, a 24 hr delay removed the aftereffect. Following a 5 s adapter period, significant adaptation survived a 10 s delay including one face for 200 ms and either a normal face or an XXX stimulus for 5 s; indeed, inclusion of the filled delay only approximately halved the effect compared to immediate test. For the 5 s adapter, a 20 s delay with twice the number of intervening stimuli removed the aftereffect. Overall, we conclude that face aftereffects are much 'stickier' than traditional aftereffects. This has important implications for both theory and methodology. In terms of theory, we consider implications for neural coding models of the face aftereffects, and for the way in which the norm of face-space changes in response to recent input. In terms of methodology, our results argue it cannot be assumed that a short delay between testing adapter conditions is sufficient to remove carryover from the previous condition.

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826 Familiarity enhances invariance of face representations in human ventral visual cortex

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Recognition of faces across changing viewing conditions is strongly improved by familiarity. The present study tested the hypothesis that the neural basis of this effect is a less view-dependent representation of

familiar faces in ventral visual cortex, by assessing priming-related repetition effects in functional MRI. 15 healthy volunteers made male/female judgements on familiar (famous) and unfamiliar (novel) faces preceded by the same image, a different image of the same face, or another (unprimed) face. Reaction times revealed priming by same and different images independent of familiarity, and more pronounced for same than different images. In the imaging data, a main effect of prime condition was found in bilateral fusiform and orbitofrontal regions. A right anterior fusiform region expressed stronger response decreases to repetition of familiar than unfamiliar faces. Bilateral mid-fusiform areas showed stronger response decreases to repetition of same than different images. A regions-of-interest analysis focussing specifically on face responsive regions suggested differences in the degree of image-dependency across fusiform cortex. Collapsing across familiarity, there was greater image dependency of repetition effects in right than left anterior fusiform, replicating previous imaging findings obtained with common objects. For familiar faces alone, there was greater generalisation of repetition effects over different images in anterior than middle fusiform. This suggests a role of anterior fusiform cortex in coding image-independent representations of familiar faces.

827 Distributed representation of facial expression in the superior temporal sulcus: an fMRI study

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According to our model of the human neural system for face perception (Haxby et al., TICS, 2000) the face-responsive region in the fusiform gyrus is more involved in the representation of invariant aspects of a face and the recognition of identity whereas the superior temporal sulcus is more involved in the representation of changeable aspects of faces such as eye gaze and expression. To test this model we employed functional magnetic resonance imaging (fMRI; 3T GE) to determine patterns of neural response to face expressions in these two regions. Five healthy individuals performed a one back repetition detection task while looking at faces with different expressions (happy, angry, disgusted, fearful, neutral) and nonsense patterns. Face-responsive voxels were identified in anatomically-defined fusiform and superior temporal sulcal cortex. Expression-related patterns of response in these regions were analyzed using the split-half correlation method (Haxby et al. Science, 2001). Patterns of response that distinguished among expressions were found in the superior temporal sulcus but not in the fusiform gyrus. These results provide further support for the hypothesis that face-responsive cortex in the superior temporal sulcus plays a stronger role than does fusiform cortex in the representation of face expression.

828 Cortical Representation of Faces, Bodies and their Parts

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This fMRI study investigated the visual representation of faces, bodies (without heads), objects and their parts in human cortex. Subjects were presented with images of faces, bodies, objects, face parts, body parts and object parts in an event-related design. Region of interest (ROI) analyses (N=11) showed a significantly higher response to whole faces compared to face parts in right fusiform gyrus and right superior temporal sulcus (STS). In contrast, right fusiform gyrus and extrastriate body area (EBA) responded equally to whole bodies and body parts. The significant effect of whole faces versus face parts but not for whole bodies versus body parts suggests that the representation of faces is more holistic than the representation of bodies.

In a whole-brain fixed-effects group analysis both faces and bodies, each compared to objects, activated the right mid-fusiform gyrus near the fusiform face area (FFA), supporting the results of Peelen and Downing

(2005). Other common activations were found in bilateral STS, bilateral posterior inferior temporal sulcus near the EBA, anterior cingulate cortex, and bilateral inferior frontal gyrus. Direct contrasts between faces and bodies, even at low thresholds ($p < 0.001$, uncorrected), revealed only significant activation in bilateral EBA for bodies, challenging the category-specificity of previously identified face-related activations.

Peelen, M.V., & Downing, P.E. (2005). Selectivity for the human body in the fusiform gyrus. *Journal of Neurophysiology* 93: 603-608.

829 Face adaptation contingent on orientation.

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Adaptation to faces can generate after-effects in the perception of facial configuration, identity, attractiveness, race and gender. Here, we investigate what level of the visual processing hierarchy mediates the effect of face adaptation on perceived gender. Subjects were presented with adapting stimuli alternating between male faces at one orientation and female faces at the opposite orientation. Their task was to report the gender of test faces drawn from a continuum morphed between average male and female faces. We found that opposite after-effects for judgments of face gender can be induced simultaneously for upright and inverted faces such that the point of subjective androgyny is shifted towards the adapting faces of the same orientation. These after-effects are robust to changes in face size between adaptor and test, ruling out adaptation of a low-level encoding mechanism. Opposite after-effects of perceived gender can also be induced for faces tilted + and -90deg from upright. The existence of these orientation-contingent after-effects indicates that dissociable populations of neurons mediating the after-effect at each orientation are susceptible to the same form of adaptive normalization, suggesting that adaptation is occurring at a view dependent stage of face processing.

830 Combining Principal Component Techniques and Psychological Spaces to Find Perceptually Similar Faces

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We explore methods for finding perceptually similar faces by combining unsupervised 'eigenface' techniques with facial similarity ratings obtained from human subjects. We use a set of 1050 face images for which we have obtained the locations of facial features as well as the facial outline. The images are from the internet and exhibit uncontrolled lighting, viewpoint, and resolution. We segment and warp the faces to register the features and extract PCA coefficients from both the warping as well as the appearance of the faces. Previous authors (e.g. Dailey, Cottrel, Busey, 1999) have observed performance gains on facial recognition tasks by utilizing a psychological space obtained from human similarity ratings. We explore whether psychological space may be modeled as a Euclidean space by constructing a mapping function from PCA space to a space which conforms to psychometric similarity judgments. The map is computed in two steps. First, we create an affinity matrix for a set of 750 train images. Similarity trees of 35 images are constructed using a greedy algorithm in which the two most similar faces are repeatedly joined together until every image has been placed in a tree (Rhodes, 1988). Each tree provides a fully ranked 35x35 matrix of distances which is used to populate the affinity matrix. Next, we explore various cost functions and optimize the parameters of the mapping in order to minimize the disparities between the similarity judgments made by subjects and the Euclidean distances of the PCA representations. The performance of the map is measured using a test set of 300 images rated using the similarity tree algorithm. Our performance metric considers the ~25 closest images to a target image. It rewards retrievals which subjects consider close to a target image, while punishing retrievals which are far. Mapping results in performance

increases of up to 20% over Euclidean PCA, indicating that mapping to a psychometric space can result in performance gains.

831 Low Spatial Frequency Channels are More Useful than High Spatial Frequency Channels in Classifying Face Emotional Expressions, Simulation of fMRI Data.

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Vuilleumier, Armony, Driver & Dolan (2003) have shown that amygdala responses to fearful expressions seem to be more activated by intact or low spatial frequency (LSF) faces than high spatial frequency (HSF) faces. The fMRI results suggest that LSF components processed by the magnocellular layers of the lateral geniculate nucleus (LGN) might be conveyed by a subcortical pathway activating the pulvinar, superior colliculus and finally the amygdala. This subcortical pathway was assumed to bypass the striate cortex in order to process LSF components faster than HSF components of visual stimuli. The purpose of the present study is to test the usefulness of LSF information as compared to HSF information and to original stimuli in a visual classification task performed by an artificial neural network. This model links a computational model of visual perception and a back-propagation classifier. The basic idea is i) to compress visual information by means of a perceptual model of vision and ii) to provide a distributed model of cognition with the above mentioned visual inputs. The results show that visual information conveyed by LSF faces, which is processed very fast by the human perceptual system, allows a distributed neural system to correctly categorize fearful or neutral faces. This is not the case for HSF components. These results suggest that high-speed connections from the magnocellular layers to the amygdala might be a fast and efficient way to perform classification of human faces with respect to their emotional expressions.

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832 Effects of image background on spatial frequency thresholds for face recognition.

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A growing number of studies have investigated the question of which spatial frequencies, if any, are optimally useful for face recognition. To our knowledge, all of these studies have used face images with monochromatic backgrounds, usually medium-gray. A potential limitation of this methodology is that it does not accurately reflect the real-world situation to which results are to be generalized. That is, in the real world the visual system must recognize faces against a variety of backgrounds, and the spatial frequencies needed for face recognition may be different in these circumstances than when the background is homogenous. In this study, we investigated the differences in spatial frequency thresholds for face matching across three different types of backgrounds: 1) Monochromatic gray, 2) fractal noise, and 3) natural scenes. Observers were asked to find their matching threshold, using the method of adjustment, in a 4AFC match-to-sample task. That is, four faces were presented at the bottom of the screen, and a high-passed or low-passed face was presented in the middle of the screen. Observers were asked to adjust the cut-off of the spatial frequency filter to the point where they could just match the center face to one of the four comparison faces. Our results show small but consistent differences in threshold according to the type of background surrounding the face. Images with a fractal noise background elicited higher low-pass thresholds and lower high-pass thresholds than did the other two background types. There was no difference between monochromatic gray backgrounds and natural backgrounds. These data support the generalizability of results from studies using monochromatic gray backgrounds to real-world vision.

However, the data also suggest that non-structured backgrounds can produce additional difficulty in recognizing spatially filtered face images. Additional data using the Method of Constant Stimuli are also being gathered.

833 The Dynamics of Visual Adaptation to Faces

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Several recent demonstrations using visual adaptation have revealed high-level aftereffects for complex patterns including faces. While traditional aftereffects involve perceptual distortion of simple attributes such as orientation or color that are processed early in the visual cortical hierarchy, face adaptation affects perceived identity and expression, which are thought to be products of higher-order processing. And, unlike most simple aftereffects, those involving faces are robust to changes in scale, position, and orientation between the adapting and test stimuli. These differences raise the question of how closely related face aftereffects are to traditional ones. Little is known about the buildup and decay of the face aftereffect, and the similarity of these dynamic processes to traditional aftereffects might provide insight into this relationship. We examined the effect of varying the duration of both the adapting and test stimuli on the magnitude of perceived distortions in face identity. We found that, just as with traditional aftereffects, the identity aftereffect grew logarithmically stronger as a function of adaptation time and exponentially weaker as a function of test duration. Even the subtle aspects of these dynamics, such as the power-law relationship between the adapting and test durations, closely resembled that of other aftereffects. These results were obtained with two different sets of face stimuli that differed greatly in their low-level properties. We postulate that the mechanisms governing these shared dynamics may be dissociable from the responses of feature-selective neurons in the early visual cortex.

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834 Middle spatial frequencies are needed for face recognition only when learned faces are unfiltered: More evidence from spatial frequency thresholds for matching.

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A number of studies (Gold, Bennett, & Sekuler, 1999; Nasanen, 1999; see Parker & Costen, 2001 for review) have suggested that middle spatial frequencies (SFs) are optimal for face recognition. A few recent studies (Liu et al., 2000; Collin et al., 2003; Kornowski & Petersik, 2003) have cast doubt on this, suggesting that perhaps spatial frequency overlap is the more important factor in determining how well spatially filtered faces are recognized. The latter studies predict that if learned faces are filtered in the same way as the tested faces, little or no advantage of middle SFs for face recognition will be found. At VSS 2004 (Collin & Martin, 2004), we presented data on SF thresholds for face recognition when comparison faces were unfiltered vs. when they were filtered in the same way as the test face. Those data showed that middle SF are needed for face recognition only when the comparison faces are unfiltered. However, the thresholds were gathered by the method of adjustment, a method thought to be vulnerable to observer criterion shifts. This opened up a potential alternative explanation for our results. Here we present similar data, but gathered by the method of constant stimuli. Observers performed a 4AFC task where they were asked to match a test face to one of four comparison faces. The test face was spatially filtered to a range of low-pass and high-pass cut-offs. In one condition, the four comparison faces were unfiltered. In the other condition, the comparison faces were filtered in the same way as the test face. Our data show that more central SFs are sought out when comparison faces are unfiltered than when they are filtered. These data are

in accordance with our previous study, suggesting that those results were not due to criterion shifts. This suggests that the high efficacy of middle SFs in face recognition is task-dependent and may arise due to interference from non-middle SFs in unfiltered learned images.

835 Adaptation and individual differences in categorical judgments of faces

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Individuals differ in the stimulus boundaries they select for categorizing faces on dimensions such as gender and ethnicity (Webster et al. Nature 2004). We asked whether these differences reflect differences only in criteria or have links to sensory differences in how faces are perceived. To test for these links, we used adaptation to identify the face image that was neutral with regard to the adapting category. Adapting to a male face causes an ambiguous face to appear more female, while adapting to a female face biases appearance in the opposite direction. Thus an intermediate adapting stimulus can be found that does not shift the judgments, and defines the neutral point for the visual processes affected by the adaptation. We tested whether these perceptual neutral points are correlated with subjects' category boundaries before the adaptation. Stimuli were morphs between a male and female face forming a graded series of 100 images. A 2AFC staircase was used to determine the gender boundary in the sequence, before adaptation or after adapting to male/female blends in proportions of 0/1, 2/.8, 4/.6, 6/.4, 8/.2, or 1/0. Adapt stimuli were shown initially for 30 s and then for 3 s before each 0.5 s test trial. The neutral adapt level was estimated from linear fits of the aftereffect vs. adapt level. Results for 23 subjects tested with two face pairs showed comparable ranges of variation in the zero-crossing for adaptation and the subjective gender boundary (though the two means differed), and a significant correlation between the two alternative ways of defining a gender-neutral image ($r = 0.63, p < 0.01$). At intermediate adapt levels near the mean for the group, there was also a high correlation ($r \sim 0.5, p < 0.05$) between the direction of shift and the individual's pre-adapt neutral point. These results suggest that at least part of the variation in how observers categorize faces may depend on actual differences in how faces are perceptually encoded.

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836 Testing for translation invariance reveals two stages of facial adaptation

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Facial adaptation - induced by prolonged exposure to an individual face - can bias the perceived identity of a subsequently presented face. The goal of the present study is to test how presenting the adapter and test stimuli in different hemifields will affect the magnitude of the perceptual facial aftereffect as well as its ERP correlates (i.e. the increase in latency and decrease in amplitude of the N170 component).

Subjects performed a gender discrimination task for peripherally (6 deg) presented facial morphs of upright or upside down presented female and male faces.

Each trial consisted of a 5 sec adaptation period followed by a test face. During adaptation two stimuli were displayed on the two sides of the fixation: within a block they were either both Fourier phase-randomised images (control condition) or one was a Fourier image and the other was a prototypical female face. After 200 msec blank a test face image (chosen from female - male morphed facial image series) was displayed for 200 ms

randomly on either side of the fixation. ERP was recorded from 23 channels. Throughout the experiments fixation was controlled by an infrared eye tracking system.

The psychophysical results showed strong adaptation effect both when the adapter and test images appeared on the same side of the fixation (SAME) as well as when they were presented in different hemifields (DIFF), compared to the control condition. However, the magnitude of adaptation was approximately twice as large in the SAME condition than in the DIFF condition. The adaptation effects on the N170 ERP component followed a similar pattern to that found in the psychophysical data. Interestingly, the behavioural and electrophysiological results were essentially the same for upright and upside down presented faces.

Our results provide evidence that facial adaptation consist of two components - one is translation invariant and the other is not - that might take place at different stages of face processing.

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<http://www.brl.ntt.co.jp/people/takeuchi/v5/index.html>

Motion 3

837 Depth-tuning of occluded moving objects by boundary selection of motion signals.

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The visual system can detect the motion direction of partially occluded objects. During this process, motion signals are assigned an appropriate depth order. For example, a car moving behind a fence is perceived as moving in the background, while the fence is perceived as a static foreground. When both occluder and occluded objects are moving, their motion signals are separated in depth as well. Single cell responses in area MT correlate with the perceived 3D configuration of moving object (Bradley and Andersen, 1998) and show disparity tuning in addition to direction selectivity (Palanca and deAngelis, 2003). A laminar cortical model of form and motion processing predicts how a depth-dependent motion signal can be computed in MT based on an interaction of V2 form projections with motion inputs to MT from magno-dominated cells in layer 4B in V1. The model simulates the shape-dependent percepts of motion behind occluders (Lorenceanu and Alais, 2001), coherent and incoherent motion in the chopsticks illusion, and capture of gelatinous ellipse motion by satellites moving in the same depth plane (Weiss and Adelson, 2000). Because these V2-to-MT projections are continuously tuned in depth, they clarify motion capture across depths, competition between feature-tracking signals located in different depths, and differential effects on motion capture and motion induction under transparent motion conditions (Murakami, 1999). These cross-stream interactions are predicted to share circuitry with top-down intra-stream attentional signals. Supported in part by the NSF, ONR and the NGA.

838 Context Effects in the Perception of Collinear Motions: Spatial Anisotropy and Non-Local Effects of Attention

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When a context motion is perceived in a particular direction (e.g., to the right), its effect on motion perception in that direction depends on whether motion sensitivity is tested "in front of" (i.e., to the right of) or "behind" (i.e., to the left of) the context motion (VSS, 2004). For some subjects, the spatial anisotropy entailed more excitatory influence on a test motion "in front of" the context motion than "behind" it. For other subjects, the spatial anisotropy entailed less inhibition on the test motion "in front of" the context motion than "behind" it. It has been found, in addition, that attention can modify the extent to which interactions among collinear

motions are excitatory or inhibitory. Interactive influences from the context stimulus are less excitatory (or more inhibitory) when attention is focused between the two locations of the test stimulus than when it is spread across the two locations. This result indicates that the effect of attention on motion perception is non-local; it extends far beyond the region where the perceiver is attending. That is, even though attention spread is manipulated in the region of the test stimulus, it affects interactive influences emanating from motion at other spatial locations.

839 Form/Motion Binding with and without Eye-Movements

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Alternations between bound and unbound motion perception of 'aperture stimuli' occur either spontaneously or through external change of critical stimulus parameters known to yield hysteresis. We recorded the transition dynamics of bound and unbound percepts using simple shapes viewed through apertures, and compared these dynamics in conditions of fixation and oculomotor pursuit. Perceptual alternations were induced at a slow rate (0.03 Hz) by smoothly changing parameters known to influence motion binding -contrast, shape, motion noise- or occurred spontaneously with an unchanging stimulus. A red dot, moving in phase with the center of the 'aperture stimulus' or kept stationary in the center of the display, was provided as a target to the oculomotor system. The results indicate different transition dynamics in the 'eyes static' and 'eyes moving' conditions, revealing either the influence of minimized retinal slip or a more general perception/action coupling mechanism. Disentangling these different possibilities was done by varying the phase lag of the target dot relative to the 'aperture stimulus'. Overall, the data indicate that spontaneous and induced perceptual transitions occur in the 'eyes moving' conditions, despite the fact that the retinal slip was minimized by accurate tracking. However, the amplitude of hysteresis and the duration and frequency of alternations is altered by pursuit eye movements, with shorter episodes of unbound percept. The results are discussed in the light of the proposed perception/action dichotomy.

840 Equivalent noise and reverse correlation analysis reveals inhibitory interactions between channels coding global direction

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Convergent evidence supports a two-stage model of visual motion perception: local direction is computed in V1 and these signals are pooled in MT to derive the global motion of large objects. The influence of local and global motion processing can be teased apart using an equivalent noise (EN) analysis, in which direction discrimination thresholds are measured as a function of the directional variability of the stimulus. The ideal observer embodied by EN analysis computes the population vector average (PVA) of the directions present (an increasingly popular model of perceived direction in complex stimuli). If PVA were correct then performance would depend wholly on the degree of directional variability irrespective of the shape of the underlying directional probability density function (p.d.f.). However, we show that the extent of observers' global motion pooling increases as p.d.f.s are made increasingly leptokurtic/"peaky" (while local motion processing is unchanged). Subjectively, more platykurtic ("flatter") distributions induce perceived transparency, and we propose that our estimate of the reduction in global pooling that results is the first objective behavioural measurement of motion transparency (since, unlike previous efforts, it is neither prone to criterion effects nor to subjects relying on directional variance). We also constructed "response classification histograms" by averaging all the directions presented at a single level of directional variability, and at a single directional offset (producing ~75% correct discrimination), according to observers' responses. Results reveal the presence of substantial inhibition between directions differing by 30-45 degrees. This inhibition explains the

perception of transparency in stimuli containing uniform distributions of motion directions (and the associated reduction in pooling), and may also contribute to other phenomena of global motion processing, such as direction repulsion.

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841 Adaptive Strategies for Perception-Action Coupling

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The detailed characteristics of perception/action coupling is studied using a sensori-motor pointing task. Using a graphical pen, subjects (n=6) had to point to the final location of the invisible center of simple geometrical shapes - cross, diamond, chevron -, after their movement along a circular - clockwise/anti-clockwise - trajectory ended. The target shapes could be fully visible, thus yielding a highly coherent motion percept, or presented behind vertical rectangular masks. In these latter conditions, perceived global coherence was dependent upon the visibility of the masks. Under these conditions, constant and variable errors and the spatial distribution of pointing responses indicate that: (1) Accuracy of pointing responses is better at high than at low motion coherence. (2) With fully coherent shapes, pointing accuracy is similar for a cross and a single spot - i.e. baseline condition - and worse for the diamond and chevron for which the profiles of the spatial distribution of pointing responses are different. In addition, pointing responses are biased in the direction of motion - representational momentum -, an effect which disappears at middle and low coherence. (3) At low coherence, the location of the target center is overestimated and many pointing errors occur. Overall, observers appear to adapt their motor strategies to the specific context - i.e. shape and coherence - within which they have to perform their action. These results, showing comparable, although slightly different, biases for perception and action, are discussed in the light of the proposed dichotomy of dedicated functional processes through the ventral and dorsal pathways.

842 Effect of directional noise on heading perception

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Watamaniuk et al. (1989) demonstrated in a 2-D direction discrimination task that the difference between mean and perceived directions was modulated by a specified range of directionally constrained noise. Here we are interested to learn whether a similar effect could be observed in a heading perception task.

The experiment consisted of a random dot kinematograms (RDK) of expanding motion that produces the illusion of straight line heading shown at 44X44 deg² aperture for 482 ms. At the end of the motion, the RDK was replaced by a static random dot frame with the same statistical properties as the RDK and a vertical line. Observers were asked to determine whether heading direction was to the left or right of the vertical line. Adaptive staircase procedures were used to measure the accuracy of the heading perception (at 79%-correct level). Three experimental conditions differing in the directional noise perturbations were employed: 1) Random-walk: Each dot was perturbed independently from its direction in the previous frame; 2) Fixed-trajectory: Each dot kept the same perturbed direction throughout its lifetime; 3) General Perturbation: Location of heading direction was perturbed frame by frame.

In heading perception without noise, observers' accuracy was about 28. Accuracy dropped to roughly 10%, when range of perturbation was 878±4.68 for random-walk and 568±8.58 for fixed-trajectory conditions. As the amount of perturbations increased, thresholds systematically increased in all three conditions ($p < 0.05$, slope of linear fits to perturbation range vs. threshold).

The results indicate that in the presence of either local (conditions 1 and 2) or global (condition 3) directional noise, heading direction can still be perceived. This implies that under noisy conditions both temporal and spatial integration mechanisms may help heading perception, suggesting that precise local direction perception is not required for the task.

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843 Speed-tuned global motion mechanisms

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Asymmetries in global motion perception have been noted for many directions of motion; yet, consistent directional asymmetries have not emerged. At VSS 2004 we reported preliminary direction discrimination results based on a slow speed of motion. We now extend those findings to a faster speed of motion. We investigated the effect of direction, speed and visual field location on global motion processing in 40 university students using random dot kinematograms. Coherence thresholds for direction discrimination using a 2 AFC paradigm were obtained for horizontal (left or right) and vertical motion (up or down), at slow (1 deg/s) and fast (8 deg/s) speeds in the full-field, and four hemifields (left, right, top, bottom). At the fast speed, horizontal coherence thresholds were lower than vertical thresholds, an effect found previously (e.g. Raymond, 1994). This effect was qualified by an interaction with location such that horizontal thresholds were significantly lower than vertical thresholds when motion was presented in the full-field and the top and bottom hemifields, but not when motion was in just the right or left hemifields. Conversely, there was no difference between horizontal and vertical thresholds and no effect of visual field location when the speed of motion was slow. Further, there was a trend for coherence thresholds to be lower for faster motion than for slower motion. Taken together, these results suggest that there are different mechanisms involved in processing slow and fast global motion, and that direction discrimination may be dependent upon speed-tuned mechanisms. This is consistent with past global motion research in which fast-moving noise dots did not impair extraction of motion signals carried by slow-moving dots (Edwards et al., 1998). Edwards and his colleagues suggested that global motion extraction occurs within speed-tuned systems; our results suggest differences in direction discrimination within these speed-tuned systems.

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844 Motion perception and temporal precision in a time-to-contact task

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In a time-to-contact task 18 volunteers were asked to tilt a lever right or left at the exact moment a moving spot overlapped a stationary spot on a computer screen. At different times before this critical moment, a third spot moved, indicating the side the lever should be tilted. The interval between the instant the direction was indicated and the instant the lever should be tilted varied randomly from 51 to 1071 ms. Clearly, for very short intervals (50-150 ms) responses in the direction indicated were 50% of the total (random performance), since it is not possible to react to the third spot that fast. When the time available to react was >350-400 ms, on the other hand, performance saturated at 100% correct. The half way mark, between random and perfect performance occurred when the time available to respond was around 220-260 ms. Two interesting phenomena were observed: for short latencies (50-200 ms) there was a tendency towards late (5-7 ms) responses; for much longer latencies (450-550 ms), minimum condition for perfect responses, there was a strong tendency to anticipate responses (10-12 ms, $p < 0.05$). It is easy to understand the delays with short latencies as a natural, even if involuntary, tendency to

wait just that instant longer when unsure which way to go. Much more difficult to understand is the anticipatory tendency when the time available to respond is much longer. Perhaps in the range of 500 ms prior to the actual movement, preparatory internal processes occur, involved with synchronizing the response to the visual stimulus. When the indication of the side to which the movement should occur coincides with these processes, the resulting interference might be the cause of this phenomenon. Indirect evidence for this was obtained from eye-movement recordings, but other explanations cannot be excluded at this time.

845 A Probabilistic Network Model of the Influence of Local Figure-Ground Representations on the Perception of Motion

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Psychophysical experiments have shown that integration of motion signals, distributed across space, must be integrated with form cues, such as those associated figure-ground segregation. These experiments have led several to conclude that mechanisms exist which enable form cues to 'veto' or completely suppress ambiguous motion signals. We present a probabilistic network model in which local figure-ground representations encoded by direction-of-figure (Sajda and Finkel, 1995) modulate the degree of certainty of local motion signals. In particular, we consider the modulation at junctions where line terminators are defined as either intrinsic or extrinsic (Shimojo, Silverman, and Nakayama, 1989). The strength of local motion suppression at extrinsic terminators is a function of the belief in the local direction-of-figure, which is defined as the strength of the evidence for surface occlusion. Unlike previous studies/models investigating the influence of motion signals at terminators and occlusion cues (Grossberg, Mingolla, and Viswanathan, 2001; Lidén and Pack, 1999), our model directly exploits the uncertainties in the observations (i.e. figure-ground cues) leading to uncertainty in the inferred direction-of-figure, which for the case of terminators provides a smooth transition between intrinsic and extrinsic classes. Simulation results show that our model can account for the continuum of perceptual bias seen for motion coherence and perceived direction of motion in psychophysical experiments (McDermott, Weiss, and Adelson, 2001; Lidén and Mingolla, 1998).

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846 Sensory-motor integration during free-viewing natural time-varying images: A theory of dynamic processing in visual systems

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We explore the hypothesis that early visual systems improve the efficiency of visual representation by dynamically changing the response properties to maintain the decorrelation of natural time-varying images. Natural time-varying images possess significant spatiotemporal correlations. Furthermore, under natural viewing conditions, such correlations are changed significantly by the saccadic eye movements and hence the visual signal has quite different characteristics during, across, and between saccadic eye movements.

Maintaining decorrelation of such visual signal requires that the response properties of the visual system also change accordingly. In addition, since the saccadic eye movements are generated and thus known to the brain, sensory changes induced by such self movements will be processed differently in comparison to sensory changes induced by intrinsic changes of the external world. Based on the measured statistical properties of visual input during free viewing of natural time-varying images, we derive the dynamic receptive-fields that achieve this decorrelation.

In particular, the derived receptive-fields change according to the timings of saccades. One of the predicted properties is the dynamic change of the

response sensitivity to sinusoidal gratings of different spatial frequencies. This is compared with human psychophysical experiments and neurophysiological experiments in LGN of animals. Another predicted property is the dynamic change of the direction selectivity. This is compared with neurophysiological experiments in visual cortex of animals and functional imaging experiments in human.

The theory gives a quantitative account for visual response differences across and between saccades.

847 Predicting Manual Reaction Time To Visual Motion By Temporal Integrator Model Of MEG Response

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Manual reaction time (RT) is a useful behavioral measure of the latency of visual responses, but its underlying neural processes are relatively unknown. We examined how RTs are related with the time course of simultaneously measured magnetoencephalography (MEG). Transitions of a dynamic random-dot pattern from incoherent motion to coherent motion were used as visual stimuli, which are known to evoke MEG responses mainly at around MT. The results showed that both the RT and the peak latency of evoked MEGs decreased as the motion coherency was increased from 20 to 80%. However, the change in the peak latency was much smaller than that in the RT, as reported by previous EEG and MEG studies. We then compared the RT with the predictions of the two models the level detection model (Grice, 1968) and the temporal integrator model (Cook and Maunsell, 2002). The two models assume that a stimulus is detected when the MEG amplitude or its temporally integrated value exceeds a threshold, respectively. The time required for motor preparation and execution was assumed to be constant. The threshold of each model was determined individually to best account for the variation in RT. The analysis showed that the integrator model can, but the level detection model cannot, fully account for the variation of RT depending on the stimulus change. Additionally, the validity of the integrator model was supported by the result that the fluctuation of MEGs across trials could account for the variations in perception (correct detection / miss) and in RT for identical stimuli. Namely, for 20% coherence, the integrated MEGs exceeded the threshold for correct detection trials, but not for miss trials. For the higher coherence levels, the integrated MEGs exceeded the threshold earlier for the shorter RT trials than for the longer RT trials. These results suggest that temporal integration of the sensory signal at the higher visual areas, such as MT, may be correlated with the detection of visual motion.

848 Cortical Evaluation of a Rule-Based Trajectory Revealed by fMRI

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Kim and Heinen (2001) introduced a novel paradigm for investigating rule-based eye movements in awake, behaving monkeys. The rule in their "baseball" task was to follow a target with eye movements if it crossed a visible "strike zone", and withhold eye movements if it did not. Neurons were recorded in the supplementary eye fields (SEF) that signaled early whether the target would cross the strike zone or not. Here, using fMRI, we show neural correlates of trajectory evaluation in humans. Three observers signaled with a key press whether or not a target's trajectory would cross a strike zone. Subjects were scanned on a 3T GE Signa system with 23 functional slices covering the entire head at a resolution of 3x3x5mm and a TR of 3s. Spiral k-space acquisition was used to reduce susceptibility artifacts in anterior cortical regions. Regions whose activity covaried with the psychophysically-determined difficulty of the baseball task were identified based on a signal coherence analysis. Three areas

showed significant, consistent activity during the task. One, the inferior parietal sulcus (IPS), is a region implicated in spatial processing and attention, and in integrating motion signals. Two frontal areas were also active: right dorsolateral prefrontal cortex (DLPFC), and bilateral inferior frontal gyrus close to or within ventrolateral prefrontal cortex (VLPFC). Right hemisphere DLPFC has been previously implicated in spatial working memory and rule evaluation. The VLPFC has been suggested to play a role in short-term storage of visual images. Our results suggest that these areas are involved in interpreting the trajectory of a moving stimulus, and using this information to guide behavior in the context of a rule. These regions may in turn send this information to the SEF if eye movements are required. This study represents a first step in humans of elucidating the network involved in interpreting the trajectory of a moving target within the context of a rule.

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849 The initial ocular following response (OFR) to moving grating patterns: Evidence for winner-take-all mechanisms

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We recorded the OFR elicited in 3 human subjects by horizontal motion applied to vertical grating patterns consisting of a sum of two sinusoids of spatial frequency 3f and 5f, which created a repeating pattern with a 'beat' at frequency, f. Motion consisted of successive steps, each ° of the wavelength of the beat, so that the 2 components each shifted ° of their wavelength, the 5f forwards and the 3f backwards. The contrast of the 3f component was varied systematically from 1% to 64% while the contrast of the 5f component was fixed at 0% or 8%. The OFR was recorded with the search coil technique. When the 5f component had 0% contrast, initial OFR was in the backward direction and its amplitude increased roughly linearly with the log contrast of the 3f sine wave. When the 5f component had 8% contrast and the contrast of the 3f component ranged from 1% to 4%, initial OFR was in the forward direction and its amplitude remained almost constant; as the contrast of the 3f component increased further, initial OFR reversed direction and, when the contrast of the 3f component exceeded 16%, the amplitude of the initial OFR showed a dependence on log contrast that was almost the same as that in the first experiment when the 5f component was absent. Thus, if the contrast of one component was less than ? that of the other then the weaker component had almost no influence on the initial OFR: winner-take-all. We repeated these experiments using grating patterns consisting of a sum of two sinusoids of frequency 3f and 7f. The steps were again ° of the beat wavelength so that each component again shifted ° of its wavelength but this time in the *same* (backward) direction. Initial OFR was now always in the backward direction and its magnitude was again largely insensitive to the component with the lower contrast. Thus, if the 2 components differed in contrast by >50%, initial OFR showed winner-take-all behavior whether those components moved in the same or opposite direction.

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850 Categorization of Complex Dynamic Patterns in the Human Brain

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The ability to categorize actions is critical for interacting in complex environments. Previous studies have examined the neural correlates of categorization using static stimuli. The goal of our study was to investigate the neural substrates that mediate learning of complex movement categories in the human brain. We used novel dynamic patterns that were generated by animation of an artificial skeleton model and presented as point-light displays. We created prototypical stimuli that differed in the spatial arrangement of their segments and their kinematics. Intermediate

stimuli between the prototypes were generated by a weighted linear combination of the prototypical trajectories in space-time. We compared fMRI activations when the observers performed a categorization vs. a spatial discrimination task on the same stimuli. In the categorization task, the observers discriminated whether each stimulus belonged to one of four prototypical classes. In the spatial discrimination task, the observers judged whether each stimulus was rotated (or translated) leftwards vs. rightwards. These tasks were matched for difficulty based on the observers' performance during a practice session. We observed significantly stronger fMRI activations for the categorization than the spatial discrimination tasks in the dorsal, inferior parietal and the medial, inferior frontal cortex, consistent with previous findings on the categorization of static stimuli. Interestingly, we also observed activations in visual motion areas (V3a, hMT+/V5), higher-order motion areas in the intraparietal sulcus (VOIPS, POIPS, DIPSM, DIPSA) and parieto-frontal areas (supramarginal gyrus, postcentral gyrus, ventral and dorsal premotor cortex) thought to be involved in action observation and imitation. These findings suggest that categorization of complex dynamic patterns may modulate processing in areas implicated in the analysis of visual motion and actions.

851 Asymmetrical cortical activation by global motion in children with dyslexia

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Several groups have reported elevated motion coherence thresholds on global motion tasks in children and adults with dyslexia (eg. Edwards et al., 2004; Raymond & Sorensen, 1998; Talcott et al., 1998). The nature of the relationship between motion perception and reading deficits, however, has not been established. We used functional MRI to study the neural basis of the global motion deficit in 12 right-handed children with dyslexia and 12 age-matched controls. Area V5/MT+ was identified with a localizer task in which blocks of dots in expanding/contracting radial motion alternated with blocks of stationary dots. Activation in the V5/MT+ region was observed in 23 of 24 hemispheres in the control group and in all 24 hemispheres in the dyslexic group. This result is contrary to previous reports of reduced or no activation in response to moving stimuli in V5/MT+ in adults with dyslexia (Demb et al., 1998; Eden et al., 1996). Global motion direction discrimination was assessed using blocks of discrete trials of horizontally moving dots alternating with blocks of stationary dots. The coherence level was 85% or 30% on alternate motion blocks. Both groups showed more widespread activation when the coherence level was 30% than when the coherence level was 85%. At 30% coherence, activation was bilateral and symmetric in the controls. In contrast, the dyslexic group showed asymmetric activation with significantly reduced left hemisphere activation in V5/MT+, posterior occipital (putative V3A, V1, V2) and posterior parietal cortex. This finding, on motion tasks, is notable because, on reading tasks: 1) normal young readers show *increasing* left hemispheric lateralization as their reading fluency increases (Turkeltaub et al., 2003), and 2) children with dyslexia show *reduced* activation in left posterior regions compared to control children (Shaywitz et al., 2002). These results implicate left posterior cortex in both reading and global motion deficits in children with dyslexia.

852 Perceptual Development of Motion Transparency in 3- to 5- month-old infants

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If the opposite moving dots were located sparse enough, we can see the global two planes moving opposite directions. This perception is called

motion transparency. We conducted three experiments on the development of the motion perception for total 112 3- to 5- month-olds infants using these opposite moving dots. Qian, et al. (1994) showed that opposite moving dots located within 0.4 deg did not produce the percept of the two global planes. We used this paired dot stimuli as a distracter and the transparent motion as a target. In Exp 1, all stimuli were consisted of 90 moving dots, and in target stimuli the distances between opposite moving dots were varied from trial to trial. The target and the distracter were presented simultaneously side by side. The percentage of the time to look at the target motions were measured based on the forced-choice preferential looking method (Teller, 1979). Results showed that 4- and 5-month-old infants showed the preference to the targets but not 3-month-olds. These results suggest that the preference to the motion transparency emerges at 4-months. In Exp 2, we examined the infants' preference to the target in small number of dots. In this experiment, we used three kinds of stimuli (2, 4 and 6 dots moving opposite directions). Results showed that 4- and 5-month-old infants did not look at the target significantly in all conditions. These results suggest that the preference to the target motions decreases according to the number of the dots. In Exp 3, we used the longer traveling length of the dots and the longer distance between opposite moving dots. Results showed that all age group looked at the target motions in all stimulus conditions. These results suggest that the perception of motion transparency based on the global motion cue emerges at 4-month-olds (Exp 1 and 2) and the traveling length of the dots promote the perception of motion transparency (Exp 3).

853 Form and Motion Processing in Dyslexia

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We report a study of motion-coherence and form-coherence in dyslexia using psychophysics and fMRI. Deficits in perceiving coherent motion have been reported in dyslexia, but no differences in form coherence have previously been found. We measured form and motion thresholds for detecting a Glass stimulus of varying coherence in a field of random dots. A coherent visual patch was depicted by dots separated by a rotational transformation in space (form coherence) or space-time (motion coherence). Stimuli were presented for 0.25s to prevent serial search strategies. Coherence was progressively reduced from 1.0 until an error was made, in the manner of a 2-up, 1-down staircase, with thresholds calculated as the mean of 6 reversals, ignoring 2 initial reversals. Motion coherence thresholds were higher in dyslexic participants than controls, replicating previous findings. Form coherence thresholds were also significantly higher in the dyslexic population, however, indicating a parvo- or ventral stream deficit. In a parallel event-related fMRI study in which participants performed the same task in the scanner at fixed coherence levels (0, 0.125, 0.25, 0.5, 1.0), BOLD responses indicated a variable but non-linear relationship with motion coherence in V5/MT for dyslexic participants, compared to the linear response in controls which was consistent with previous studies (Rees et al, 2000 *Nature Neuroscience* 3 716-723). No significant difference was found between dyslexics and controls in the relationship between BOLD response and form coherence in any of the four occipital regions of interest.

Object Recognition in Context

854 Can A Gun Prime A Hairbrush? The 'Initial Guesses' that Drive Top-Down Contextual Facilitation of Object Recognition.

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Contextual associations provide predictive information about which visual objects are likely to appear together. How does the human brain use

these environmental regularities for object recognition? Contextual associations are processed using a network including the parahippocampal cortex (PHC; Bar & Aminoff, 2003). We propose that a partially analyzed version of the input image (i.e., a blurred image) is projected rapidly from early visual areas to the PHC. This rudimentary representation activates an experience-based 'guess' about the present context (i.e. a context frame). This information is then projected to the inferior temporal cortex, where it activates the representations of the objects associated with the specific context frame (Bar, 2004). When the coarse input to the PHC is ambiguous, it will result in the activation of multiple such context frames. We tested a rather counter-intuitive prediction of this model, best explained with an example: A picture of a gun, when projected rapidly in a blurred (i.e., low spatial frequency) form to the PHC, may be interpreted also as a drill and a hairdryer. These three objects are associated with three different context frames, and will subsequently trigger the activation of three sets of objects. Consequently, a gun will not only prime the recognition of a police car (i.e., contextual priming), but also the recognition of a hairbrush (i.e., a member of the context frame activated by the hairdryer), despite the lack of a perceptual or contextual relation between a gun and a hairbrush. Indeed, we found significant priming for this condition. Furthermore, we found that this indirect priming existed for relatively short-duration (250 ms), but not longer (1000 ms), exposures. This supports our notion that the arrival of additional information leaves only the most relevant context frame active. This novel result, along with neuroimaging data, elaborates the cortical mechanisms of top-down contextual facilitation of object recognition.

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855 Cortical Manifestations of Context-Related Facilitation of Visual Object Recognition.

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The term priming typically denotes a behavioral change (usually an improvement) in the speed or ability to identify a stimulus following a prior exposure to the same, or a related, stimulus. Experience-based facilitation of object recognition is also achieved through context-specific expectations about which objects are likely to appear together in a specific scene. Seeing a computer mouse, for instance, can facilitate subsequent recognition of contextually related objects such as a keyboard and a monitor. The benefit of prior experience during object recognition is typically associated with a physiological response reduction in occipito-temporal cortex. Moreover, the specific regions that exhibit response reductions in priming tasks can vary according to the nature of the relation between the target objects and the preceding prime objects. Using event-related fMRI, we sought to elaborate the cortical network involved in experience-based facilitation of object recognition; specifically, by examining the different foci of response reductions for targets preceded by primes that were either the same object or were contextually related (but perceptually different). Priming in both cases was reflected by improvements in RTs and a reduced fMRI signal relative to that for novel objects. Context-related facilitation was uniquely associated with response reduction in bilateral parahippocampal cortex (PHC). Perceptual-related facilitation was uniquely associated with reductions in bilateral mid-fusiform gyrus and occipito-temporal sulcus, reflecting item specific effects. Response reductions were observed for both types of primes in left anterior fusiform gyrus and inferior frontal and lateral occipital cortices. Finding contextually mediated response reductions in object processing regions suggests that contextual facilitation of object recognition is mediated by the sensitization of the representations of contextually related objects in the occipito-temporal cortex.

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856 Combined and Dissociable Effects of Spatial and Semantic Contextual Information on Visual Object Recognition

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Objects in our environment tend to be grouped in typical visual settings. These settings may be represented in contextual frames that contain information regarding the identity of objects in specific scenes, and the spatial relations between them. To what extent are the semantic and spatial information linked to each other within a unified contextual frame, and to what degree do these contextual components independently contribute to object identification?

We investigated this question using a priming task in which the spatial and semantic relations of prime and target were independently manipulated. In the spatial dimension, target and prime were either properly or improperly positioned (e.g., an ashtray appearing below or above a cigarette, respectively). In the semantic dimension, target and prime were either semantically related or unrelated (e.g., an ashtray and a cigarette, vs. an ashtray and an ice cream cone, respectively). Prime and target were successively presented, each for 250ms. The prime always appeared in the center of the screen, while the target appeared either above or below it. Subjects judged whether the target was a real or a nonsense object (the prime was a real object in all cases).

Results revealed a strong spatial priming effect, presumably mediated by an automatic shift of attention to the location implied by the prime. In addition, spatial and semantic factors interacted with each other, showing a larger spatial priming effect in the semantically-related than the semantically-unrelated condition. These results suggest that contextual effects are mediated by a crude mechanism that directs attention to the most likely location of an object, as well as a more fine-tuned mechanism (or contextual frame) that generates a specific association involving both semantic and spatial dimensions of object representation. fMRI data corresponding to these findings will also be presented. Supported by NIH R01NS050615 and J.S. McDonnell Foundation 21002039.

857 Temporal dynamics of object-repetition effects in the human visual cortex

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Repetition of the same object typically yields a reduction of the fMR signal (adaptation) over object-selective cortex. EEG studies report repetition effects, but results vary from decreased cortical activity starting at around 200 ms (or later) to increased activity around 170 ms. Since fMRI does not yield information about the time course and the EEG effects are variable it is difficult to judge whether these repetition-effects are driven by bottom-up or top-down processing. Here we measured EEG and fMRI activation in the same subjects and for the same stimuli consisting of repeated and non-repeated animals.

Six subjects participated in 61-channel EEG experiments. From two of these subjects, we obtained fMRI data. Subject viewed repeated images of the same dog (18 repetitions), the same bird (18 repetitions), or non-repeated images of dogs and birds. Images were presented in an event-related design for 150 ms followed by a blank interval of 1850 ms. Conditions appeared in pseudo-randomized order and were intermixed with scrambled images and fixation trials. Subjects participated in 10 blocks of 108 trials and were asked to categorize images to 'bird' or "dog" or "other" while fixating. In each block, a different set of images was used.

All subjects showed an occipito-temporal increase for repeated images peaking around 150 ms. This is earlier than previously reported. In later time intervals, there was a high inter-subject variability. Consistent with earlier studies, but in contrast to the EEG, fMRI activations in object-selective cortex were reduced for repeated images. The difference between EEG and fMRI may have at least two sources: The source of the EEG signal is different from the loci of fMRI activation or the early increase seen in the

EEG is lost due to temporal integration in fMRI. Based on the EEG time course we conclude that at least some repetition effects occur during bottom-up processing.

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858 Human ventral temporal areas contain flexible position-invariant information about subordinate-level objects

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Recent fMRI studies have shown that basic-level object categories can be distinguished by the differential patterns of activity that they evoke in human ventral temporal cortex (Haxby et al., 2001). Here, we investigated if distributed patterns of fMRI activity can differentiate objects at the subordinate level, and tested if these distributed representations reflect the coding of local, low-level features or position-invariant, high-level features. We observed fMRI activity while subjects viewed images from 1 of 8 different bird species (e.g. seagull, penguin). Birds were presented at random orientations, either at fixation (Exp 1), or in the upper- and lower-left visual field (Exp 2). Correlational analyses were used to evaluate if different types of birds could be reliably classified by comparing activity patterns on test trials to those evoked by the different bird species on training trials. When training and test stimuli were both presented at fixation, birds were correctly classified on 70% of trials (chance=50%) based on activity patterns in ventral temporal cortex. However, activity patterns in retinotopic visual cortex were equally effective at subordinate-level discriminations (73% correct), suggesting that local low-level feature information alone might entirely account for successful classification performance. In Exp 2, activity patterns in ventral temporal areas were effective at discriminating between different bird species irrespective of whether the test and training stimuli were presented in the same location or different locations (67% and 62%). In contrast, activity patterns in the retinotopic cortex were unable to generalize across changes in location and led to chance levels of discrimination performance. Our results demonstrate that ventral temporal areas contain flexible position-invariant information that effectively discriminate the subtle differences between subordinate-level objects.

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859 Viewpoint representation in object recognition: evidence from repetition blindness

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We used the paradigm of Repetition Blindness (RB) to explore representations of viewpoint in object recognition. RB refers to the difficulty that participants have in detecting or reporting repetitions of words, letters, or pictures presented quickly in sequence, specifically when the two instances occur within 400ms. This finding has been interpreted as a failure in token individuation for the second occurrence of the repeated item. Such an explanation makes it possible to use the RB paradigm to test viewpoint generalization of object representations. Harris and Dux (VSS 2004) tested whether RB can be obtained for repeated line drawing objects that were presented either at the same (canonical) viewpoint or separated by 30, 60, 90, or 180 degrees in the picture-plane. Experiment 1 was largely a replication of Harris and Dux (VSS 2004); in Experiment 2 we used the same design but tested shaded images rather than line drawings. The results of Experiment 1 essentially replicated Harris and Dux; significant RB was obtained for all viewpoint conditions, and was basically viewpoint invariant, though a reduction in RB was observed at 180 degrees. In Experiment 2, significant RB was again found; however, it appeared to be reduced with changes in viewpoint beyond 60 degrees. These results suggest that patterns of view-dependence and view-invariance in RB are

determined by the information available from the stimulus rather than view-specificity of the underlying object representation.

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860 Repetition Blindness With Natural Images.

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Human observers can accurately recognize visual stimuli presented during 100 ms in rapid serial visual presentation (RSVP). However, the repetition of a given stimulus can decrease its detection and report. This phenomenon, called repetition blindness (RB), has been found for linguistic stimuli, drawings, silhouettes and familiar faces (Mondy and Coltheart 2004). Here we report one RSVP experiment dealing with pictures of natural objects: three natural objects with three points of view over the same natural background were used for a recognition task with RSVP (two pre-experiments were designed to measure duration thresholds for single objects in a recognition task). Observers had to estimate the number of apparition a given object they had seen in a sequence. Results were valued in term of correct responses to compute the repetition blindness rate. A non parametric signal detection analysis (A' and B') was also computed (Arnell and Jolicoeur 1997).

RB was found with pictures of objects within a natural background. Results also showed viewpoint invariance, in agreement with Kanwisher (Kanwisher, Yin et al. 1999). These data are discussed in the light of Chun's dual theory (Chun and Potter 1995) and current models of object recognition (Biederman and Gerhardstein 1993; Tarr 2004).

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861 Is Recognition of Visual Sequences better if Canonical Viewpoints are used?

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Three studies examined cognitive processing of visually presented dynamic scenes. Garsoffky, Schwan and Hesse (2002) showed that the recognition of dynamic scenes is viewpoint dependent, i.e. visual recognition becomes worse, if the viewpoint used for the test stimulus differs from the viewpoint from which a dynamic scene was initially learned. Based on this finding it can be asked whether this viewpoint deviation effect diminishes if special viewpoints are used, namely canonical viewpoints which are assumed to deliver more information than other viewpoints (Palmer, Rosch & Chase, 1981). As experimental material, short video clips of four moving balls were used. Based on the paradigm of Palmer et al. (1981), experiment 1 examined the existence of canonical viewpoints for dynamic scenes: Participants saw the scenes from various viewpoints and had to decide from which viewpoint in their

opinion the scene was presented best. As a main result, participants preferred the viewpoint perpendicular to the axis of main movement of the scene over any other viewpoint. The more the viewpoints deviated from this angle, the worse they were rated. Experiment 2 and 3 used a recognition paradigm and examined if the usage of canonical viewpoints, i.e. the preferred viewpoints in experiment 1, weaken the viewpoint deviation effect in visual recognition due to their information richness, either in the learning phase (experiment 2) or the test phase (experiment 3). Experiment 2 found a general viewpoint deviation effect both for canonical and less canonical viewpoints in the learning phase, although it was weaker for the canonical views. In experiment 3 the use of canonical viewpoints in the test phase had no influence on the viewpoint deviation effect. This means that the influence of canonical viewpoints on the viewpoint deviation effect is more important during storage than during retrieval.

862 The seductive effect of context on object recognition

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Extracting a target object from a cluttered background is a complex task that is a significant problem for theories of object recognition. For most theories to function properly, the human visual system needs to be capable of highly accurate segmentation that takes place prior to attempting to recognize the target object. If this is true, we would expect relatively little effect of adding irrelevant background objects to a shape discrimination task, as long as the target object is not obscured.

In our study, the background consisted of objects placed behind a target object such that the target always partially occluded each of the background objects. Observers were asked to look at the target, in the center of three background objects; the image was then masked. A second image was then shown that could have either the same or a different target shape, and either the same background objects or different ones. This image was masked, and observers were then asked to respond 'same' or 'different' to the target object while ignoring the background objects.

The pattern of results obtained demonstrates that segmentation was not perfect and that the background interfered with accurate task performance. Comparing performance with and without background objects, we observed a decrease in accuracy of approximately 10% when background objects were added. While this decrease was significant, performance was still well above chance, which suggests that the visual system is fairly efficient at segmentation when the background is present. There was also an unexpected interaction effect: accuracy in correctly responding 'different' to a shape change in the target object increased by approximately 20% when the background changed as well. Our results suggest that the observers were unable to completely filter out the background; for at least some trials, they were seduced into basing their response on the background rather than the target object.

Perceptual Learning 2

863 The effects of local context in visual search: a connectionist model and behavioral study of contextual cueing

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Predictive visual context facilitates visual search in a paradigm known as contextual cueing (Chun & Jiang, 1998). In the original paradigm, search arrays were repeated across blocks such that the spatial configuration of all of the distractors in a display predicted an embedded target location on half of the trials. It was later shown that this benefit could occur even when only the context on the same half of the computer screen as the target was predictive (Olson & Chun, 2002). We successfully modeled these results using a connectionist architecture, and then used this model to predict the results of novel manipulations. The first novel manipulation was to test

whether cueing would still occur from repetition of even more locally restricted contexts, defined as the configuration of two distractors in the same quadrant as the target. The model predicted significant contextual cueing, and a behavioral study with 12 subjects confirmed this prediction. Next, we examined whether such local contextual cueing would transfer to different quadrants of the screen. Thus, the target and its local configuration were moved to a different quadrant of the screen each time they were repeated. The model predicted that no cueing would result, and 12 subjects displayed no significant cueing in a behavioral experiment. Thus both the human subjects and our model were able to learn local contexts only when the target and the neighboring distractors remained in the same absolute location on the screen. These behavioral results and the model suggest that spatial contextual cueing of visual search can be based on position-dependent learning of local context.

864 Learning to Identify Contrast-Defined Letters in Peripheral Vision

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Performance for identifying luminance-defined letters in peripheral vision improves with training. The purpose of the present study was to examine whether performance for identifying contrast-defined letters also improves with training in peripheral vision, and whether any improvement transfers to luminance-defined letters. Eight observers were trained to identify contrast-defined letters presented singly at 108 eccentricity in the inferior visual field. Before and after training, we measured observers' contrast thresholds for identifying luminance-defined and contrast-defined letters, embedded within a field of white luminance noise (RMS contrast = 0, 0.25 and 0.5), at the same eccentric location. Training consisted of 10 blocks of identifying contrast-defined letters at a background noise contrast of 0.5. Letters (x-height = 4.28) were the 26 lowercase letters of the Times-Roman alphabet. Luminance-defined letters were generated by introducing a luminance difference between the stimulus letter and its mid-gray background. The background noise covered both the letter and its background. Contrast-defined letters were generated by introducing a differential noise contrast between the group of pixels that made up the stimulus letter and the group of pixels that made up the background. Following training, observers showed a reduction in contrast threshold for identifying contrast-defined letters. Averaged across observers and background noise contrasts, the reduction was 29%, with the greatest reduction (36%) occurring at the trained background noise contrast (0.5). There was little transfer of improvement to luminance-defined letters (average threshold reduction = 9%). Our results extend previous findings (Doshier & Lu, VSS 2004) in showing that training also improves performance for identifying contrast-defined letters in peripheral vision. This learning effect seems to be stimulus-specific, as it shows little transfer to the identification of luminance-defined letters.

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865 Examining the Top-Down Component of Perceptual Learning

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Perceptual learning (PL) has been observed in tasks as dissimilar as pop-out detection (Ahissar & Hochstein, 2004), illusory contours shape discrimination (Rubin, Nakayama & Shapley, 2002), face identification (Gold, Bennett & Sekuler, 1999) and visual position discrimination (Li, Levi & Klein, 2004). PL can be rapid (Fahle, Edelson & Poggio, 1995) or require several months of practice (Watanabe et al., 2002). Usually the improvements are preserved after several years without practice (Karni & Sagi, 1993) but sometimes retention is only partial (Santhian & Zangaladze, 1998; Kapadia, Gilbert & Westheimer, 1994) or even null

(Godde, Stauffenberg, Spengler & Dinse, 2000). A part of this remarkable diversity in PL manifestations may stem from the respective involvement of top-down and bottom-up processes in the task. Some attempts have been made to disambiguate the effects of these processes by isolating them (Godde et al., 2000; Watanabe, Nanez & Sasaki, 2002; Ahissar & Hochstein, 1993, 2000, 2002). Last year we have isolated top-down components of PL in a detection task by completely removing the signal in the practice trials (see Gosselin & Dupuis-Roy (2003) for methodological details). Here, we further examine this type of PL. Results show that the improvement is preserved after a one-year interruption. Comparison of our subjects' performance to that of an ideal observer indicates that no-signal training increases efficiency and decreases internal noise.

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866 Recruitment of New Perceptual Cues

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To reliably construct percepts from visual signals, the visual system must exploit the statistical relationships between properties of the world and signals. We propose that the visual system actively monitors and refines the process by which signals are converted into percepts. In particular, the visual system should start to utilize arbitrary signals as perceptual "cues" when exposed to novel correlations between those signals and the world. We tested this proposition using the perceived rotation direction of a rotating Necker cube covered with dots. Perceived rotation based on structure-from-motion alone is bistable for this stimulus and therefore might be easily biased by newly recruited cues. On "training" trials, we added stereo and occlusion cues to disambiguate the rotation direction. Critically, the rotation of the cube was also artificially correlated with one of three novel training signals - position in the visual field, translational movement of the cube, and the frequency of a sound tone. On "probe" trials, stereo and occlusion cues were eliminated so the direction of rotation was ambiguous unless subjects made use of the newly trained cue. We found that position and translation became effective at biasing perceived rotation on probe trials, but the auditory cue did not. Effects persisted into the next day. An additional session with opposite correlation reduced or reversed the previous learned bias, but the amplitude of the reversed bias was weaker than the original. These results suggest that there are processes that actively seek to learn the statistical contingencies of the world.

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867 Seeing what isn't there; the costs of perceptual learning

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Perceptual learning is defined as plasticity in one's sensory brain-areas and helps us to better perceive the visual environment. A natural question to ask when evaluating studies of perceptual learning is what is the cost of perceptual learning? If there is no cost, why wouldn't sensory processing already be at its maximal level of performance? To date studies of perceptual learning have concentrated only on its benefits, and the possible costs of such learning are ignored. Here we show that perceptual learning can also lead to misperceptions, such that subjects actually perceive stimuli when none are physically presented. We demonstrate this counterintuitive result by using a reinforcement procedure in which motion stimuli, which were too dim for subjects to detect, were temporally paired with the targets of a letter task. After learning, subjects not only showed enhanced sensitivity to the motion direction of the trained stimulus but often reported seeing dots moving in the trained direction when no stimulus was displayed. We further show that these

misperceptions result from a perceptual bias and are not attributable to a response bias. These results show that there are costs as well as benefits to perceptual learning and that sensitivity enhancements for a specific feature can also be accompanied by misperceptions of the visual environment.

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868 Categorical Perception: Categorisation Dependent Perceptual Learning

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The hallmark of categorical perception (CP) is that observers show superior discrimination between equally spaced stimuli on physical continua when those stimuli straddle a category boundary. Recent work has shown that CP effects can be learned. Yet there is debate about whether these learned CP effects are really perceptual and if so about the mechanisms and locus of learning. To address these issues we created morphed continua of cervical cells varying from normal to abnormal. We selected these stimuli because of their novelty to most observers and because they have similar image statistics to natural scenes. In experiment 1 we compared experts and novices. Both groups completed two tasks (order counterbalanced). In one task they categorised the stimuli into normal and abnormal. In the other task they reported whether pairs of stimuli selected from the continua were the same (physically identical) or not. Analysis, using signal detection theory measures, showed that the experts were significantly better at discriminating pairs of stimuli from either side of their category boundary compared to within category pairs. The novices showed no such CP effect. These findings are consistent with the possibility that category learning has modified the experts' perception of the stimuli. In experiment 2 we trained novices to categorise the stimuli, briefly presented to one retinal location, into normal and abnormal. Following training a CP effect was apparent at the trained location, but not at locations 3.6 deg. away. This experiment supports the view that category learning modifies perception of these images. Further the retinotopic specificity of learning suggests that the CP is dependent on perceptual processing at relatively early stages of visual analysis, where smaller receptive field sizes are observed. Thus, we conclude that CP effects can reflect a visual perceptual learning process that is driven by categorisation task and modulated by attention.

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869 Better Contextual Memory for Dense Displays

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When searching for a target, people implicitly remember the configuration of the search display, showing faster reaction times when the display is later repeated versus new (random) displays. This implicit configuration memory, called contextual cuing, occurs regardless of stimulus color or jittering, but disappears when the target is moved to a different location in a repeated display (Chun & Jiang, 1998). The relationship between targets and surrounding distractors is clearly important to contextual cuing and suggests that the closeness of distractors to the target may affect observers' memory for context. Targets are more difficult to detect as target-distractor proximities decrease within an individual display (Motter & Holsapple, 2000; Eriksen & Eriksen, 1974), but this effect has not been examined using repeated displays. In the experiments presented here, we investigate how stimulus density affects contextual cuing. We used a traditional search task comprised of rotated T's and L's where a left or right rotated T was the target and stimuli were either monochromatic or contained an equal number of red, yellow, green, and blue stimuli (as in Chun & Jiang, 1998). There were two display densities, sparse and dense, with an equal number of stimuli in each. For the sparse displays, the entire display was used, and for the dense displays, the stimuli were restricted to 1 of 4 quadrants. Each

block of trials contained an equal number of new and repeated displays of both densities. Overall, subjects' reaction times were faster for dense displays, possibly because of the smaller search area. Interestingly, the contextual cuing effect was larger for dense displays. One possible explanation is that there are more items close to the fovea in the dense displays, requiring fewer fixations to perceive the configuration.

870 Bias in an unbiased land? Criterion shifts in perceptual learning using two-interval two-alternative forced-choice staircase procedure.

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Prominent models of perceptual learning (e.g., Gold, Bennett, & Sekuler, 1999; Doshier & Lu, 1999) assume an internal response criterion that is stable across time. In addition, many studies use a two-interval two-alternative forced-choice (2AFC) staircase procedure that is assumed to be immune from the effects of response bias. However, this assumption goes counter to the contrary (e.g., Green & Swets, 1966; Nisbett & Wilson, 1977). In addition, the limited discussions of bias in this procedure concern themselves with a bias for one of the two presentation intervals, rather than a general response bias. We report a simple signal detection theory model of this task, and show that a general response bias can alter threshold estimates, even when an observer shows no interval bias. We then report an experimental investigation of perceptual learning for contrast detection using a modified version of the two-interval 2AFC staircase that allows us to collect false alarm rates. Each trial on each run of the 3-down 1-up staircase consisted of a first display (75 ms), a noise mask (75 ms), a blank interval (925 ms), the second display (75 ms), and a final noise mask (75 ms). Equal numbers of target-present and target-absent trials were presented; the target-present trials were divided evenly with respect to interval containing contrast. Observers used their index fingers to indicate interval 1, their middle fingers to indicate interval 2, and their ring fingers to indicate neither interval. Feedback was given at the end of each trial. Reliable reductions in threshold were accompanied by reliable increases in false alarm rates. The data are thus consistent with our previous results (VSS 2003, 2004) documenting liberal shifts in response bias in perceptual learning, and indicate that such shifts can be obtained in experimental conditions that have been assumed to be immune from such effects. The results are discussed with respect to decisional influences in perceptual learning.

871 Learning and recognition of textured objects

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A neural model is proposed of how laminar interactions in the visual cortex may learn and recognize both object form and texture. The model brings together four interacting processes: region-based texture classification, contour-based boundary grouping, surface filling-in, and spatial attention. These processes interact to learn texture prototypes, which in turn generate better texture boundaries, as well as figural shapes. The model can perform discrimination of abutted textures with blurred boundaries (e.g., Gurnsey & Laundry 1992, *Canad. J. Psych.*) and shows sensitivity to texture boundaries including those due to discontinuities in orientation (e.g., Nothdurft 1992, *Percept. and Psychophy.*), texture flow curvature (e.g., Ben-Shahar and Zucker 2004, *Vis. Res.*), and relative orientations of texture boundary and texture elements (e.g., Wolfson and Landy 1995, *Vis. Res.*). Object boundary output of the model is also benchmarked against the performance of human subjects and some popular computer algorithms using a database of natural images (Martin et al. 2001, *ICCV*). The model achieves near-perfect classification performance on a set of texture images chosen from the Brodatz micro-texture album (Brodatz, 1966). In the model, texture is categorized using a multi-scale oriented filter-bank and a distributed Adaptive Resonance Theory (dART) classifier which together classify textures and suppress

noise. The matched signal between the bottom-up inputs and top-down learned texture categories is further processed using oriented competitive and cooperative grouping processes to generate texture boundary groupings that control surface filling-in and spatial attention. Top-down modulatory attentional feedback from boundary and surface representations to early filtering stages results in enhanced texture boundaries and more efficient learning of texture classification within attended surface regions.

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872 Visual learning and the selection of perceived shape from shading

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INTRODUCTION: Although reconstructing shape from shading is an ill-posed problem which has multiple solutions, human visual system selects a shape from a shading easily. For example, a disk with shading definable either a spherical or saddle shape, is mostly perceived as a spherical shape. This selection is often inconsistent with the assumptions for perceiving shape from shading, such as light-from-above assumption. What determines the selection, experience, physical validity or other factors? In this study, we investigated the effect of experience on the selection for perceiving shape from shading. **EXPERIMENT:** An experimental session consisted of three blocks; two test blocks and a learning block between the test blocks. In the test block, observers viewed monocularly the shading stimuli simulating a saddle shape, which were perceived as spherical mostly. In the learning block, they viewed the same shading stimuli binocularly with disparity indicating the same saddle shape. Thus observers experienced the specific relation between the shading and the saddle shape from disparity in the learning block. They responded perceived shape in all blocks. We compared the perceived shapes in pre- and post-learning test blocks to show whether there was the effect of the learning for selecting shape from shading. The session was repeated five times in different days. Seven observers participated in this experiment. **RESULT:** Three subjects became to perceive the saddle shape in the test block after the learning block. This result indicates that they learned to perceive the saddle shape for the stimuli with shading only. However the other subjects didn't. Two of them couldn't perceive the saddle shape in the learning block, so it is reasonable that they didn't learn to perceive the saddle shape. These results suggest that the selection of perceived shape from shading is, at least partly, empirically determined.

873 Independent perceptual learning in monocular and binocular motion systems

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Eye-transfer tests, external noise manipulations and observer models were used to systematically characterize learning mechanisms in judging motion direction of moving luminance-defined objects in visual periphery (Experiment 1) and fovea (Experiment 2) and to investigate the degree of transfer of the mechanisms of learning from the trained to the untrained eyes. Perceptual learning in one eye was measured over ten practice sessions and subsequent learning in the untrained eye was assessed in five transfer sessions. Learning in the trained eye improved performance in that eye with virtually equal magnitude across a wide range of external noise levels. A mixture mechanism of stimulus enhancement and template retuning accounted for the performance improvements. The magnitude and mechanisms of subsequent learning in the untrained eye were used to characterize the transfer of each learning mechanism -- if a learning mechanism is substantially trained and then transferred completely, no subsequent learning would be associated with this mechanism; otherwise,

the mechanism would exhibit subsequent learning. The degree of transfer depended on the amount of external noise added to the signal stimuli. In high external noise conditions, learning transferred completely to the untrained eye. In low external noise conditions, there was only partial transfer of learning: 63% in Experiment 1 and 54% in Experiment 2. Subsequent practice in the untrained eye further improved performance via stimulus enhancement in transfer sessions. The results suggest that independent mechanisms underlie perceptual learning of motion direction identification in monocular and binocular motion systems.

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874 Localization, not perturbation, affects visuomotor recalibration

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The visuomotor system recalibrates when visual and motor maps are in conflict, bringing the maps back into correspondence. For recalibration to occur, a conflict has to be detected. Ernst and Endre? (VSS '04) showed that the rate of recalibration in a one-dimensional visually guided pointing task depends on the uncertainty of the feedback: faster recalibration with less uncertainty. In the present work, we examined two-dimensional recalibration and how the form of visual feedback affects it. Subjects pointed with an unseen hand to a brief visual target. Visual feedback was given indicating where the point landed. We introduced a constant conflict between pointing and feedback location and examined the changes in pointing as the subject adapted. We asked whether differential vertical and horizontal uncertainty in the visual feedback affects recalibration rate differentially, or whether rate is determined by the total uncertainty. We also varied feedback uncertainty in two ways. (1) We blurred the visual feedback, thereby reducing its localizability; in this condition, uncertainty could be determined on-line from one feedback stimulus. (2) We introduced random trial-by-trial perturbations in the feedback; in this condition, uncertainty had to be learned over time. In both cases, the distributions determining the vertical and horizontal uncertainties were 2D Gaussians. Adaptation profiles (changes over time in the point location relative to the visual feedback) changed only in response to changes in localizability. Recalibration was slowest in the direction of greatest uncertainty when uncertainty was due to blur, but rate was unaffected by trial-by-trial variation. This means that subjects do not estimate uncertainty over time in order to adjust reaching. Rather, they adjust trial by trial based mostly on feedback from the previous trial.

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Sensory Integration: Vision and Hearing

875 Plasticity in auditory-visual integration

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Visual contrast detection learning is known to be very slow and needs several sessions or thousands of trials to be apparent. Previously, we showed that training with sound-coupled visual stimuli, where the sound is presented simultaneously with the visual contrast stimulus, can improve contrast detection within a single session. The improvement effect was found to be significant only for sound-coupled visual stimuli. Therefore, this sound-dependent training effect maybe due to cross-modal plasticity. Yet another possibility is that sound might serve simply as a timing cue, learned by repeated exposure and utilized to predict the onset of the stimuli in the two-alternative forced-choice intervals. Also, it was

unclear whether the training effect reflected long-lasting perceptual learning, or a short-term modification. To examine the characteristics of the training effect we tested contrast detection of the five most successful learners, 6-10 weeks following the sound-coupled training session, and compared their performance in different timing and sound conditions. Four out of the five subjects had maintained their significant improvement in detection. In addition, performance in trials where stimulus timing was variable (within a 500ms time window) was not significantly different from performance in fixed-timing trials, rejecting the role of sound as a timing cue. Also, no clear specificity of learning to sound frequency was found. Altogether, these preliminary results suggest that the training effect reflects a long-term learning in auditory-visual interactions, and that learning is not specific to sound frequency.

876 Visual token individuation by sound in repetition blindness

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Repetition blindness (RB; Kanwisher, 1987) is the failure to perceive the second occurrence of a repeated item in rapid serial visual presentation (RSVP). Such a repetition deficit has also been demonstrated in auditory presentation (repetition deafness, RD; Miller & MacKay, 1994). RB and RD, however, occur within the same modality, and no cross-modal repetition deficit is observed (Soto-Faraco & Spence, 2002). We examined whether two sounds accompanied the two critical items (C1, C2) could reduce the effect of RB. Each trial consisted of 3 Chinese characters and 4 symbols, and the participants were asked to write down the characters shown in RSVP. C1 and C2 were identical (the repeated condition) or different (the unrepeated condition). We first replicated the RB effect for the stimuli we used (Experiment 1): Lower accuracy was found in the repeated condition than that in the unrepeated condition. In Experiment 2-4, two sounds were presented during the RSVP. The first sound was presented simultaneously with the onset of C1, whereas the second sound was presented simultaneously (Experiment 2), 86 ms before (Experiment 3), or 86 ms after (Experiment 4) the onset of C2. Results showed that the added sounds could effectively reduce the effect of RB, except for the condition in which the second sound appeared after C2. These results are best explained by the token individuation failure hypothesis of RB, and suggest that auditory and visual inputs can be integrated into an episodic representation within a time window to facilitate the visual tokenization process.

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877 Crossmodal binding of audio-visual correspondent features

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Objects and events in the environment typically produce correlated input to several sensory modalities at once. It is important to understand the conditions under which the different sensory streams are integrated and the supporting mechanism. We ask whether there is crossmodal binding of non-speech auditory and visual stimuli and how and where it is realized physiologically. Do the pitch of a sound and the location of a visual object have some crossmodal correspondence that might provide a basis for their integration (as suggested by the shared use of verbal labels like 'high' and 'low'). In two studies, participants made speeded discrimination responses to one modality of a bimodal audiovisual stimulus, with congruent, incongruent, or neutral pairing of features. RTs were significantly faster to either the location of the object or the pitch of the sound when the bimodal stimuli were congruent (a high pitch sound with an object in the upper location) than when they were incongruent (a low pitch sound with an object in the upper location). The second study asked if the enhancement was due to perceptual integration, by using a discrimination that was orthogonal to the congruent or incongruent features, and so could not be enhanced by shared response activation. We found faster RT's for

congruent stimuli even when the task was to discriminate the object shape or the instrument sound. The advantage of the congruent over the incongruent condition in this orthogonal task must reflect a crossmodal perceptual process rather than crossmodally induced shifts in response criteria. Since the synchrony and spatial proximity were matched across conditions, the bimodal interaction was based primarily on the featural or content correspondence. We conclude that the pitch of a sound and the spatial location of a visual object have a natural correspondence or mapping and may be automatically integrated. An fMRI study explored the neural basis of this crossmodal interaction.

878 Auditory stimulation modifies the apparent motion.

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A single flash accompanied with two auditory stimuli would be perceived as two flashes (Shams et al., 2000). In present study, we examined whether the number of auditory stimuli could affect the apparent motion, which is induced by multiple flash stimuli. We conducted experiments in which the visual stimuli (2.9 X 8.7 arc min) that induced the apparent motion on the front parallel plane, or in depth dimension, were accompanied with multiple auditory stimuli (105 Hz tones). The number of the visual and auditory stimuli ranged from two to four. The duration of each stimulus and inter stimulus interval were respectively 67 msec and 83 msec for both visual and auditory stimuli. There were three distance conditions, which was defined by the distance between the first and last visual stimuli: 0 (stationary), 52.0, and 104.0 arc min for the motion on the front parallel plane (rightward, or leftward), and 0, 7.2, and 17.4 arc min (crossed, or uncrossed disparity) for the motion in depth (approaching, or going away from observer). The visual stimuli were located within these distances at regular intervals. Each condition was presented 10 times in random order for each observer. In each trial, the observer reported the number of the visual stimuli (Exps 1, 2), and the distance between the first and last visual stimuli (Exp 2). When the number of the auditory stimuli was more (less) than that of the visual stimuli, observers tended to perceive more (less) visual stimuli than the veridical number of the visual stimuli for both motion on the front parallel plane and in depth dimension. When the observers perceived more (less) visual stimuli than the veridical number, the perceived distance of the apparent motion was significantly larger (smaller) than the reported distance in the trials in which they perceived the visual stimuli with veridical numbers. These results indicate that the auditory stimulation modifies the apparent motion by modulating the extent of the displacement and step numbers.

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879 Cross modal correlation search in the presence of visual distractors

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Previous studies on cross-modal event detection have focused on coincidence detection between single visual and auditory events. In the natural environment we are usually confronted with multiple visual and/or auditory events that occur simultaneously. In order to correctly match these auditory and visual events it is necessary to determine the temporal correlation between them. One question that arises is whether cross-modal correlation detection is a pre-attentive low-level process or an attention driven process. If cross-modal correlation detection is an attention driven process then each visual cue that could potentially be correlated with the sound needs to be analyzed in series. If it is a pre-attentive process then parallel processing may occur. To test if the cross-modal correlation detection is pre- or post-attentive we measured the time needed to find the

visual target correlated with the sound, embedded among uncorrelated distractors, as a function of the number of visual elements in the stimulus. Our results suggest that the time required for 75% target detection increases linearly with the number of visual elements. This suggests an attention mediated search. Additionally, when the exposure duration was fixed, the accuracy to identify the correlated visual target steeply decreased with the number of visual elements. This cannot be ascribed to the visual crowding effect, since when the target location was indicated by a prior cue, correlation detection was as easy as when the target was presented alone. Both experiments indicate that these cross-modal temporal comparisons are done by serial attention demanding, rather than parallel pre-attentive, mechanisms.

880 Auditory Tones Influence Perceived Speed in Apparent Motion

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Several cross-modal studies show an interaction when two modalities provide converging evidence for a given attribute, for instance an estimate of spatial location in the ventriloquist effect. Which modality dominates depends on the reliability of each modality for that particular attribute. For a stimulus that varies across both space and time, we therefore anticipate that vision will have a predominant role over its spatial properties and audition a predominant role over its temporal properties. We tested this prediction on the perceived speed of an apparent motion display in presence of fluttering tones. We hypothesized that the temporal frequency of the auditory signal could influence the perceived temporal frequency of the visual display, and in turn affect its perceived speed. Visual stimuli were two Gabors presented on either side of the fixation cross, moving in opposite directions (either inwards or outwards). The spatial envelope stayed stationary and the motion was produced by shifting the carrier's phase by 90deg at a rate of 19Hz. This visual display was presented simultaneously with a fluttering sequence of tones at a rate of 16 or 22Hz. Observers had to decide whether this bimodal stimulus appeared to move faster or slower than a purely visual stimulus whose phase was varied between trials. The point of subjective equality was taken as a measure of the perceived speed of the bimodal stimulus. The rate of the auditory tones influenced the perceived speed of the visual display: the slow auditory rate slowed down the perceived speed, and the fast rate accelerated it. These results suggest that the integration between auditory and visual temporal signals occurs before the estimation of speed.

881 Response Biases in the Illusory-Flash Effect

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In the illusory-flash effect (Shams et al., 2000, *Nature*, 408,788), two flashes presented with three tones have a tendency to be perceived as three flashes. The origin of this illusory percept is uncertain. In particular, it is not clear whether this illusory percept results from an increased willingness to report seeing three flashes (criterion shift) or a decrease in accuracy (sensitivity change). We address this issue by measuring the ability to detect a low-contrast target presented simultaneously with an auditory tone. Four possible combinations of audio-visual events were presented, with 2 or 3 flashed Gabors and 2 or 3 auditory tones. When present, the central flash had a modulated contrast. A tone was always presented simultaneously with both the first and the last flash. In half of the trials, a third tone was presented equidistant in time between the others, synchronously with the central flash if present. Observers reported whether they perceived 2 or 3 flashes. A comparison of the psychometric functions for contrast detection showed a lateral shift of the 3-tone relative to the 2-tone condition, while the slopes of the psychometric functions remained approximately constant. These results suggest that the additional tone produced a criterion shift in the observer's decision, not a change in sensitivity. Our results contrast with previous reports of an

increased sensitivity in orientation discrimination when a rapid series of tones are presented simultaneously with visual flickering stimuli (Berger et al., 2003, *J. Vision*, 3, 406-412). We discuss potential reasons for this discrepancy and implications for models of cross-modal interaction.

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882 Lights can reverse auditory localization

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Adding brief flashes of light to a series of auditory click-pairs (Hari, 1995) alters their perceived location. Observers listened over headphones to eight click-pairs (i.e., 4 left-ear leading then 4 right-ear leading) separated by several ISI's, then reported the perceived location of each click-pair within the head. In three related experiments, flashing a light(s) leftward on a CRT screen during specific temporally coincident click-pairs made observers report the location of the sounds in roughly equally spaced steps from left-to-right through the head. In contrast, clicks originating rightward either minimized this rating scale range, or in some cases, went so far as to reverse it, so that the sound appeared to originate rightward and shift leftward. This multimodal effect occurs although the light was external to the head while the headphone sounds occurred within the head.

References Hari, R. (1995). Illusory directional hearing in humans. *Neuroscience Letters*, 189, 29-30.

883 Pitch of Concurrent Pure Tone Influences Visual Gender Perception

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Hearing a concurrent high or low tone affects perception of gender. To dissociate the tone from the gender task, two response dimensions were used, with the tone serving as a task-switching cue. Observers were asked to categorize natural faces based on gender (male or female) and race (Asian or Caucasian). Each face was presented for 200 ms, accompanied by either a high or low pure auditory tone. The high tone was 240 Hz, a midrange fundamental speaking frequency for female voices, while the low tone was 120 Hz, a midrange frequency for male voices. Half of the Os were instructed to name the gender of the face if they heard a high tone, and the race if they heard a low tone. Half of the Os had the tone assignments reversed. Os who had the gender task paired with the high tone responded faster to female faces than those who had gender paired with the low tone, while there was no effect of tone for male faces. A possible reason for this asymmetry is that a female with a low voice would be highly improbable, whereas pre-pubescent males with high voices are commonplace. In order to determine if the tone would directly influence perceived gender, Os were shown digitally generated gender-morphed faces, which were determined to be androgynous in a pilot study. The results not only replicated previous RT findings, with the high tone leading to faster female responses and the low tone yielding faster male responses, but androgynous faces were also perceived as female more frequently when they were paired with the high tone than with the low tone. To determine that this effect was dependent on the tones being in male or female fundamental speaking frequency ranges, we used high and low tones outside of the human vocal range (3200 and 55 Hz), and tones that are both in the male speaking frequency range (100 and 140 Hz). The results suggest that the tone effect is tuned to speaking frequencies, providing additional support for cross-modal integration of gender cues.

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884 Implicit Auditory Signal Can Scale Men's Egocentric Spatial Representation

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As we move we generate changes in the internal and external sensory signals, and the coupling between the two types of signals calibrates our actions. The calibration is stored and can be used to update an accurate egocentric representation of space when external sensory information is absent. We recently showed that the calibration established in the real world is inoperative in novel immersive virtual environments (VR). In that experiment, subjects walked without vision to a target in a VR scene. The only external source capable of providing feedback was a beep emitted at the end of a trial, implicitly signaling target distance. Initially, paths varied with the changing scene context, indicating a reliance on the memory of non-motion-generated visual information to define an egocentric position. Over time, men's paths were less affected by scene context. We postulate that the men used the implicit auditory cue to calibrate their action system. Here we test this hypothesis by varying the distance at which a beep is emitted. Using VR, 5 men and 5 women saw a 1-s display of a scene with a ball in a doorway located 6 m away. The ball was 38 left or right of starting position, and the task was to walk to the ball. A beep, indicating end of trial, was emitted when the subject passed a certain distance. Distance of beep (4 or 8 m) was tested in blocks of 18 trials, and data were analyzed in 3 time epochs. If subjects used the auditory cue for calibration, their angular path to target should scale with beep distance. Predicted scaling of the actual 38 target angle is 4.58 for a 4m beep and 2.38 for an 8m beep. The results showed an interaction between beep distance, epoch, and gender. Only men had significant differences in path angle between the 4 and 8 m beep distances (4.88 vs 2.98), occurring as early as the 2nd epoch. Women's angles were 5.28 vs 5.58. Our findings demonstrate that implicit auditory cues can calibrate men's action system and scale their egocentric representation of space.

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885 The Influences of Visual Pitch on Visually Perceived Eye Level, Visually Perceived Pitch, Felt Head Orientation, and Felt Hand Orientation

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A pitched environment exerts a large systematic influence on the visually perceived elevation of objects within the visual field; however, reports by observers of changes in the perceived orientation of their own bodies relative to gravity have been very rare. We now present measurements showing that systematic changes in felt orientation of the head and of the hand are general. Our investigation was conducted in a well-illuminated, complexly structured pitchroom (1.52 m x 1.82 m x 1.52 m) with binocular viewing of the pitchroom at a viewing distance of 1 m. Ten participants made four types of settings while binocularly viewing the pitchroom at six orientations from -30° to +20°: (1) setting the elevation of a small luminous target to appear at eye level (VPEL); (2) setting the pitch of a 30 cm x 30 cm surface (80 cm in front of the observer) to appear erect, i.e. unpitched; (3) setting the pitch of the head to feel erect; (4) manually setting the pitch of an unseen plane surface laterally located within the observer's midfrontal plane to feel erect. All four settings changed systematically with physical pitch. The average slopes of the functions relative to physical pitch are: (1) VPEL, 0.69; (2) visual pitch, 0.87; (3) head pitch, 0.10; (4) hand pitch, 0.11. The influences on felt head pitch and felt hand pitch are 14% and 16% of the VPEL setting, respectively. These changes in head and hand pitch suggest that changes in felt body orientation contribute to changes in VPEL. Taking into consideration the average head and hand pitches calculated in this experiment, an average VPEL-vs-pitch slope of 0.59 is directly accounted for by an uncompensated change in retinal orientation of the pitched visual environment. This pattern is consistent with the earlier view that the pitch-induced change in VPEL is a consequence of a

linear weighted sum of inputs from the visual field and from a body-referenced mechanism that makes use of extraretinal information.

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886 An ideal observer analysis of variability in visual-only speech

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Purpose: Normal-hearing observers are typically able to understand speech to some degree when it is presented in the visual-only modality, without an accompanying auditory signal. However, different talkers vary in how easily they can be understood through visual-only speech perception. It has previously been unclear whether this variability in talker intelligibility is due to differences in the amount of physical information available in the visual speech signal or to human perceptual strategies that are more optimally suited to some talkers than others. We investigated this issue by comparing human performance to that of an ideal observer constrained only by the availability of information in visual-only speech.

Methods: 8 talkers (4 male, 4 female) were videotaped saying 10 monosyllabic English words equated for frequency. The visual portions of the movies were presented to observers in a 1-interval, 10-alternative identification task that was blocked by talker. On each trial, dynamic Gaussian pixel noise was added to a randomly chosen word movie. The contrast of the movies was varied across trials using a staircase procedure to obtain each observer's 71% correct word-identification threshold for each talker. Ideal observer thresholds for each talker were measured using Monte Carlo simulations.

Results & Conclusions: Although the ideal observer's thresholds varied somewhat across talkers, human observer thresholds showed a different pattern and a much wider range of variability. Pilot data from 2 human observers indicated that word recognition efficiencies (ideal/human thresholds) varied by as much as a factor of 30 across talkers. This variability in efficiency suggests that the differences across talkers in human visual speech recognition are not due to differences in the amount of physical information available in visual speech patterns, but instead to differences in the relative suitability of human perceptual strategies for different talkers.

887 Sound-induced illusory flash perception modulates V1 activity

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Abstract

The auditory-induced double flash illusion shows that conscious visual perception can be modified by irrelevant auditory stimulation. A single visual flash is perceived incorrectly as two flashes when it is accompanied by two auditory bleeps. Here, we used event-related high field functional MRI in conjunction with retinotopic mapping of early visual cortex to examine the neural basis of this illusory phenomenon. On each trial, participants were presented with either one or two successively flashed high contrast annuli around fixation, either alone or in association with one or two binaurally presented bleeps. Participants indicated on each trial by 2AFC button press whether they perceived either one or two flashes. Behaviorally, on a significant proportion of single flash trials that were accompanied by two bleeps, participants reported the perceptual experience of two flashes i.e. the illusion. We then compared brain activity evoked by physically identical but perceptually dissimilar (illusion versus no illusion) one-flash-two-bleep trials. In retinotopic area V1, there was significantly greater activation for illusion versus no illusion trials. Such activation cannot reflect a general auditory alerting effect as the trials in such a comparison are physically identical. Taken together, our findings

provide strong evidence that irrelevant auditory stimulation can modulate brain activity and conscious perception at the earliest stages of "visual" cortical processing.

888 Attending to Visual or Auditory Motion Affects Perception within and across Modalities: An Event-related Potential Study

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Several previous studies have shown that spatial attention not only affects perception within the attended modality (unimodal), but also within task-irrelevant modalities (crossmodal). The present event-related potential (ERP) study examined whether dynamic features such as the direction of motion are also important in multisensory binding. Participants perceived horizontally moving dot patterns and sounds which were presented either continuously (standards) or were briefly interrupted (infrequent deviants). Their task was to detect deviants moving in a particular direction within a primary modality, but to detect all deviants irrespective of their motion direction within the secondary modality. Attending to the motion direction of visual stimuli resulted in enhanced visual ERPs over parietal sites starting at about 200 ms post stimulus onset. Attending to the motion direction of sounds elicited a positive difference (Pd) wave at 150 ms that was followed by a broad negativity (Nd) starting at about 200 ms in auditory ERPs. Moreover, attention to motion within one modality also affected processing of moving stimuli within another modality (crossmodal effects). Dot patterns moving in a direction that was relevant within audition were detected faster and elicited stronger visual ERPs than dot patterns moving in the opposite direction. Similarly, sounds moving in a direction that was relevant within vision were detected faster and were associated with larger auditory ERPs than oppositely moving sounds. These crossmodal effects were smaller than unimodal effects. Their scalp distribution partially differed from the topographies of their unimodal counterparts. The present results suggest that motion is an important feature in order to link auditory and visual input as, for instance, within multisensory integration.

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889 Neurophysiological changes in the visual cortex after cochlear implantation

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Using visual evoked potentials (VEP), the cortical network engaged by apparent motion in the central and peripheral visual field in twenty subjects with normal hearing was compared with that in five patients who received a cochlear implant (CI) after a period of profound deafness. All the patients wore the CI for two years, but they did not react in the same manner to the reintroduction of the auditory input. The three first patients (SL, SB and JFR) quickly learned to use the device whereas the fourth patient (JD) resigned after having attempted unsuccessfully for a full year, and the fifth (JME) and the sixth (JSG) patients had mitigated success using the CI. The visual evoked potentials of the three most successful CI users showed supranormal amplitudes in their VEP but only after the CI implantation; the waveforms of the other CI users did not strikingly differ from those of the control participants. These results are interpreted and discussed in terms of intermodal plasticity.

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890 Monkeys match the number of voices they hear to the number of faces they see

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A wealth of data demonstrates that nonhuman animals, infants, and adults represent number nonverbally as analog magnitudes (e.g., Brannon and Roitman, 2003). A recent study (Barth et al., 2003) suggests that the nonverbal number representations held by adults are modality independent, leading to the prediction that nonlinguistic organisms may also hold number representations that transcend the modality in which they were created. In our first experiment, we ask whether rhesus monkeys will preferentially attend to visual displays of vocalizing conspecifics that numerically match the number of calls they hear. Subjects viewed two side-by-side videos of vocalizing, unfamiliar monkey faces; one contained 2 monkeys and one contained 3. Synchronous with the videos, subjects heard 2 or 3 concurrent coo calls. Onset and offset of auditory and visual stimuli were equated to eliminate the possibility that monkeys could match based on synchrony. Each subject was tested with only a single trial and was not rewarded. This design eliminated the possibility of matching based on the relative intensity of auditory and visual stimuli. Monkeys directed 60% of their total looking time to the matching display, which differed significantly from chance [$t(19)=3.00$, $p < 0.01$]. A 2 (match vs. non-match) \times 2 (2-sound vs. 3-sound) \times 3 (stimulus set 1, 2, or 3) ANOVA revealed that monkeys looked longer at the numerically matching display than at the nonmatching display [$F(1,15) = 7.5$, $p < .02$] and no other main effects or interactions. Our second experiment demonstrated that monkeys did not look preferentially at the numerically matching display when arbitrarily related animated visual shapes and complex tones were used as stimuli. Results demonstrate that rhesus monkeys represent the equivalence between the number of voices they hear and the number of faces they see and suggest that monkeys share with adult humans nonverbal number representations unfettered by stimulus modality.

Visual Cortical Organization

891 The Role of the LGN on the Spatial Frequency Dependence of Surround Suppression in V1: Investigations Using a Computational Model

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Using a large scale model of macaque V1, we have shown (Wielaard & Sajda 2003, 2005) how only local short-range (< 0.5 mm) connections within V1 can mediate surround suppression and account for a large fraction of the magnitude of suppression seen experimentally. In our model surround suppression arises from one of three mechanisms: (a) an increase in cortical inhibition, (b) a decrease in cortical excitation, or (c) both of these simultaneously. It is known that LGN neurons exhibit both classical and extraclassical surround suppression, with classical surround suppression observed at lower spatial frequencies. This leaves open the question of whether the unexplained fraction of suppression seen in our model could be inherited from the LGN or instead requires considering long-range lateral connections and/or extrastriate feedback. Using our model, we consider the effect of classical LGN surround suppression on suppression in V1 cortical neurons, in particular by measuring the distribution of the suppression index at spatial frequencies that are a quarter of those typically used to optimally drive cortical neurons. We find that at these lower spatial frequencies, nearly all of the classical surround suppression of LGN cells is transferred to V1 cells, either via direct LGN input into the cell and/or suppression of recurrent cortico-cortical excitation. We also see that at these low spatial frequencies, the prevalence

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of the cortical mechanisms for surround suppression is shifted in favor of mechanisms b and C, which rely on the reduction of excitation. This shift occurs at the expense of mechanism a, which relies on direct inhibition. Our model thus predicts 1) a substantial increase in V1 surround suppression is possible by sufficiently lowering the stimulus spatial frequency and 2) that ultimately the magnitude of surround suppression seen in V1 neurons is explainable by considering only the short-range cortical connections and the LGN input.

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892 Multifocal 60 region fMRI mapping of human visual cortex

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Human visual cortical areas have in the past been mapped with functional MRI by analyzing the phase-encoded responses to rotating wedge and expanding/contracting annular stimuli. We present here a method for the multifocal fMRI analysis of visual cortex, with the extraction of activation maps for multiple fixed visual field locations by decomposition of the compound response to test stimulus sequences applied concurrently to each location. The stimulus layout was a 60 region cortically-scaled dartboard of diameter 24° comprising 12 sectors in each of 5 concentric rings scaled to activate approximately equal areas in cortical area V1. For each 7.2 second block of the run, a different set of half of the 60 regions was active with 4x4 checkerboards reversing at 8 reversals/s, according to an orthogonal design. Two runs of 8 minutes give adequate results. Six subjects had scans done in a 3T GE Signa scanner, along with structural MRI and phase-encoded retinotopic analysis of conventional design. Data were analyzed with SPM2 with custom extensions, including optimization of the haemodynamic response model, noise autocorrelation and low-frequency trend removal. The resulting maps with these stimulus parameters reliably show each of the 60 regions activating area V1, in accordance with expected topography. Statistically significant activations also occurred in areas V2 and V3 for many regions, in the expected retinotopic locations. The method demonstrates the viability of mapping human visual areas with fMRI using a multifocal array of 60 known visual field locations, and results are compared with maps from phase-encoded stimulation recorded in the same sessions. The method opens possibilities for more flexible design of what stimulus type may be presented at each location, allows estimation of spatial interactions, and also facilitates the use of identical spatial layouts for fMRI and in correlative visual evoked activity analysis using EEG and MEG recording.

893 Multifocal 60 region fMRI derivation of the 3D structure and magnification factor of human primary visual cortex

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Results are presented here from the multifocal fMRI analysis of human primary visual cortex, which derives activation maps for 60 fixed visual field locations by decomposition of the compound response to test stimulus sequences applied concurrently to each location. The stimulus layout was a 60 region cortically-scaled dartboard of diameter 24° comprising 12 sectors in each of 5 concentric rings scaled to activate approximately equal areas in cortical area V1. For each 7.2 second block of the run, a different set of half of the 60 regions was active with 4x4 checkerboards reversing at 8 reversals/s, according to an orthogonal design. Two runs of 8 minutes give adequate results. Six subjects had scans done in a 3T GE Signa scanner, along with structural MRI and phase-

encoded retinotopic analysis of conventional design. Data were analyzed with SPM2 with custom extensions to optimally estimate activation strength and significance maps for each of the 60 stimulus regions. Calculation of the centre of mass of the thresholded volume distributions for each of the 60 visual field regions produces robust 3D localization of the centre of primary visual cortex response for each stimulus region, in all subjects. The 30 points in each hemisphere produce surfaces in 3D reliably mapping primary visual cortex in and around the calcarine sulcus. The surfaces obtained are in agreement with the white matter-gray matter border derived from segmentation of high-resolution anatomical scans, but can be derived without them. Thin-plate splines were used to fit smooth surfaces through the primary 3D data, from which estimates of the cortical magnification factor are derived with respect to eccentricity and polar angle, and compared with current models. The viability of detailed mapping of the 3D structure of human primary visual cortex without requiring co-registration with high resolution anatomical data is demonstrated.

894 The structure of cortical hypercolumns: receptive field scatter may enhance rather than degrade boundary contour representation in V1

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The spatial relationship of orientation mapping, ocularity, and receptive field (RF) position provides an operational definition of the term "hypercolumn" in V1. Optical recording suggests that pinwheel centers and blobs are spatially uncorrelated. However, error analysis indicates a 100-2150 micron systematic pinwheel center positional offset. This analysis suggests that pinwheel singularities and cytochrome oxidase blobs in primate V1 may in fact be coterminous. The only model to date that accounts for this detailed spatial relationship of ocularity, orientation mapping, and RF position is the columnar shear model (Wood and Schwartz, *Neural Networks*, 12:205-210, 1999). Here, we generalize this model to include RF scatter, which is observed to be in the range of one third to one half of the local RF size. This model provides a computational basis to address the following question: How is the existence of RF scatter consistent with accurate edge localization? We show that scatter of about one half the average RF size can provide an accurate representation of region and edge structure in an image based on a simple form of local inhibition between the blob (spatially low-pass) and interblob (spatially band-pass) neurons resulting in a process equivalent to nonlinear diffusion. The advantages afforded by this mechanism for edge preservation and noise suppression are that it avoids the slowness of diffusion (where time is proportional to distance squared) and is fully consistent with a correct understanding of the structure of the cortical hypercolumn. We demonstrate the effectiveness of this algorithm, known in the computer vision literature as the offset filter (Fischl and Schwartz, *IEEE PAMI* 22:42-748, 1999), by providing results on natural images corrupted with noise. This work emphasizes the importance of a low-pass response to accurate edge-representation—a function usually attributed to the intensity normalized, band-pass response of extra-blob neurons.

895 Multifocal VEP signal dependence on stimulus area

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Multifocal VEPs can be used to investigate retinotopically organized visual areas. Source localization works best using the smallest patch sizes that give reliable signals. We investigated how the scalp signal varies with stimulus patch size.

The stimulus was a dartboard pattern consisting of 12 spokes and 4 concentric cortically scaled rings for a total of 48 patches. The rings extended from 1 to 6.5 deg in eccentricity. Each patch contained 4 squares in the radial direction, and from 1 to 7 squares per spoke in the tangential direction. Patches were modulated using a binary M-sequence and the scalp potential topographies (64 to 96 recording electrodes) were cross correlated to get 2nd order kernel responses.

Amazingly, reliable responses were obtained for stimuli that activate approximately 2 by 8 mm of cortical surface in V1. Moreover, when averaged across all stimulus locations signal strength increased linearly with patch size. Some individual patches exhibited deviations from linearity that were consistent with known cortical topography. For example, if the activated cortical area were at the apex of a sulcus, as patch size grows the activated area would extend around the sulcus. As it grows around the sulcus equal and opposite currents cancel with little or no change in signal strength at the recording electrode.

In further experiments we tested spatial summation directly by independently stimulating subdivisions of patches and comparing the summed response to the undivided patch response. For patches in the inner and outer rings the linear summation of the sub-regions matched the response to the large region. However, in the two middle rings subdivisions exhibited faster response latencies.

Future VEP source localization studies using small areas of activation could potentially provide a fine 3D retinotopic map of the cortical surface.

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896 Cortical Folding as a Sparseness Criterion for Identifying VEP Sources

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Background. Topographic mapping of the multifocal VEP can reveal temporal processing and interactions between closely spaced sources in early visual areas, such as V1 and V2. To identify closely spaced sources (the inverse problem) a sparseness condition is needed. The present study asks whether sparseness of cortical folding at certain time points might be exhibited in the changing topographic maps in multielectrode, multifocal VEP data.

Methods. The VEP stimuli consisted of a dartboard pattern containing 96 checkerboard patches. The patches were arranged in 4 rings of 24 patches each. Each patch was modulated according to a binary m-sequence and was cortically scaled to activate about 30 mm² of primary cortex. Each subject viewed the stimulus wearing a cap with 64 or 96 recording electrodes. The checkerboard reversal response for each patch at each electrode was calculated by cross-correlation (1st cut of 2nd order kernel) and topographic maps of scalp activation for each stimulus patch were evaluated. When the area of activation moves around a cortical fold in response to a neighboring stimulus patch the scalp topography is expected to change dramatically. The number of distinct response topographies was estimated for each time period of strong activation.

Results. We found that in the densely sampled hemifields (48 patches per hemifield) there were between 5 and 10 distinct cortical maps indicative of sites of activation having moved around a cortical fold or a dorsal/ventral jump. At some time points the distinct map count was much smaller as expected when the response of one cortical area passes through a zero point and is effectively silenced.

Discussion. We expect the reduction of distinct folds at particular time points provides the sparseness condition needed to resolve the rotation ambiguity that has stymied previous attempts to disambiguate closely spaced sources in early visual areas.

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897 Cortical representation of space around the blind spot

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Two hypotheses have been proposed to explain filling-in of the blind spot. The active completion theory proposes that neuronal filling-in of the blind spot only occurs when the blind spot is also perceptually filled-in, such as when a stimulus is congruently presented to opposite sides of the blind spot. Alternatively, the passive remapping hypothesis proposes that neuronal filling-in can occur in the absence of perceptual filling-in when only a single side of the blind spot is stimulated. Thus, the passive account predicts that independent stimulation applied to the left or right of the blind spot should lead to neuronal filling-in (despite no perceptual filling-in), resulting in neighboring activations in visual cortex when the blind-spot eye is stimulated, but more separated activations when the fellow eye is stimulated. Using functional MRI, we tested the remapping hypothesis in four subjects by calculating the distance between cortical activations evoked by flickering checkerboard wedges (~5 deg) presented independently to the left or to the right of the blind spot's spatial location, either to the blind-spot eye or to the fellow eye. Irrespective of which eye was stimulated, we found separate activations corresponding to the left and right wedges. Distances between cortical activations were measured after identifying the activation's centroid on a cortical flat map. These distances were highly precise and reliable (mean distance 6-8 mm across subjects, SD ~1 mm within subjects) and are not different for the blind-spot eye and the fellow eye in area V1 and in area V2/V3. These results suggest that passive remapping is not the mechanism underlying filling-in of the blind spot. Instead, our findings are consistent with the active completion theory, which proposes that neuronal filling-in of the blind spot only occurs if the blind spot is also perceptually filled-in. Follow-up experiments to investigate the active completion theory are in progress.

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898 Gibson, meet topography: the dipole structure of extra striate cortex facilitates navigation via optical flow

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Gibson's sketch of a bird flying through a spherical vector field containing a *source* (frontwards) and a *sink* (rearwards) of the optical flow sparked the beginning of interest in optical flow as a navigational cue. He claimed "the anatomical fact of an approximate 'wiring system' from retina to brain has nothing to do with perception", an opinion which some still hold. The source and sink lie along the direction of motion, but the sink is apparently uncomputable—it lies beyond the limits of the visual field. However, recent advances in understanding visuotopic mapping (the *dipole model*; see Polimeni et al., *VSS 2005 Annual Meeting*) indicate the existence of both a foveal source and a peripheral sink in the cortical representation of optical flow field that is realizable in the retinal and cortical representations. The dipole geometry of topographic mappings provides accurate cues for navigation and egomotion estimation which solve several of the problems which have plagued earlier attempts that ignored peripheral vision. Specifically, the peripheral flow (i) is tolerant of misalignment of the optical and motion axes; (ii) is insensitive to significant occlusion by distractors of unknown motion; and (iii) represents an accurate model of wide-field visuotopy. This algorithm is based on the Helmholtz-Hodge decomposition of the optical flow field, and the basic measurements are given by the divergence and curl operations on the cortical representation of the vector field. We demonstrate its advantages using synthetic optical flow fields as well as natural image sequences obtained from high resolution wide-field natural movie sequences. It is the peripheral rather than the foveal structure of the optical flow field that provides the most robust estimate of egomotion,

particularly when the peripheral field is represented in terms of a (negative) logarithmic pole in addition to the familiar (positive) logarithmic pole at the fovea, as in the dipole model of cortical visuotopic mapping.

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899 Enhanced Concepts of Occipital Retinotopy

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Rationale. Retinotopic mapping is a key property of organization of occipital cortex, predominantly on the medial surface but increasingly being identified in lateral and ventral regions. The organization of retinotopic activation these extended regions remains to be fully resolved. **Methods.** Rotating wedge and logarithmic expanding ring stimuli were used with functional magnetic resonance imaging (fMRI), cortical segmentation and cut-free flattening to define a full array of retinotopic activation maps.

Results. In the dorsal occipital regions, we confirm the general agreement that there is a retinotopic V3B map lateral to V3A, and that beyond them lies a further map, V7. We specify for the first time the eccentricity mapping for V3B as running obliquely dorsal, and for V7 as running roughly parallel to the meridional mapping, offering a formal account of the paradox of co-oriented meridional and eccentricity mapping. In ventral occipital cortex, we support the view that V4 maps the full hemifield but with a shorter eccentricity span than the adjacent V3v map, and show the existence of two more maps in each hemisphere, a ventromedial occipital (VMO) map of the upper quadrant, emphasizing the upper vertical meridian, and an adjacent map with a dominant foveal representation. In lateral cortex, a dorsolateral occipital (DLO) map lies between the motion area and V3B, representing the lower quadrant with an emphasis on the lower vertical meridian, may be a counterpart to the ventromedial map. This retinotopic DLO map occupies most of the territory designated as V4d on topological considerations.

Conclusion. Several retinotopic maps may be identified beyond area V4 but they have unconventional mapping properties. This new scheme offers a novel resolution to the issue of the V4 homology with monkey, by moving the ventral/dorsal split up to the next higher mapping in human occipital cortex.

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<http://www.rdg.ac.uk/ar/>

900 Geometric and metric properties of visual areas V1 and V2 in humans.

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INTRODUCTION: Before the human cortex was measured by fMRI, Schwartz (1980, Biological Cybernetics) proposed a set of complex-logarithmic mapping functions to match the actually measured structure of visual cortex for primates and cats, and proposed a model for human visual cortex. Since 1980, the size, shape and cortical magnification functions of early visual areas have been measured in humans with fMRI using retinotopic mapping procedures. As it is well known, the relationship between visual field eccentricity and cortical distance from the fovea can be described approximately by a log function. The function describing the increase in width of each visual area with eccentricity is not known, however. The complete mapping between visual space and cortex is a combination of these two functions.

METHODS: We have collected retinotopic mapping data on 8 subjects using standard fMRI procedures. We are using the atlas fitting functions from the VISTA-toolbox (Dougherty et al. 2003) to define iso-eccentricity lines on the flattened cortices of these subjects. We can then measure the length of these lines along the 3D-surface of the reconstructed cortical manifold.

RESULTS: We find a substantial increase in V1 width with eccentricity. In our subjects, V1 width continuously increased by a factor of between two and four from 18 to 168 eccentricity.

CONCLUSIONS: The combined measurements of eccentricity magnification functions and width magnification functions can be used to calculate the amount and isotropy of cortical area devoted to visual space at any eccentricity, which may be compared with theoretical treatments of the mapping of visual space to cortex. These results are inconsistent with the mapping function $\log(z+a)$ with an estimated $a < 0.88$, proposed by Schwartz (1993 in Visual Science and Engineering). We will also provide data to rigorously constrain more elaborated models such as the conformal dipole mapping scheme of Balasubramanian et al. (2002 Neural Networks).

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901 Two-dimensional mathematical structure of the human visuotopic map complex in V1, V2, and V3 measured via fMRI at 3 and 7 Tesla

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We describe an improved methodology for recording human visual topography in striate and extra-striate cortex via fMRI at 3 T and 7 T field strengths, as well as the first fit of a two-dimensional map function which jointly models the visuotopic structure within cortical areas V1, V2, and V3 to fMRI visual topography data. We discuss five methodological improvements for fMRI visual topography studies. (1) We constructed a custom multi-channel surface coil covering occipital cortex for an improvement in signal-to-noise ratio relative to standard head coil systems. (2) Real-time feedback to subjects, based on psychometrically established eye fixation performance for individual subjects, motivated subjects to maintain fixation. This enabled us to verify accurate long-term fixation and to discard trials where performance was poor. (3) We developed a phase encoding stimulus paradigm where the standard M-factor scaling of a black-and-white checkerboard pattern is replaced with a dynamic spatial noise pattern, in which the correlation length of the noise is matched to cortical magnification factor and thus scales with distance from the center of the visual field. (4) Least-squares optimal quasi-isometric brain flattening was used to obtain flat representations of the two-dimensional cortical surface without relaxation cuts through V1 or any other retinotopic area. (5) Finally, we fit a recently developed model of the structure of V1, V2, and V3 visual topography (Balasubramanian et al., *Neural Networks*, 15:1157-1163, 2002) to our data. This mathematical model allows for shear (i.e., anisotropy) in the cortical map and uses a small number of parameters (two global parameters and one additional parameter each for V1, V2, and V3 shear). Results of this new methodology and data analysis are presented on five human subjects, four collected at 3 T field strength and one collected at 7 T field strength.

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902 Dynamics of Line Motion Illusion Reflects the Anatomical and Functional Architecture of the Early Visual Cortex

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BACKGROUND A static line gives a motion perception when it follows a cue appearing at one of its ends, dubbed line motion illusion (LMI)

* Student Travel Fellowship Recipient

(Hikosaka et al., 1993). Despite many attempts to understand how attention affects LMI, its neural basis remained relatively unexplored until recently. However, a real-time optical imaging study on anaesthetized cats (Jancke et al., 2004) suggests that LMI can be mediated by subthreshold cortical activity triggered by a cue. In addition, psychophysical and fMRI studies on humans demonstrated that the dynamics of perceptual waves well coincides with the functional structure of V1 (Wilson et al., 2001; Lee et al., 2004). Inspired by these findings, we assessed how LMI is constrained by the properties of the early visual cortex. **METHOD** As carriers of LMI, Gabors ($sf = 3$ cycles/8, $\sigma = .28$, peak contrast = $.15 \sim .3$) appeared on a 68-radius annulus. In most trials, a single Gabor ('cue') briefly appeared randomly at one of the 8 locations equally spaced, and was followed by 8 neighboring Gabors ('line probe') covering a 908 arc at either side of the cue. The contrasts of Gabors were modulated in a manner that generates clock-wise or counter clock-wise physical motion. We asked subjects to judge motion direction to find the speed of physical motion that nulls LMI using a stair-case method. The orientations of Gabors were collinear to one another in half of trials and parallel in the other half. Trials without a cue were included to detect possible biases in motion perception over the annulus. **RESULT** The speed of LMI was faster for collinear line probes than for parallel ones. Furthermore, spatial inhomogeneity in LMI speed reflected the anatomy of the visual cortex: there was a time delay (.1~.2 s) for interhemispheric LMI. **CONCLUSION** The dynamics of LMI is tightly linked to the functional and anatomical properties of the visual cortex, providing a means for investigating perceptual concomitants of the propagation of neural excitability in human brains.

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903 A self-organizing neural network model of the development of motion direction selectivity, orientation, and ocular dominance maps and receptive fields in V1 and MT.

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Purpose: Numerous neural models have been proposed to explain how major characteristics of ocular dominance (OD) and orientation selectivity (OS) maps and receptive fields (RFs) may develop in V1. Yet, few examine the development of other features in V1, and hardly any examine the development of features in higher visual areas. In 1999 and 2000 (ARVO), we presented the first models of the simultaneous development of motion direction selective (DS) maps and RFs in V1 and MT/V5, respectively, given moving bar stimuli. Here, we extend this model to examine the joint development of DS, OS, and OD maps and RFs in V1 and MT given noise and natural moving stimuli to simulate pre- and postnatal conditions.

Methods: To learn multiple maps in multiple areas, we developed a new type of high-dimensional self-organizing map (SOM) involving multiple layers, parallel 'winners', and biologically realistic mechanisms. To model DS, each spatial connection contains multiple time-delayed connections and our unique principal-component-based, spatiotemporal learning rule.

Results: Given stationary stimuli, the model develops joint, ocularly-matched OS and OD maps and RFs with most of the major characteristics observed in V1 (Blasdel, 1992) under both post- and prenatal conditions. It uniquely shows the automatic formation of OS singularities near OD band centers and local orthogonality between OS and OD. Given moving stimuli, the model produces DS maps and RFs with many of the characteristics recently observed in MT (Diogo et al, 2003; Livingstone et al, 2001) and V1 (Weliky et al, 1996; Emerson, 1997), including opposing DS fractures, which are unique and common in DS maps. **Conclusion:** These results demonstrate that computational principles employed for learning OS and OD (e.g. competitive Hebbian learning with faster-than-linear inhibition) can be generalized to learn complex features in higher areas with the addition of multiple layers and spatiotemporal learning.

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904 The El Greco Effect: Perceptual Distortion from Visual Cortical Reorganization

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Cortical reorganization resulting from loss of sensory input (e.g., digit amputation, retinal lesions) has been studied extensively in the somatosensory system and to a lesser extent in the visual system. However, little work has considered the perceptual consequences of cortical reorganization. We present evidence from stroke patient BL, who has a damage to right-hemisphere inferior optic radiations. The damage caused a loss of sensory input to primary visual cortex representing the upper left visual field (LVF), producing a left superior homonymous quadrantanopia (i.e., blindness in the left upper quadrant). However, primary visual cortex itself is intact. BL exhibits dramatic distortion of perceived shape for stimuli in the lower LVF: The stimuli appear vertically elongated (toward and into the blind upper quadrant). For example, when shown a circle, he reports a "cigar" extending upward. Psychophysical testing confirmed that the distortion selectively affects the vertical dimension of shapes (i.e., the height); judgments concerning the horizontal dimension (width) are intact. Additional experiments revealed that the deficit is selective to vision (i.e., tactile shape judgments are intact); that vertical distance as well as shape judgments are affected; that the vertical distortion arises in a retinocentric frame of reference; that the extent of vertical distortion monotonically decreases with distance from the blind quadrant; and that deficit affects not only vision-for-perception, but also vision-for-action (grip aperture). Taken together, these results support the hypothesis that BL's perceptual distortions result from cortical reorganization in the early visual system: Visual cortex deprived of input from the upper LVF has apparently become responsive to stimuli in the lower LVF. These results have implications for understanding the nature and perceptual consequences of cortical reorganization in the human visual system.

905 Cross-modal activation of visual cortex during depth perception using auditory substitution of vision

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Previous neuroimaging studies identified multimodal brain areas in the visual cortex that are specialized in the processing of specific information, such as visual-haptic recognition of objects. Here we test whether visual brain areas are involved in depth perception when auditory substitution of vision is used. Seven early blind subjects (EB) and nine blindfolded sighted volunteers (BS) were trained to use a prosthesis substituting vision with audition (PSVA) to recognize two-dimensional figures. They were also taught some pictorial monocular depth cues during an object distance estimation task with the prosthesis in a real three-dimensional environment. Using positron emission tomography, regional cerebral blood flow was assessed during exploration of virtual 3D images with the prosthesis while focusing either on 2D features (target search) or on depth (target distance comparison). Results in sighted subjects showed activation in visual association areas for both the target search task, involving the occipito-parietal cortex, and the depth perception condition, which activated occipito-parietal and occipito-temporal areas. This indicates that some brain areas of the visual cortex are relatively multimodal and may be recruited for depth processing via another sense than vision. By contrast in EB subjects the activation patterns during both target search and 3D perception were quite similar and restricted to the dorsal visual stream. The absence of any specific brain activation for depth perception in the EB subjects underlined the crucial role of previous visual experience to get a visual-like depth perception with the PSVA.

906 Rendering Visual Representations From Oscillatory Brain Activity

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The subjectively seamless nature of visual experience would intuitively suggest that the underlying representations of the visual world evolve continuously. There is, however, a controversial alternative suggesting that these visual representations are in fact discrete, built up in the brain over a number of discrete processing epochs. In order to investigate this assertion we extended a new method, based on Bubbles (Gosselin & Schyns, 2001; Smith, Gosselin & Schyns, 2004), to relate EEG oscillatory activity (low frequency theta band, 4-8Hz) to the time course of visual stimulus information processing. In a first experiment naïve observers categorized sparsely sampled pictures of faces, by gender in one session and expressive or not in a second. Using estimates of the information driving behavioral response (accuracy, reaction times) we derived the sensitivity of low frequency EEG oscillations to facial features when observers resolved each of the tasks. We show that theta (4-8Hz) oscillations support discrete information processing epochs, corresponding to a modulated sensitivity of the brain to specific facial features. We reveal the integration of these features over several epochs to forge specific visual representations for different face categorizations. These later epochs not only represent more facial features, but they also integrate information across hemi-fields (i.e. bilaterally rather than contralaterally). In a second experiment, we instructed naïve observers to categorize by expression, (fear, disgust, anger or surprise), sparsely presented images of expressive faces sampled over a range of spatial frequency bands. Applying this methodology we again found evidence of discrete processing epochs. This technique also enables a tracking in time of the sensitivity to specific facial features in the brain providing more direct evidence of 'information picking' strategies.

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907 Greater Sensitivity to Convexities than Concavities in Human Lateral Occipital Complex

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When subjects are asked to divide objects into natural parts, they tend to choose convex contour segments as parts. Furthermore, they are faster and more accurate in remembering and judging convex than concave contours (Driver & Baylis, 1995). One potential underlying neural mechanism is that cells in the human lateral occipital complex (LOC), an area thought to be critical for object recognition, are more sensitive to differences in convex than in concave contours. To test this hypothesis, we used event-related fMRI adaptation, in which neural sensitivity to the difference between two sequentially presented stimuli manifests itself in a higher BOLD response when the two stimuli are different than when they are the same or similar. We presented subjects with sequential pairs of convex or concave contours, viewed stereoscopically behind a circular aperture. Critically, the convex and concave contours were identical except for a stereo reversal that caused subjects to see either the convex or the concave contour as the figure. The contours were varied parametrically in either skew or aspect ratio, and the magnitude of the difference between the two stimuli in a given trial varied across trials. Subjects performed a same/different task on the pairs of contours. Reaction times were significantly shorter for convex than concave contours, confirming the behavioral advantage for convex stimuli. Concomitantly, the BOLD response in LOC was higher for different than for identical contour pairs when the contours were convex

($p < 0.001$), but not when they were concave ($p = 0.89$; interaction $p = 0.03$). This effect was more pronounced in anterior than in posterior LOC, and was absent in retinotopic cortex. These results indicate greater sensitivity to convexities than concavities in high-level human visual cortex, a difference that could underlie the psychophysical advantage for convex over concave contours.

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908 Topography of high-order human object areas measured with DTI and fMRI

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Positional invariance is a characteristic of object category selectivity. Given the fact that the central visual fields become progressively overrepresented in higher visual areas, one might assume that a confluence of information from central fields is necessary to generate positional invariance. Alternatively, it seems also reasonable to suppose that a convergence of peripheral inputs is necessary to support positional invariance. In the present study, we used diffusion tensor imaging (DTI) fiber tracking to separately follow the connectivity of central and peripheral fields in the human visual system. The functional areas (FFA, LOC, and PPA) including primary/higher order organization of the both hemispheres of the human visual cortices were obtained using standard stimuli. DTI in conjunction with functional MRI was performed using a 3 Tesla whole body scanner (Intera, Philips). Functional imaging scans were used to localize retinotopic and non-retinotopic visual areas in healthy human volunteers. BOLD contrast was obtained using gradient-echo echo-planar imaging (EPI) sequence (30 axial slices of 2-mm thickness). For DTI, diffusion-weighted images (DWI) with 15 gradient encoding directions were acquired from the same subjects by spin-echo EPI. fMRI data was analyzed with BrainVoyager (Brain Innovation, Netherlands), and custom-written Matlab (Mathworks) software was used for diagonalization, fiber tracing, and visualization. The areas identified using functional imaging were used as seeding ROIs for DTI based axonal fiber reconstructions. The results of our study suggest that central and peripheral visual field areas in the primary visual cortices preferentially connect with the areas FFA, LO (central-biased) and PPA (peripheral-biased), respectively. This differential pattern of eccentricity-dependent connectivity pattern may form the basis for the distinct positional/object specific processing properties in these higher visual areas.

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909 Neural correlates of human creativity revealed using diffusion tensor imaging

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Creating art is among the most complex expressions of visual and other brain function. What is the neural basis of creativity? Here we show that specific white matter organization is correlated with an individual's degree of creativity. Thirty-six healthy volunteers were tested for creativity using the Torrance Tests of Creative Thinking (TTCT), tests which ask participants to produce novel visual and lexical solutions to semantically challenging problems. Combined scores from the TTCT provided a creativity index (CI). CI was then correlated with each participant's fractional anisotropy (FA) values obtained via diffusion tensor imaging (DTI; GE 1.5T, 6 directions). Our whole-brain voxel-wise correlational analysis revealed that more creative participants exhibited

more highly organized (i.e. anisotropic) white matter, primarily in right hemispheric brain areas, including right frontal areas, the right corona radiata and the right angular gyrus. For example, we found a strong positive correlation (max. r -value = 0.6523) between CI and FA in white matter near the right medial frontal gyrus (Talairach coordinates = TC: 11, 46, -15). Fiber tractography (DTIstudio, H. Jiang and S. Mori, Johns Hopkins U.) revealed that fibers from this ROI innervate much of the frontal lobe, including the right inferior and superior frontal gyri. These results suggest that highly creative individuals engage a network of right frontal areas when solving semantically rich problems. In addition, our finding of positively correlated clusters in the right angular gyrus and the right corona radiata indicate that creative individuals use an extended network of right hemisphere functional areas to produce novel solutions to complex problems. Fiber tractography strikingly demonstrates the difference in connectivity between creative and non-creative brains.

Talk Sessions

May 10, 2005 – Tuesday PM

Objects: Cortical Mechanisms (910-914), Visual Memory (915-919), Looking, Decisions, Search (920-926), Motion (927-933)

Objects: Cortical Mechanisms

2:00 - 3:15 pm

Hyatt North Hall

Moderator: Brad Motter

910 The Parahippocampal Cortex Mediates Both Spatial and Non-Spatial Associative Processing

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The parahippocampal cortex (PHC) has been implicated in several cognitive processes, most prominently in place-related processing, in episodic memory, and, recently, in processing contextual associations (Bar and Aminoff, 2003). These seemingly independent processes have the unifying characteristic of dependence on associations. Consequently, we proposed that the PHC mediates general processing of associations, regardless of their use in navigation, memory or context. A place within the PHC, termed the parahippocampal place area (PPA), has specifically been implicated in processing space and landmark-related information. Because the representation of a landmark can be considered an associative conjunction of individual constituents, we re-interpreted place-related activity in the PHC as reflecting spatial associative processing. We tested this idea here by creating novel associations among novel visual patterns that had no prior association with any place or concept. Subjects were trained to associate each of the studied patterns with one of three conditions: Spatial (3 items always appearing together in the same spatial configuration), Non-Spatial (3 items in random locations), or No-Association (an item appearing alone in a random location). The studied items were presented individually to subjects while using fMRI. All associated items activated the PHC: items associated with spatial contexts activated the posterior PHC whereas items associated with non-spatial contexts activated the anterior PHC. This replicates the hierarchical organization we have reported previously using pictures of real objects. Furthermore, a PPA localizer scan revealed that photographs of places (e.g., a street) elicited activation confined to the posterior PHC, as the spatial, meaningless, patterns we used. This study provides evidence that the PHC has a global role of processing associations in general, with a hierarchy depending, at least in part, on degree of spatial specificity.

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911 Responses of V4 neurons to colored Glass patterns.

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Glass patterns are made by taking an array of randomly positioned dots, and pairing each with another according to a predefined geometric rule. Glass patterns have been used in numerous studies to study how local signals are integrated to generate a coherent percept of form. In light of several studies suggesting that form and color are treated independently in the primate brain, it is of interest to study the chromatic selectivity of the physiological mechanisms supporting Glass pattern detection.

We recorded extracellularly from neurons in area V4 of an awake, passively viewing monkey while the neurons' receptive field was stimulated with different types of Glass patterns (circular, radial, parallel, and hyperbolic), or by an array of randomly oriented dot pairs. All patterns were made of 500 dot pairs presented on a dark background. A given pattern was presented for 1.6 sec, and was redrawn 4 times during that interval to avoid local retinal adaptation. Among 51 individual neurons or multiunit clusters, 29 showed preferential responses to one type of Glass pattern compared to the random array. Each form selective neurons was then tested with its preferred pattern presented in different, equiluminant colors. Of the 29 form selective neurons, 24 showed a clear preference for a specific color: their response to the preferred color was at least 1.5 times that for a white pattern. We conclude that V4 neurons represent a likely substrate for the processing of global form. Moreover, our data show that color and form are not treated by distinct neural populations within V4.

912 Sensitivity of V4 neurons to sequences of letter-like stimuli

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During active visual search, visual receptive fields are faced with a new view of the scene about every 200 milliseconds. The neuronal coding of the visual information in these views may be a function not only of the classic receptive field properties and spatial crowding conditions surrounding the receptive field, but also of the temporal history of receptive field stimulation.

The neural dynamics associated with a 5-8 item sequence of flashed letter-like stimuli were investigated in macaque extrastriate area V4 neurons while the monkeys performed a standard maintained fixation task. As the interstimulus interval (ISI) is reduced to durations mimicking saccade durations (55ms or less), the neural coding of sequences of identical stimuli undergo major changes in both amplitude and latency of activation. The initial transient response of many neurons is completely suppressed and the resulting response profile is shifted to longer latencies. At ISI's of 100 ms the response profiles are partially restored although ISI's of several hundred ms are needed to return to baseline responsiveness. Re-emergence of the transient response phase is seen in sequences of mixed stimu-

lus types, although this is dependent on the stimulus selectivity of the neuron. The dampening of responsiveness at saccade like timing intervals as seen in V4 may be a basic factor in controlling the stability of vision across saccades. Supported by the VA Medical Research Program.

913 Electrophysiological evidence for early access to object memories during figure assignment in humans

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During figure assignment, configural cues (e.g., area, closure, convexity, symmetry) along the same side of a contour cooperate in assigning that side figural status; cues across a contour compete. Here we report human electrophysiological evidence that object memories play a role in figure assignment. We created silhouettes in which the cue balance along the bounding contour biased the inner region to be seen as figure; the inner regions portrayed novel shapes. Control silhouettes suggested novel shapes on the outside of their edges as well as on the inside. Experimental silhouettes suggested familiar objects on the outside, which nonetheless appeared as shapeless grounds. Electroencephalographic (EEG) activity was recorded from 29 scalp sites while the observers viewed experimental and control silhouettes for 50 ms in the context of a cover task in which they categorized line drawings of familiar and novel objects shown 500 ms after the silhouettes. Event-related potentials (ERPs) were created by averaging the EEG traces across trials with respect to the onset of the silhouettes. The P100 component of the ERP was smaller for experimental than for control silhouettes. This difference was maximal over midline occipital, and right hemisphere occipital and parietal-occipital sites ($p < 0.05$). The differential P100 responses may reflect either 1) access to object memories, which occurs on the outside of the experimental, but not the control, silhouettes during cross-contour competition; or 2) the inhibition of the object memories by cues on the side of the contour ultimately seen as figure. Thus, object memory influences are evident in the first 100 ms of processing the silhouettes, even though the familiar objects in the grounds were not perceived consciously. Physiological data obtained in monkey V1 by other investigators follows a similar time course. Results are discussed within the context of models of figure-ground assignment and shape perception.

Acknowledgment: Supported by NSF BCS 0425650 to MAP.

914 Functionally distinct sub-regions in the Lateral Occipital Complex revealed by fMRI responses to abstract 2-Dimensional shapes and familiar objects.

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The Lateral Occipital Complex (LOC) has been consistently implicated in the perception of objects, object fragments, and shapes. The purpose of this study was to functionally characterize sub-regions within the LOC by mapping fMRI responses to images of abstract 2-Dimensional shapes and everyday objects. fMRI data were collected for 5 observers while they viewed images of objects or abstract 2-D shapes, contrasted with phase-scrambled controls of the same images in a block design. Based on these data, the LOC was divided into 3 sub-regions. A posterior region in the lateral occipital sulcus (pLOC) was more active for both objects and 2-D shapes than controls. An anterior region including the fusiform gyrus and collateral sulcus (aLOC) was more active for objects versus controls but not for 2-D shapes versus controls. A third region, posterior to aLOC and ventral to pLOC (potentially V4v), was more active for objects than controls but more active for controls than 2-D shapes (Obj+Shp-). This is consistent with reports that V4v is sensitive to local stimulus features (Grill-Spector et al, 1998) - objects and phase-scrambled controls contained more local heterogeneity than the 2-D shapes which were internally homogeneous. In addition to the localizer experiments we also performed an event-related adaptation experiment. On each trial two images (objects or shapes) were presented in rapid succession and were either identical or

different. We found more adaptation in posterior than anterior regions. Interestingly, the observed adaptation was stimulus selective: in aLOC there was significant adaptation to 2-D shapes but not objects, while in Obj+Shp- this pattern was reversed. When adaptation wasn't observed it was likely due to saturation from across-trial adaptation (the same object or shape images were used on each trial). This pattern of adaptation is consistent with the findings from the localizer scans further supporting the functional distinction of these regions.

Acknowledgment: Funding was provided by the National Eye Institute grant EY14030 and the National Institute of Mental Health pre-doctoral Individual Kirschstein-National Research Service Award 1 F31 MH65805-01A2

Visual Memory

2:00 - 3:15 pm

Hyatt South Hall

Moderator: Ingrid Olson

915 The decay of perceptual representations in iconic memory.

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Sensory memory refers to a modality-specific neural representation of sensory stimuli in the human brain. Iconic memory - very short term visual memory - historically was measured in noiseless, high-contrast displays of multiple items using partial report cuing methods (Sperling, *Psychol. Mono.*, 1960). Here, we derive an observer model for iconic memory at a range of contrasts in order to characterize the decaying perceptual representation. We measure the duration of iconic memory for basic visual stimuli at a range of contrasts and with and without external noise. The visual displays consisted of an annular arrangement of 8 Gabor patches, all eight displayed either with or without external noise and at one of three contrast levels. Each Gabor could appear in one of four orientations, chosen independently. Very short-term visual or iconic memory was measured through a partial report procedure in which one Gabor was cued for report of orientation at one of 8 delays between 0 (simultaneous cue) and 3.2 sec. The three contrasts, varying across trials, were chosen separately for no-noise and high noise displays to yield approximately 60, 75, and 90 percent correct based on individual observer pretests. Four observers were tested. For all 6 (2 noise x 3 contrast) conditions, iconic memory decayed exponentially over the maximum test interval of 3.2 seconds with the same or nearly the same decay constants of about 0.3 sec. This rapid decay in multi-element displays is consistent with early estimates of the persistence of iconic memory. The systematic relationship between noise and contrast conditions was well accounted for by a divisive gain-control formulation of the Perceptual Template Model (Lu & Doshier, *Vis. Res.* 1998) in which an initial encoded representation of the stimulus decays exponentially, with constant, late noise.

Acknowledgment: Funded by AFOSR

916 Binding in Visual Short Term Memory is Impaired in Patients with Medial Temporal Lobe Amnesia

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Previous research has shown that various types of relational processing, e.g. 'binding', are critically involved in visual short-term memory (STM). Luck & Vogel (1997) showed that when features are bound into objects,

more features can be remembered. Jiang, Olson, and Chun (2000) showed that when items are bound into a spatial configuration, more items can be remembered. What brain areas are necessary for binding in visual STM? One possibility is that the medial temporal lobe is involved. The relational processing theory proposes that the medial temporal lobes are critically involved in binding together different elements of a memory trace in long-term memory (Eichenbaum, 1999; Winocur & Kinsbourne, 1978). Whether or not this region is involved in mnemonic binding over short delay intervals is not known. Although prior studies showed that amnesic patients have intact visual STM for simple stimuli they did not examine amnesic performance on STM tasks that required binding.

Here we test medial temporal lobe amnesics and age-matched controls on a STM task for singular or bound information. Subjects were required to remember either three sequentially presented objects, locations, or object-location conjunctions. After a delay of either 1 s or 8 s, recognition performance was assessed. Memory capacity and A prime were computed. Preliminary results show that amnesic patients have intact object STM and location STM but impaired memory for object-location conjunctions. These findings suggest that (1) the medial temporal lobes are not exclusively involved in long-term memory because memory was impaired at short delay intervals; and (2) that different types of visual STM rely on different processing areas, depending on task demands.

917 Capacity limit of visual working memory in parietal cortex reflects capacity limit of spatial selection

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Purpose: Recent neuroimaging studies have revealed that the activation seen in fMRI of the parietal cortex parallels behavioral performance in visual working memory (VWM) tasks: As the number of visual objects increases from 1 to 4, the posterior parietal cortex increases its activity monotonically but remains constant thereafter as does memory performance (Todd & Marois, 2004). However, the capacity limits of VWM can arise from two different sources, 1) holding attention on multiple locations in space and 2) maintaining identity information in memory. To determine which process causes the saturation of parietal activation, we conducted a VWM experiment in fMRI using two different modes of presentation: simultaneous (items presented simultaneously at different spatial locations) and sequential (items presented sequentially at the same location). Indexing spatial positions and storing identity information are both necessary in the simultaneous presentation, but indexing spatial locations is minimized in the sequential presentation, leaving only the memory component. **Methods:** 1, 2, 3, 4, or 6 colors were presented, either simultaneously or sequentially, for subjects to remember. We estimated capacity in each set size from behavioral data and compared them to the response functions of the parietal cortex. **Results:** While memory capacity was matched between simultaneous and sequential conditions, the parietal area showed differential activity. In particular, parietal activity as a function of set size paralleled behavioral performance in the simultaneous condition, but was insensitive to set size in the sequential condition. **Conclusion:** These results support the idea that VWM limitation reflects two dissociable components: maintaining spatial attention to the target locations and remembering their identities. These components have separable neural correlates. The parietal cortex contributes more to the maintenance of attention than to remembering each item's identity.

Acknowledgment: Supported by NSF 0345525.

918 VOLUNTARY AMNESIA: PUTTING SIGHTS OUT OF MIND

Robert Sekuler (*vision@brandeis.edu*), Yuko Yotsumoto¹; Volen Center for Complex Systems, Brandeis University, Waltham MA USA

Does visual information enjoy automatic, obligate entry into memory or, after such information has been seen, can it still be voluntarily excluded? To answer the question, we measured visual episodic recognition memory for series of compound grating stimuli whose horizontal and vertical spa-

tial frequencies varied. Because recognition declines as additional study items enter memory, episodic recognition performance provides a sensitive index of memory's contents. A set of experiments showed that subjects had considerable success in excluding from memory any stimulus occupying a particular serial position in a series of study items.

Successful exclusion did not depend upon low-level information, such as stimulus orientation, contrast; also it did not depend upon location-specific attention or change in gaze. Additionally, exclusion did not require consistent, predictable timing of components within the stimulus sequence. This last result suggests that the exclusion process is gated, in part, by the onset of the to-be-excluded stimulus.

To identify the stage(s) at which voluntary amnesia might operate, we analyzed key results within the framework of a summed similarity model for visual recognition model (**NeMO**; Kahana & Sekuler, *Vision Research* 2002). This analysis revealed that even when a study item seemed to have been excluded from recognition memory, its spatial frequency content still strongly influenced recognition memory for other study items. This result suggests that exclusion operates after considerable visual processing of the to-be-excluded item.

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919 Preserved Memory for Scene Brightness Following an Undetected Change

Andrew Hollingworth (*andrew-hollingworth@uiowa.edu*); The University of Iowa

Hollingworth and Henderson (2004) found that through the incremental addition of small rotations of a scene, participants came to consider a significantly different scene viewpoint as an unchanged continuation of the original view. The present study extended this earlier work to the perception of scene brightness and examined the nature of the memory representation retained after an undetected change. Gradual changes in global illumination are quite common in the visual world, such as the illumination change produced by the sun emerging from behind a cloud. To simulate such changes, we incrementally brightened a scene image in a flicker paradigm, with each scene image separated by a brief pattern mask. We first replicated the finding of insensitivity to incremental change: The median luminance at detection was more than a 7-fold increase over the original luminance. To examine memory updating, the scene was incrementally brightened and then returned in one step to the original image. Seventy-five percent of participants detected the change back to the original image and reported only that the scene had become darker. This result suggests that participants may have failed to retain any memory of the original state of the scene. To examine scene memory, we incrementally brightened or darkened the scene. For participants who had not detected the change, we asked them to adjust the brightness of the scene until it matched the first image viewed. Eighty percent of participants adjusted in the correct direction, and the magnitude of adjustment was larger than for a control group of participants for whom the scene did not change. Thus, although memory is updated to reflect changed visual conditions, participants still retain memory for the original state of the environment, all in the absence of explicit awareness of change.

Looking, Decisions, Search

3:30 - 5:15 pm

Hyatt North Hall

Moderator: Miguel Eckstein

920 ATTENTIONAL CUES IN REAL SCENES, SACCADIC TARGETING AND BAYESIAN PRIORS

Miguel P. Eckstein (eckstein@psych.ucsb.edu), Barbara A. Drescher¹, Steven S. Shimozaki¹; Department of Psychology, University of California, Santa Barbara

Search performance with synthetic images improves when a target appears at an expected location (indicated by an artificial cue) rather than an unexpected (uncued) location. Similarly in real scenes the accuracy of the 1st saccade improves when the target appears at an expected location vs. an unexpected location (Drescher et al., 2003). The attentional processes mediating the context effect in real scenes are unknown (Chun, 2000). One standard explanation of the classical cue effect is that the observer deploys limited attentional resources to the cued location improving the quality of processing. A competing theory is that the benefit occurs due to differential weighting of visual information (for linear weighting: Kinchla et al., 1995; for Bayesian priors: Eckstein et al., 2002; Shimozaki et al., 2003; Oliva et al., 2003). Here, we measured the accuracy of the 1st saccade during search in 24 real scenes when the target was placed at expected and unexpected locations. The study controlled for target detectability and initial retinal eccentricity. A third condition in which the target was absent from the images allows to distinguish between the limited resources vs. differential weighting models. Human results were compared to computational implementations of the two attention models. Results: Accuracy of the 1st saccade averaged across observers improved by 3.6 deg ($p < 0.05$) when the target was at an expected location vs. an unexpected location. Observers' 1st saccade endpoints in target absent images were significantly closer to the expected rather than the unexpected locations, consistent with the differential weighting model (Bayesian priors) and inconsistent with the limited resources model. Conclusions: The results suggest that the increased saccadic accuracy in real scenes when the target appears at an expected (rather than unexpected) location is due to a higher observer weighting (prior) of visual information at likely target locations.

921 Saccadic eye-movements cause relativistic compression of time as well as space

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Saccades cause relativistic compression of time as well as space

There is now considerable evidence that space is compressed when stimuli are flashed shortly before or after the onset of a saccadic eye movement (Ross, Morrone & Burr Nature 384, 598-601, 1997). The compression is predominantly one-dimensional, parallel to the path of the saccade. New experiments show that not only is space compressed by saccades, but so too is time: the apparent temporal separation of two briefly-flashed bars is halved when they are presented near saccadic onset. Estimates of temporal separation at this time are also more precise, remaining proportional (following Weber's Law) to the perceived rather than the actual temporal separation. More surprisingly, in a critical interval before saccades, perceived temporal order is sometimes consistently reversed: the bar presented second being reported as seen before the first. Taken together, the spatial and temporal phenomena accompanying saccades strongly suggest that vision may be subject to relativistic effects, similar to physical relativistic effects that occur at speeds approaching the speed of light. In many visual areas, neural receptive fields shift peri-saccadically to offset the effect of saccades. This dynamic coordinate transformation is rapid, approaching the physical limit of neural information transfer, hence

producing relativistic consequences in both space and time. Transient stimuli captured during the dynamic coordinate transformation will be measured against spatial and temporal scales that are dilated by the Lorentz transform, and will therefore appear compressed in one spatial dimension and in time.

922 A causal link between scene exploration, local saliency and scene context

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Do image properties drive first ocular explorations of natural scene during free viewing? The response is positive, according to previous works defining image properties with statistical measures or modeled with a saliency map. But, because these works were mainly based on correlation analysis (but see Einhauser, 2002), no causal link could be established between image properties and ocular fixations.

Therefore, across three experiments (180 subjects) we manipulated the saliency and semantic congruency of small regions within 72 natural scenes during a categorization task. In the 'saliency' experiment, the mean saliency of one region was reduced for half the scenes. In the 'semantic' experiment, an incongruent object (object with a very low probability of occurrence in the scene context) was introduced. This object was substituted for another but without any modification in the saliency. For both experiments the luminance distribution of the modified regions were held constant. The third experiment was a control condition (without any manipulation). Eye movements were recorded during the 3s of scene presentation. The number of fixations and the time spent inside the manipulated regions were calculated.

In contrast with control condition, data analysis showed that, first, when the saliency of one region was reduced the region was less attractive (the number of fixations and the time spent inside the region were lower than in the control condition). Secondly, when an incongruent object was inserted, in contrast to the expectations of the literature (Henderson & Hollingworth, 1998), the region was less attractive. In conclusion, on one hand; we establish a causal link between saliency and ocular fixations. On the other hand; keeping most of image properties constant, we show that ocular fixations are flexibly driven by the congruency of an object and its context. Incongruent object were less attractive during the first moment of exploration, in contrary to longer exploration.

923 Bayesian modeling of task dependent visual attention strategy in a virtual reality environment.

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The deployment of visual attention is commonly framed as being determined by the properties of the visual scene. Top-down factors have been acknowledged, but they have been described as modulating bottom-up saliency. Alternative models have proposed to understand visual attention in terms of the requirements of goal directed tasks. In such a setting, the underlying task structure is the focus of the observed fixation patterns.

Here we report results from experiments and a model designed to test the relative importance of these alternatives by quantifying the task dependence of subject's visual strategies. Human subjects walked along a walkway, avoided obstacles, and picked up litter in a virtual reality environment. The spatial distributions of objects as well as the combinations and priorities of the different tasks were varied across subjects. Additionally, a large number of very salient distracters were embedded in the visual scene on control trials. The eye and head movements of subjects were recorded using a head mounted eye-tracker integrated into the vir-

tual reality display.

The sequential order of the image features at fixated locations was subsequently analyzed using a Bayesian formulation: the fixated features in the context of the visual scene are observable variables and the model learns the best parameters for hidden internal states, corresponding to features of the tasks the subject was involved in. The results from applying the model to the empirical data show that the best fit in terms of the posterior probabilities is obtained by incorporating an explicit level representing the context of the scene and the temporal sequence of fixated features. We show that the context-augmented model is able to capture the employed strategy better than a HMM with a comparable number of free parameters. Additionally we demonstrate that the trained models can be used to recognize which task a subject is carrying out, using only the fixated features and the scene context.

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924 Modeling eye movements in a shape discrimination task

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We investigated the pattern and sequence of eye movements that humans produce when they study a novel object. We have presented sequential information maximization (SIM) as a viable eye movement planning strategy (Renninger & Malik, VSS 2004; Renninger, Coughlan, Verghese & Malik, NIPS 2004). SIM selects fixation locations that will maximize information about the global stimulus. This strategy causes implicit inhibition-of-return (IOR) behavior, because fixation will not return to a location unless it offers new information. We evaluate the model with a shape discrimination task. The stimuli are novel, high contrast silhouettes that subtend 12.5 deg to force observers to make eye movements. A discrimination task ensures that the figures are studied carefully. Observers fixate a marker while the silhouette is presented peripherally for 300ms. The marker disappears to cue the observer to study the shape for 1.2 seconds while their eye movements are recorded. Following the study interval, the shape just studied must be identified from two possible choices. The distractor shape is highly similar to the target, but differs slightly in its contour. We compared the eye movements of three observers to the predictions of the SIM model and found a good alignment. As a control, we also compared the results to predictions from a saliency model (Itti & Koch, 2001). This model uses center-surround contrast to score salient hotspots on or around the figure. An explicit IOR mechanism creates a sequence of eye movements to points in order of decreasing salience. The saliency model also shows a good alignment with the human data, but neither model exactly captures their behavior. Superimposing the eye movement traces on spatial prediction maps from the two models clearly indicates that including 1) the eccentric fall-off of acuity and 2) the rate at which observers incorporate the information from a fixation will greatly improve the alignment.

Acknowledgment: Smith-Kettlewell; Ruth L. Kirschstein NRSA to LWR; NSF IIS-0415310 & NIDDR H133G030080 to JC

<http://www.cs.kent.ac.uk/projects/cncs/online/bw5/ncp02004/ncp02004proceedings.pdf>

925 Visual Sampling and Saccadic Decisions: A Reverse Correlation Approach

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A period of stable fixation is used to sample the visual field in order to decide where to fixate next in the scene. We used a reverse correlation paradigm (Caspi, Beutter, & Eckstein, 2004) to elucidate when the critical signals driving the eye movement decision occur.

Observers were presented with two dynamically modulating Gaussian blobs. The luminance of the patches was resampled at 40 Hz from two,

partly overlapping, Gaussian distributions that differed in their means. The task was to saccade to the patch that was, on average, of higher luminance. We analysed the average luminance noise (at both the target and the distractor location) preceding the oculomotor decisions.

Our findings can be summarised as follows:

1. Error saccades occurred when, during some temporal interval, the distractor luminance was high or the target luminance was low.
2. This temporal interval appeared to be time-locked to the first 100 ms after display onset, regardless of the latency of the eye movement.
3. For correct saccades to the target there was a small, but consistent relationship between the average luminance difference between the target and distractor during this interval, and saccade latency.

These results suggest that decisions within the oculomotor system are based on visual sampling in a restricted time window. This sampling window appears to be relatively constant and unrelated to the variability in saccade latency. We propose that the sampled signals feed into an oculomotor decision stage. The major sources of saccade latency variability appear to originate from this decision mechanism and a subsequent dead time during which the metrics of the upcoming saccade can no longer be altered.

Caspi, A., Beutter, B. R., & Eckstein, M. P. (2004). The time course of visual information accrual guiding eye movement decisions. *Proceedings of the National Academy of Sciences*, 101, 13086-13090.

926 Functional imaging of categorical decision processes

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Current models of decision making have suggested that the frontal and parietal cortices contain neurons that underlie volitional choice. However, a locus of categorical decision making has not been conclusively identified. The identification of brain regions with activity specific to categorization is complicated by general task related activity that is correlated with, but is distinct from, decision specific activity. These ancillary processes include working memory, attention, motor planning, and motivation. To dissociate decision related activity from general task related activity, we designed a categorical decision making task that required subjects to classify a vertical line segment as 'long' or 'short' using one of two learned criteria that varied from trial to trial. In this task, decision uncertainty, defined by distance from the criterion, is parametrically modulated while the stimulus set, categorization rule, and response set all remain constant. In addition, we attempted to equalize attention and working memory load, as well as task difficulty, by equating psychophysical functions across trial type and across subjects. Rapid event-related fMRI on human subjects was used to identify areas of the brain that have general task related and/or decision specific activation. We found that the medial frontal gyrus, anterior insula, and posterior parietal cortex showed general task related activation. However, only the medial frontal gyrus and anterior insula showed additional activity modulated by decision uncertainty. In fact, after accounting for general task related variance, posterior parietal cortex showed no additional modulation related to decision uncertainty. These data suggest that a specific network of areas in the frontal cortex (i.e. a "decision triangle") is directly involved in categorization and volitional choice.

Motion

3:30 - 5:15 pm

Hyatt South Hall

Moderator: Peter Thompson

927 The path of least persistence: Disrupting object continuity causes a release from motion deblurring

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A stimulus that is presented in apparent motion has shorter visible persistence than the same stimulus presented in isolation, a phenomenon known as *motion deblurring*. Here we show that disrupting the spatio-temporal continuity of stimuli in apparent motion causes a release from motion deblurring in that there is visible persistence of the stimulus under conditions in which little or no persistence occurs without the disruption. Observers viewed scenes in which a disc traveled around a central fixation point and underwent an abrupt change in appearance, either in the second-to-last or the last frame of motion. Different changes were tested including size, luminance, hue, and direction of motion. Control conditions included two discs in the final frame of motion, the original version and the changed version. Observers reported whether they perceived one or two discs in the final frame. When the change was large and in the second-to-last frame of motion, observers were nearly as likely to report having perceived two discs as they were in the control condition where two discs were physically present. This tendency decreased when the change was small and when the change was in the final frame of motion. The results suggest that motion deblurring occurs because of object-mediated updating. Updating representations of scenes requires that new information be appropriately associated with previously encoded information. We have argued that this process occurs within representations that have undergone considerable organization in terms of the components within the scene, and in particular, that updating is mediated through object representations. Under this view, a large spatio-temporal disruption triggers the establishment of a new object representation, which protects the original object representation from being overwritten. This in turn gives rise to visible persistence of that object and the perception of two objects, the original one and the new one.

928 Dynamic, not Static, MAE Follows the Illusory Percept

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Can one illusion trigger another illusion? It has been reported that a stationary patch of random dot motion is perceptually displaced along the direction of motion (Ramachandran et al. 1990). This illusion has drawn new interest since a MRI study reported that cortical representation of the motion patch is shifted in the opposite direction of motion, indicating that neural activity of the primary visual cortex can be dissociated from perceived location (Whitney et al. 2003). So the second question is, from what level on along the visual pathway, does neural activity match the illusory percept?

The motion aftereffect is a nice tool to hack into the level of visual processing due to the existence of static and dynamic test, which is sensitive to retinotopic low-level MAE and non-retinotopic higher-order MAE, respectively. We observed MAEs at the borders of the illusory shifted patch of motion to investigate the level of percept - neural activity accordance.

The adaptation stimulus was a patch of random dot motion (3 deg x 3 deg) placed at the center of a larger patch (9 deg x 9 deg). The two patches had

opposite direction of motion and the inner patch appeared to be displaced. In blocks measuring the static test, we presented a stationary spot (0.5 deg, 500ms) around the physical borders of the two patches after adaptation. For the dynamic test, we presented three discrete phases (250 ms each) of Gabor patch (0.5 deg, 3 cpd).

The experimental results indicated that static MAE follows the physical border of the patches, say, the direction of motion aftereffect switches at the physical boundary. In contrast, the changeover point of dynamic MAE is shifted to the direction of inner patch motion, indicating correspondence of percept and higher-order activity. To answer the two questions, yes, an illusion can trigger another illusion, as long as it involves the higher areas where neural activity is likely to be in accordance with the illusory percept.

929 Neuromagnetic Responses to First- and Second-Order Motion

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We measured evoked neuromagnetic responses to the direction-reversal of translating visual gratings. The direction reversal itself is designed to eliminate flicker cues during the transient reversal and provide a pure motion signal. The gratings are highly similar in appearance (same carrier) but carefully calibrated to stimulate only the first- and only the second-order motion systems. Magnetoencephalographic (MEG) data was recorded from three subjects as they passively viewed these direction reversing, first- and second-order motion displays. Visually evoked magnetic fields (VEFs) yielded high amplitude focal activation, with dipolar sensor distributions, located over lateral sensors in all subjects. Data were additionally analyzed by Second-Order Blind Identification (SOBI), Independent Component Analysis (ICA), and Cortically-constrained Current Density (CCD) source localization. The data reveal a characteristic profile of MEG activity accompanying the change in motion direction. Activated sites include extrastriate dorsal and lateral visual areas (putatively V3/MT+), and portions of the inferior parietal lobe, but canceling the flicker cue seems to have eliminated VEFs in early visual cortical areas (V1/V2). The spatiotemporal VEFs for first- and second-order stimuli are quite similar; the SOBI analysis suggests that second-order responses are delayed relative to first-order responses by about 20 msec (which may be due to uncontrolled differences in stimulus strength between the first- and second-order stimuli). The similarity of VEFs for both kinds of stimuli, the high correlations between first- and second-order derived SOBI and ICA components, and the large degree of overlap in CCD sources indicate that spatial differences --if any--between first- and second-order visual motion sources are not resolvable by MEG.

930 The vector-average readout model of MT fails to account for contrast-induced changes in speed perception

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A car that approaches you through the fog is not only less visible; it also appears to move more slowly than it really does. This is a rather unfortunate but real-life example of the laboratory observation that lowering contrast causes a reduction in perceived speed. A common hypothesis about the neural representation of perceived speed states that perceived speed corresponds to a vector-average readout of cells in the medial temporal area. We exploited the lawful relationship between contrast and perceived speed as a tool to test this hypothesis.

We used circular patches of random dots as test stimuli. The patches were positioned in a cell's receptive field and 100 dots moved in the cell's preferred direction for 0.5s. On randomly interleaved trials, the dots moved at 1, 2, 4, 8, 16, 32, or 64 deg/s and the Michelson point contrast between any individual dot and the 5cd/m² background was either 5%, 10%, 20% or 70%.

We recorded from 96 speed-tuned cells in two monkeys that fixated a central dot during stimulus presentation. The vast majority of cells had a reduced firing rate for low contrast stimuli. Interestingly, we found that, for a subset of cells, lowering the contrast at low speeds led to an increase in firing rate. Lowering the contrast, however, did not just change the overall firing rate. Most speed tuning curves became narrower and, surprisingly, the peaks (the preferred speed) shifted to lower speeds.

In the vector-average labeled-line model, such a shift of the preferred speed to lower speeds predicts an increase in perceived speed, clearly in contradiction with behavioral report. Hence, our data show that a vector-average readout of MT cell responses cannot explain the full range of perceptual speed reports.

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931 Constraining the prior and likelihood in a Bayesian model of human visual speed perception

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The perceived visual speed of a translating spatial intensity pattern varies as a function of stimulus contrast, and is qualitatively consistent with that predicted by an optimal Bayesian estimator based on a Gaussian prior probability distribution that favors slow speeds (Weiss, Simoncelli & Adelson, 2002). In order to validate and further refine this hypothesis, we have developed a more general version of the model. Specifically, we assume the estimator computes velocity from internal measurements corrupted by internal noise whose variance can depend on both stimulus speed and contrast. Furthermore, we allow the prior probability distribution over speed to take on an arbitrary shape. Using classical signal detection theory, we derive a direct relationship between the model parameters (the noise variance, and the shape of the prior) and single trial data obtained in a two-alternative forced choice speed-discrimination task. We have collected psychophysical data, in which subjects were asked to compare the apparent speeds of paired patches of drifting gratings differing in contrast and/or speed. The experiments were performed over a large range of perceptually relevant contrast and speed values. Local parametric fits to the data reveal that the likelihood function is well approximated by a Normal distribution in the log speed domain, with a variance that depends only on contrast. The prior distribution on speed that best accounts for the data shows significantly heavier tails than a Gaussian, and can be well approximated across all subjects by a power-law function with an exponent of 1.4. We describe a potential neural implementation of this model that matches the derived forms of the likelihood and prior functions.

932 Retracing Our Footsteps: A Revised Theory of the Footsteps Illusion

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In the footsteps illusion, Anstis (2001, 2003a, b, 2004) has shown that when a grey square drifts steadily across stationary black and white stripes, it appears to stop and start as its contrast varies. A dark grey square has high contrast when passing over a white stripe and appears to speed up. On a black stripe it has low contrast and appears to slow down. The opposite is true for a light grey square. To explain this effect, Anstis appealed to Thompson's finding that low contrast stimuli appear to move more slowly than high contrast stimuli, (Thompson 1976, 1982). However, in the Anstis effect the square can appear to stop moving completely, whilst Thompson's contrast effect rarely exceeds an apparent speed change of 25%. We now report that, if the moving square is made progressively smaller than the width of a background stripe, the illusion is reduced and is finally abolished. We propose that the footsteps illusion involves not only weak motion signals from its low-contrast moving edges, but also spurious signals of stationarity from its partly occluded lateral edges. These interacting

signals from different parts of a grey square also generate Zollner-like zig-zags in a stationary analogue (the Wenceslas illusion).

933 Local motion speed affects the perceived speed of motion-defined motion.

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It has been known that the perceived speed of luminance-defined(LD) stimuli increases as the contrast increases. Similar results have been reported for motions of contrast-modulated stimuli, but little is known as for the parameters that affect perceived speed for the other second-order motions. In this study, we examined the effect of local motion speed on perceived speed of motion defined(MD) motion by using comparison against that of LD motion. The carrier for LD and MD stimuli was 1024 random dots scattered within a 4(H) × 10(V) deg field. The LD stimuli were square wave gratings of 0.2 c/d created by modulating the dot luminance. The contrast between light and dark dots(dot contrast) was fixed at 0.75. This corresponds approximately to 0.6 of the space average luminance contrast for dark and light areas. The MD gratings were generated by moving the dots in either up or down direction within the areas corresponding to the dark and light bars of LD gratings. The dots were shifted up or down by either 100, 200, 300, or 400 min/sec. The frame-rate for this local motion for pattern generation was 50 Hz. Clearly segregated patterns were observed for all these stimuli. The motion defined patterns were then shifted horizontally by 3.5 deg once every 120 ms to generate MDM. The speed of LDM was varied in 6 steps around that of MDM to obtain an equivalent speed by a successive comparison method. It was found that the perceived speed of MDM increases by 30% as its local motion speed increases from 100 to 400 min/sec. The MDM with 400 min/sec appears faster than LDM. We conducted a similar experiment using randomly refreshed incoherent dots as carriers for LD stimuli to examine effect of temporal frequency component, and found the same results. Thus the LDM/MDM speed difference seems intrinsic to the nature of motion types. This is a first report of a parameter that modulates the perceived speed of MD motion and provides a useful method for motion studies.

Poster Session H

May 10, 2005 – Tuesday PM

Biological Motion 2 (934-946), Visual Search (947-962), Perceptual Organization 2 (963-980), Faces 3 (981-992), 3D Processing: Motion and Texture (993-1001), Attentional Selection (1002-1020), Color Vision 2 (1021-1033), Object- and Space-Based Attention (1034-1049)

2:00 - 7:00 pm (Authors present 5:15 - 7:00 pm)

Municipal Auditorium

Biological Motion 2

934 The effect of perception of complex human movement on late event-related brain responses

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It has been recently reported that there are posterior hemispheric differences in brain neural activity in response to normal biological motion of human walking versus scrambled versions of the same displays where a walker was not visible. In our study we investigated neural electrical responses resulting from the introduction of temporal offset noise into the joint angles of complex human ballet movements. The introduction of such noise results in a human figure being visible at each frame, but the coordination of the movement is disrupted. By introducing more noise into all segments of the body we were able to create displays with less apparent coordination among the limbs. Movement duration of the ballet stimuli was fixed at 2 sec. Each of 16 movies (4 movements X 4 noise levels, including 0) were presented for 35 trials, resulting in a total of 560 trials. We displayed the movements to naïve observers and asked them to judge whether a movement was possible or not by rating it on a 4 point scale that varied from definitely possible to definitely impossible. ERP responses were recorded from 62 electrodes. Results showed that the intact biological motions elicited anterior parietal late electrical responses in the right hemisphere. In addition, a latency difference was found in the early and late parietal responses between the different levels of noise. The intact movements elicited pronounced responses. In light of previous neuroimaging results we speculate that firstly the results are consistent with the involvement of the STS in the perception of biological motions. Secondly, that the right posterior area is involved in the further cognitive evaluation of information related to complex human movements.

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935 Neural Plasticity Mechanisms for Learning of Biological Motion

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The recognition of complex movements and actions is a fundamental visual capability. In a series of psychophysical and functional imaging studies we have investigated the role of learning for the recognition of biological motion. Subjects were able to learn the discrimination between artificial novel biological motion stimuli. fMRI results indicate that several visual areas are involved in this learning process. More specifically, lower-level motion-related areas (hMT+/V5 and KO/V3B) show an emerging sensitivity for the differences between the discriminated stimuli, and higher-level areas (STS and FFA) show an increase of sensitivity after

training. In addition, we find an overall reduction of the BOLD activity after training. Based on a hierarchical physiologically-inspired neural model for biological motion recognition (Giese & Poggio, 2003) we tried to reproduce the BOLD signal changes during discrimination learning. We show that learning of novel templates for complex movement patterns, which are encoded by sequences of body shapes and optic flow patterns, can be implemented by hebbian learning. We propose a model for the learning process that combines competitive and time-dependent hebbian plasticity, implementing physiologically plausible local learning rules. Our results demonstrate that these mechanisms can account for the emerging sensitivity for novel movement patterns observed in fMRI. We conclude that our model provides a well-defined framework to test different hypotheses about the mechanisms of neuronal plasticity underlying the learning of novel biological movements.

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936 The Visual Analysis of Bodily Emotions

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Previous research has established that emotional information conveyed through body and facial movement is systematically and reliably identified (Bassili, 1979, Dittrich et al., 1996, Atkinson et al., 2004). Furthermore, the neural circuitry involved in such emotion perception (e.g., Heberlein et al., 2004) overlaps with the neural areas involved in the visual analysis of human motion per se (e.g., Puce & Perrett, 2003). This raises the question of whether emotion detection processes and action detection processes interact. Specifically, do emotion related processes contribute to the detection of human movement? Or, is human action first detected and then subsequently interpreted by emotional processes? We examined the relationships between emotion and action detection with psychophysical discriminations of point-light walkers of various emotional states. Emotional gaits were performed by professional actors and were captured with an optical motion tracking system. Pilot studies were used to identify gaits that conveyed anger, sadness, happiness, or emotional neutrality equally well. Point-light walkers were then placed within masks of positionally scrambled but otherwise identically moving points. On half the trials, a point-light walker was present within the mask. On the remaining trials, the walker was scrambled and thus absent. Observers reported whether or not the human form was present in each movie. Discrimination performance was emotion dependent. Furthermore, performance depended upon the observer-relative direction of gait as discrimination was best when point-light actors walked toward observers. Importantly, sensitivity analyses indicated that detection accuracy was modulated by emotion and direction interactions. These

results suggest that the visual analysis of human motion cannot be understood independently from the visual analysis of emotion.

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937 Biological motion versus coherent motion perception: The role of the cerebellum

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Perception of biological motion is a fundamental property of the human visual system. It is as yet unclear which role the cerebellum plays with respect to the perceptual analysis of biological motion represented as point-light displays. Imaging studies investigating biological motion perception revealed inconsistent results concerning cerebellar contribution. The present study aims to explore the role of the cerebellum in the perception of biological motion by testing the performance of biological motion perception in patients suffering from circumscribed cerebellar lesions and comparing their performance with an age-matched control group.

Perceptual performance was investigated in an experimental task testing the threshold to detect biological motion masked by scrambled motion and a control task testing detection of motion direction of coherent motion masked by random noise. Results show clear evidence for a differential contribution of the cerebellum to the perceptual analysis of coherent motion compared to biological motion. Whereas the ability to detect biological motion masked by scrambled motion was unaffected in the patient group, their ability to discriminate direction of coherent motion in random noise was substantially affected. We conclude that intact cerebellar function is not a prerequisite for a preserved ability to detect biological motion. Since the dorsal motion pathway as well as the ventral form pathway contribute to the visual perception of biological motion, the question remains open, whether cerebellar dysfunction affecting the dorsal pathway is compensated for by the not affected ventral pathway or whether perceptual analysis of biological motion is performed completely without cerebellar contribution.

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938 Biological motion perception in deaf signers and hearing non-signers

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The ability to discriminate human actions from other types of motion in the visual environment is especially vital to deaf individuals who use a visual-manual language as their primary form of communication. Signers must be sensitive both to non-linguistic human actions and to symbolic, rule-governed motions that have communicative relevance. **PURPOSE:** In this study we ask whether deaf signers and hearing non-signers with comparable abilities to discriminate *non-linguistic* biological motion from visual noise differ in their sensitivity to *sign language* biological motion. **METHOD:** Deaf fluent signers of American Sign Language (ASL) and hearing, non-signing speakers of English observed 252 randomized trials, on 2/3 of which a human point-light figure performing a single, non-linguistic goal-directed action or signing a single ASL lexical sign appeared embedded in one of seven levels of visual noise. Participants were blind to the type of human action being presented and simply indicated whether they did or did not observe a human figure on a given trial. Data from seven participants from each group who had comparable discriminability indices on the non-linguistic trials were selected for

analysis. **RESULTS:** Hearing non-signers were significantly less sensitive to the presence of ASL signs in noise than to the presence of non-linguistic actions, whereas deaf signers were equally sensitive to both types of motion. This pattern was consistent across six of the seven noise levels tested. **DISCUSSION:** Differential sensitivity to linguistic and non-linguistic biological motions on the part of *hearing* participants who are unfamiliar with sign language suggests that differences exist between these two classes of motion that are salient to the sign-uninitiated visual system. Equivalent sensitivity to these motion types in *deaf* participants further suggests that lifelong exposure to a signed language, and/or lifelong auditory deprivation, can offset these signal differences.

939 Towards Canonical Views of Animacy from Scenes of Human Action

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It is well known that social intention and meaning can be attributed to displays of moving geometric shapes, yet the cognitive processes that underlie this perception of animacy are, however, still open to debate. We have further explored this issue by making abstract displays of human movement using the multimedia analysis program Eyesweb (www.eyesweb.org). We first videotaped the movement of two actors from two viewing directions - an overhead and a side view. The actors performed everyday actions, interactions and scenes based on stimuli from the literature of animacy and causality research. These actions fell into the classes of highly scripted and loosely scripted actions. We then processed the video to obtain two visual conditions that depicted the motion centre of each actor as either a square remaining stable in size or changing in size according to the quantity of motion (QoM). The resultant stimuli depicted two white squares moving on a black background. We presented the four kinds of displays (side-view/overhead with no QoM/QoM) to naive observers with the task of rating the perception of animacy on a 9-point scale. The results suggest that there is a slight difference in viewpoint, with overhead being favoured and, that there is an effect of QoM in the side-view, yet this may be due to the change in size being interpreted as a depth cue. Finally, a trend was noted that displays with a greater control over the actors produced higher ratings of animacy than those displays obtained with a lower degree of control over the actors. Results are discussed in terms of variations in the creation of the stimuli and factors that influence the perception of animacy.

Acknowledgment: EPSRC

940 A Library of Human Movements for the Study of Identity, Gender and Emotion Perception from Biological Motion

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We present the methods that were used in capturing a library of human movements for use in computer animated displays of human movement. The library is an attempt to systematically tap into and represent the wide range of person properties, such as identity, gender and emotion that is available in a person's movements and it has been made available online at <http://paco.psy.gla.ac.uk/>. The movements from a total of 30 non-professional actors (15 female) were captured while they performed walking, knocking, lifting and throwing actions as well as their combination in angry, happy, neutral and sad affective styles. From the raw motion capture data, a library of 4080 movements were obtained using techniques based on Character Studio (plug-ins for 3D Studio Max, Autodesk Inc.), Matlab (The Mathworks) or a combination of these two. For the knocking, lifting and throwing actions 10 repetitions of the simple action unit were obtained for each affect, and for the other actions two longer movement recordings were obtained for each affect. We discuss the potential use of the library for computational and behavioural analyses of

movement variability, human character animation and how gender, emotion and identity are encoded and decoded from human movement.

941 Attitudinal and biometric contributions to the recognition of identity from point-light walkers

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It has been observed that the gait motion of the human body is stable across individuals for the lower body but extremely variable for the upper body. This regularity of the lower body has made it attractive for biometric approaches to identity recognition that can capitalize on systematic deviations to a regular structure. The motion of the upper body on the other hand has been termed attitudinal as it is not necessary for locomotion but seems to vary with the manner of the walker. We wished to contrast these two sources of information in the recognition of identity from point light walkers. To do this we started with a library of 29 point light walkers and created three types of displays: full body, upper body and lower body displays. Each point-light display consisted of a side view of a single gait cycle. Next, for each display condition we provided observers with a sequential presentation of two walkers for each of the possible pairwise combinations of the 29 individuals and had them give a dissimilarity rating for the pair. We thus obtained an average dissimilarity matrix for each of the three display conditions. These matrices were analyzed using techniques of hierarchical data clustering that provided us with an indication of which walkers were grouped together and which individual walkers were prototypical for each cluster. These results showed that all three display conditions shared some prototypes, but that the prototypes for the whole-body and upper-body clusters were nearly identical. These results suggest that the motion of the upper-body predominates in the recognition of identity by human observers. However, theoretical analyses are ongoing to determine to what extent human observers' recognition of identity from the lower body can be accounted for by biometric theories of identity recognition.

Acknowledgment: EPSRC Attitudinal and Biometric Contributions to the Recognition of Identity from Point-light Walkers

942 Unintentional Movements during Action Observation: Copying or Compensating?

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Previous research has shown that individuals unintentionally mimic the actions of an interaction partner. This phenomenon has been explained in terms of ideomotor theory, which suggests that upon perceiving an action, a tendency to perform this action is activated. In line with this claim, neurophysiological and brain imaging research has shown that perceiving somebody performing an action activates the representational structures involved in one's own planning and execution of this action. What happens when one observes the actions of a person who has difficulties achieving her action goal, as for example, when one observes a soccer player trying to score a goal from a difficult position? We conducted a series of studies to investigate whether in such a situation, the unintentional movements of an observer reflect the observed movements or whether the observer performs compensatory movements that are in accordance with the actor's intention rather than her actual movements. Participants viewed movies of a person balancing on a foam roller. The movies ended before the actor had reached the end of the roller, and the participants' task was to indicate how likely they thought it was that the actor would reach the end of the foam roller. Using a motion capture system, we measured the participants' unintentional movements while observing the movies. We varied the perspective from which the actor was filmed (front and back) and the task instructions. Our results show that participants mimicked the observed actions a large amount of the time. They also made corrective movements with their bodies (e.g., leaning to

the right when the actor was almost falling off to the left). These 'intentional ideomotor movements' were modulated by the perspective and by the task instruction. Our findings provide evidence that unintentional movements occur not only as the result of a direct perception-action link, but are also influenced by shared representations of intentions.

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943 How Perceptions of Body Motion and Morphology Affect Complex Social Judgments

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Bodily cues such as shape and motion reliably affect social perception. Historically, the perception of these cues has been studied in isolation. Recent research has provided new insights regarding the relative importance of shape and motion for person perception. Morphology, for example, is a more potent visual cue for biological sex, and motion is a more potent visual cue for gender (i.e., masculinity & femininity). The confluence of these percepts is likely to affect higher-order social perception, or *meta-perception*, yet these have received minimal attention to date.

We explored how body motion and morphology affect the perception of sex and gender, and how these perceptions in turn affect perceived attractiveness and perceived sexual orientation. Stimuli were animated human *walkers* that varied in motion (from extreme shoulder 'swagger' to extreme hip 'sway') and morphology (waist-to-hip ratios, WHR, from 0.5 to 0.9). Participants judged each walkers' biological sex, gender, sexual orientation, and attractiveness.

Walkers with small WHRs - corresponding to a female percept - were judged to be more attractive and heterosexual when 'swaying,' but to be less attractive homosexual when 'swaggering.' In contrast, walkers with larger WHRs - corresponding to a male percept - were judged to be less attractive and homosexual when 'swaying,' but to be more attractive and heterosexual when 'swaggering.' Importantly, the relative potency of motion and morphology for perceived sexual orientation differed for targets perceived to be male and targets perceived to be female. Morphology was the more potent determinant of perceived sexual orientation for walkers judged to be female. The opposite was true, however, for judged to be male; for these walkers motion was the more potent determinant of perceived sexual orientation. These results highlight the importance of 'meta-perception' in determining how physical characteristics such as motion and morphology are perceived and ultimately evaluated.

944 Person recognition across multiple viewpoints

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Individuals' identities can be determined from point-light displays of their actions (Cutting, 1977). Interestingly, observers demonstrate the greatest visual sensitivity to their own movements (Loula, Prasad, & Shiffrar, 2005). Does enhanced visual sensitivity to self-produced motion reflect a lifetime of experience observing one's own limbs move? If so, then visual sensitivity to actor identity should be viewpoint dependent. To test this hypothesis, naïve participants viewed point-light movies of themselves, friends, and strangers performing various actions. Viewpoint varied across condition. Actors were matched for gender, age, and body size so that these cues could not be used for actor identification. Each trial consisted of two different sequentially presented point-light movies of actors performing two different actions. Participants performed a 2AFC identity discrimination task and reported whether each trial showed the same actor or two different actors. In Experiment 1, head mounted cameras were used to create head-centered, axial displays of the point-light actors. In Experiment 2, front and rear views of the point-light actors were created. Consistent with Bulthoff et al (1997), performance was

uniformly poor with axial depictions since these point-light displays are difficult to organize. This finding is interesting because observers have extensive visual experience with the head-centered, axial perspective on their own body. Yet, this experience was not reflected with a performance increment. In Experiment 2, identity discrimination performance with self-motion was superior to that with friend and stranger motion across both the front and back views. Since observers have substantially more experience viewing the front, as compared to the back, of their own bodies, these findings suggest that identity discrimination is not defined by view specific experience.

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945 Integration of Synergies in Visual Recognition of Emotional Human Walking

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In the domain of motor control it has been hypothesized that the control of complex body movements might be organized in terms of *synergies*. A synergy is a smaller subset of degrees of freedom (or joints) that are jointly controlled. This raises the question if synergies are also important for the visual perception of body movements. We tested how the information from two synergies, arm and leg motion, are integrated during the perception of human walking with different emotions. In particular, we tested whether the information provided by different synergies is integrated by the visual system in a statistically optimal way.

Method: Using a 3D motion capture system we recorded neutral human gaits, and gaits with four different emotional affects (angry, happy, sad and fearful). By motion morphing (modifying a technique of Giese & Lappe, 2002, *Vis. Res.* 38:1847) between neutral gait and the individual emotional gaits we created stimuli containing different amounts of information about the emotion categories. We created 3 different stimulus classes by: (1) morphing all degrees of freedom at the same time; (2) morphing only the arm movements, presented in combination with a neutral leg movement; and (3) morphing only the leg movements, combined with a neutral arm movement. Stimuli were presented as point light walkers.

Results: All morphed stimuli look very natural, even if they are composed from neutral and emotional synergies. The amount of information carried by the two synergies varies from emotion to emotion. Consistent with earlier work, the recognizability of the emotions increases when the movements are caricatured in space-time. Recognizability also increases if only individual synergies are exaggerated. Present work focuses on fitting the data with Bayesian ideal observer models to study whether the integration of the information from the two synergies is accomplished in a statistically optimal way.

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946 Attractiveness, averageness, and sexual dimorphism in biological motion

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While the study of facial attractiveness has explored a number of factors such as familiarity, symmetry, and sexual dimorphism, perhaps the most popular notion to emerge has been that the mean of a population is what is considered most attractive. In contrast to this concept of "averageness," however, exaggerations of sex differences have been shown to play a key role in attractiveness -- a finding now mirrored in the domain of biological motion (i.e., point-light walkers) where, in men's ratings of female walkers, attractiveness correlates very well with a gender axis (Troje, 2003). We should like to clarify that this is not due to merely approaching a

hypothetical average female walker but more specifically to the relative display of sexually dimorphic characteristics, even to the detriment of averageness.

As with averages of faces, synthetic walkers made by averaging two or more individuals do generally appear to be attractive. This is certainly the case with the full population average, and, indeed, even averaging all walkers of below-average attractiveness can yield a walker that is above-average. However, even the maximally average walker is nevertheless less attractive than a number of real, individual walkers. Moreover, the most attractive individuals are not necessarily nearer to the average; direction of deviation from the mean may be more meaningful than distance, so that, e.g., far-from-average walkers may be very attractive if they exaggerate female characteristics.

Thus, the most average walker is not the most attractive, the most attractive walkers are not the most average, and walkers equidistant from the average may be very attractive or unattractive depending on their relative expression of sexually dimorphic traits. For biological motion, then, the perception of attractiveness (and perhaps of gender) might be guided not simply by prototypes anchored at averages of categories but by representations specifically attuned to salient variation between categories.

Visual Search

947 Distinguishing serial and parallel processing in visual search without depending on set size effect

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Two-stage models (e.g., Treisman & Gelad, 1980; Wolfe, 1994) for visual search commonly assume a serial attentive processing stage following a parallel object encoding stage. A novel experimental manipulation was devised in a series of experiments with increasing task difficulty, intended to selectively influence processes in the attentive processing stage of a two stage system.

In Experiment 1, subjects searched for a red T among green Ts and red Os (4 stimuli). In some trials, one or two distracters were replaced independently by special distracters that require longer processing time than the ones replaced. In Experiment 2, subjects searched for a letter L among an upright T, a T rotated by 180° and two Os. In some trials, two Os were independently replaced by Ts rotated by 90° and 270°. In Experiment 3, subjects searched for upright or rotated Ts among Os, an upright T, and a T rotated by 180° whose vertical strokes were slightly shifted to the left or right. In some trials, Os were replaced by stroke-shifted Ts rotated by 90° and 270°.

Patterns of interactions produced by the two special distracters (Experiment 1) and Ts rotated by 90° and 270° (Experiment 2) in terms of means and cumulative distribution functions of reaction times support parallel processing (sub-additivity) rather than serial processing (additivity). The serial processing assumption was only supported in experiment 3. Also the same conclusion was drawn from the same experiments with a large set size (8 & 12 stimuli) with an exception that can be attributed to salience.

The results indicate that the assumption of serial attentive processing is rejected in for these situations and the set size effect should not be considered as a sole criterion for identifying the process organization in visual search (serial vs. parallel) even if its magnitude of effect is large.

948 Coarse-to-fine encoding of contextual information in visual search

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A previous study demonstrated that individual target-distractor associations were learned in contextual cueing (Jiang & Wagner, 2004). In the present study, we examined whether individual association can be learned in an efficient visual search task that does not involve attentional deployment individually to search items. In Experiment 1, participants engaged in a learning phase of an efficient search, followed by a test phase in which they performed an inefficient search task. A given target location was paired with two sets of distractor locations on separate trials, and they were repeatedly presented in the learning phase (repeated layouts). In the following test phase, the half of the repeated layouts were made invariant, while the other half of those were reconstructed by recombining half of distractors in one trained set with half of distractors in another trained set (recombined layouts). The result showed that the contextual cueing effect was transferred to the test phase only for repeated layouts, not for recombined layouts. These results can be interpreted as evidence that attentional deployment to individual search items is necessary for learning of the individual association. However, an alternative possibility is that shorter reaction time for efficient search may not allow enough time to encode individual associations. To test the possibility, in Experiment 2, search display was preceded by placeholders that marked the future locations of the items. The placeholders appeared for 750 ms and allowed to start encoding of contextual cueing before the presentation of the search display. The result showed that the contextual cueing effect was transferred for recombined layouts to the same level as repeated layouts, indicating that the learning of individual associations does not require attentional deployment, but just sufficient time. Our data suggest that contextual information is encoded in a coarse-to-fine manner with available time for encoding.

949 Why search for singletons when you know the target feature?

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When a visual search target is both salient (i.e., a singleton) and has a known defining feature (e.g., red), observers often search for the singleton rather than adopting a narrower attentional set tuned specifically to the target feature (e.g., redness) -- even when the narrower set (*feature search mode*; Bacon & Egeth, 1994) would prevent interference from irrelevant distractors. One possible explanation for this bias is that the feature mode is difficult to maintain under conditions of distractor homogeneity. However, recent work by Leber and Egeth (OPAM 2002, 2003) has argued against this *maintenance* account. Here, we evaluate whether feature search mode is difficult to *configure* in homogeneous displays. To examine the configuration process, we asked observers to switch between two tasks in alternating runs of two trials (i.e., AABB, etc.): A) search for the 'oddball' color in a rapid serial visual presentation (RSVP) of homogeneously colored non-targets (singleton search); B) search specifically for red among heterogeneously colored non-targets (feature search). In this design, performance for both tasks is worse on switch trials, reflecting the cost of reconfiguration. (Leber, 2003). Our study focused on the feature search trials (Task B), where we compared the switch cost in two conditions. On 50% of the feature search trials, non-target items were all homogeneous in color; on the remaining feature search trials, the non-targets were initially homogeneous and did not become heterogeneous until 300 ms prior to the target. If configuration of feature search mode is more difficult with homogeneous displays, then task-switch recovery should be impaired in the homogeneous-onset trials. Results confirmed this expectation, suggesting that feature search is indeed difficult to configure under conditions of homogeneity. These results may explain why observers often

search for singletons rather than specific features when both strategies are available.

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950 Attentional capacity limit for visual search causes spatial neglect in normal observers

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When observers simultaneously monitor several positions in the visual field, distracting stimuli have a devastating effect on the ability to discriminate between similar shapes. For example, the minimum tilt necessary for an observer to discriminate between a clockwise and anticlockwise tilt has been shown to increase with the square root of the number of untilted distractors. Here we show that these rapid visual searches remain inefficient even with extended practice. Moreover, each of our observers performed particularly poorly when uncued targets appeared in certain idiosyncratic positions, as though he or she neglected to process part of the visual field. This type of neglect is consistent with either an ideal decision strategy, based on a spatially inhomogeneous encoding of tilt, or a sub-ideal strategy, based on a linear (but anisotropic) combination of tilts. However, as we demonstrate, it is not commensurate with the popular 'Max Rule' strategy, in which observers simply report the direction of the largest apparent tilt.

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951 In visual search, can the average features of a scene guide attention to a target?

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BACKGROUND: In visual search for a target item among distractors, attention can be guided to a target by basic features of that target (Find the RED "x"). Chun and Jiang's (1998) "contextual cueing" effect shows that RTs are speeded if the spatial configuration of items in a scene is repeated over time: If the items are laid out in this pattern, then the target is at location XY. We ask if featural properties of the scene as a whole guide attention? (i.e. If the display is mostly RED, then the target is at location XY). **METHOD:** We ran a series of visual search tasks where the dominant color or orientation, present in the background, predicted the exact target location. Unlike guided search, the target did not have a defining color or orientation texture. Unlike contextual cueing, the spatial layouts of items were not informative. The basic feature could serve as an endogenous cue to target location. In Exp. 1, the mean color or texture of the background could predict the exact target location while distractor locations were randomized. In Exp. 2, the background was presented prior to the search display, to see if cueing observers ahead of time aided performance. In Exp. 3, the spatial configuration of the stimuli was the same for all trials while the features of the background cued target location. **RESULTS:** In Exp 1, there was no benefit in search when mean features of the background predicted target location in the absence of an exact target-distractor configuration. In Exp 2., a preview of the background of up to 800 msec, failed to improve search. However, in Exp. 3, when the configuration of the stimuli was invariant, predictive features in the background produced a benefit. Endogenous cueing by background features like color or texture is possible but it appears to be easily vetoed by other background information such as spatial layout.

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952 Searching for Search Asymmetries With Simple and Complex Stimuli

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When the roles of target and non-target stimuli are reversed, visual search asymmetry can result, with set-size effects so large for one target that

capacity limitations are implied, but not for the other target (Treisman & Gormican, 1988). One explanation is that it is easier to find a deviant stimulus, such as a tilted line, amid prototypical non-targets (vertical lines) than vice versa: The deviant stimulus activates a unique channel whereas the prototypical stimulus does not. Another explanation is that it is easier to discern a stimulus with more of some quantifiable feature, such as a longer line, than one with less (a shorter line). The first explanation suggests demands are placed on attention whereas the second may not. Moreover, both explanations emphasize the features of simple stimuli.

Some researchers propose the local feature information of faces and their configuration help distinguish one face from another (e.g., Diamond & Carey, 1986). Thus search asymmetry explanations for simpler stimuli may also hold for the more complex stimuli of human faces. However, other researchers postulate faces are processed holistically so that neither the individual features nor their configuration is explicitly represented (Farah, et al., 1998).

We wanted to know (a) if demands are placed on attention or at an earlier level and (b) if similar explanations could account for processing simple and complex stimuli. To do so, we parsed processing into component parts and compared results to predictions of competing models (Davis, et al., 2003). Both simpler stimuli (tilted vs. vertical lines and longer vs. shorter lines) as well as more complex stimuli (human faces) were explored. Line length only affected early visual processing so that search asymmetry was eliminated when target discrimination was balanced across conditions. In contrast, tilted vs. vertical line search still resulted in a search asymmetry effect. Search results for faces also are revealing.

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953 Predictive metacognitive judgments in a visual search task

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Purpose: Strategy selection and effort allocation in cognitive tasks are often mediated by metacognitive assessments of self-performance (e.g., Nelson & Leonesio, 1988). The current experiment examined the accuracy and role of predictive metacognitive judgments in a real-world visual search task. Method: Procedure was modeled after the judgments-of-learning task (e.g., Dunlosky & Nelson, 1992) commonly used to study metacognitive accuracy and control. In a pair of experiments, subjects performed a simulated luggage x-ray screening task, searching for knives hidden among varying numbers of background objects in passenger bags. Before performing the search task, subjects viewed each stimulus image without the embedded target item and rated how likely they would be to find the knife if it were hidden somewhere in that image. Ratings were made on a 5-point Likert scale. Experiment 1 used a 2IFC procedure for the visual search task. Experiment 2 used a speeded response procedure. Results: Experiment 1 produced a statistically significant but weak correlation between predicted and observed target detection performance (mean Goodman-Kruskal gamma = .161), indicating that subjects' predictive metacognitive judgments were only modestly accurate. Experiment 2 found that target-present RTs were similar across levels of predicted detection likelihood, but that target-absent RTs were longer for stimulus images in which target detection was predicted to be difficult. Conclusions: Results suggest that predictive metacognitive judgments are only modestly accurate, but that the information used in metacognitive judgments is nonetheless used to regulate criterion for terminating search when no target is detected.

954 Top-down interference in visual search

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In our visual search experiment, each item had two bars: one was tilted 45 degrees to the left from vertical for distractors and 45 degrees to the right for the target; the other is a horizontal or vertical bar centered at the same

location. Each target or distractor is a rotated version of all other items. As the target had a uniquely oriented bar, it was typically the most salient item, both by the Feature Integration Theory (Treisman & Gelade, *Cognitive Psychology* 12:97-136, 1980), and the theory of the bottom up saliency map in V1 (Li, *Trends in Cognitive Sciences*, 6:9-16, 2002). The subjects were informed of this unique orientation, and were instructed to quickly report by button press whether the target was in the left or right half of the stimulus display. Reaction times (RTs) were measured and subjects' eye positions were tracked. We also measured the "reaction time of the eye" (RTE) defined as the first time that the eye position is close enough to the target. Typically, RT > RTE. Subjects reported that the target often "vanished" after they had initially detected it. Eyes were often seen to saccade to the target, then moved away or loitered around for a long time, before moving back to the target and the subject's button press. A control condition was designed by changing the uniquely oriented bar in the target to tilt 20 degrees to the right from vertical, so the target was no longer a rotated version of distractors. The gap between RT and RTE was significantly shorter in this control than that in the original condition, even though their RTs were comparable. The same result was found for other control conditions with comparable RTs. In the original condition, it is as if the eyes, driven by V1 through superior colliculus, locate the target by the bottom up saliency process of unique orientation pop out, while the top-down process of object recognition, presumably rotation invariant, intervenes with the fact that all items are identical objects.

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955 Rapid Resumption Of Visual Search Is More Than Lucky Spatial Orienting

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Rapid Resumption (RR) is the observation that participants are faster to resume a visual search after it has been momentarily interrupted than they are to start a new search. In a RR study, participants are presented with brief search displays (100ms exposure) that alternate with blank displays (900ms duration) until participants successfully find the target. Typically, only 5% of responses are recorded within the first 500ms after viewing the search display for the first time, whereas more than 40% of responses are recorded during equivalent intervals following subsequent looks at the display. Here we examine the role of spatial attention in this phenomenon. Perhaps RR occurs when participants orient spatial attention to the target location during a blank display, either by chance or because they acquired partial target information on the preceding look. As a result, when the search display reappears, participants are already oriented toward the correct location and can thus identify and report the target very quickly. We tested this hypothesis in two ways. First, each item location was indicated by four surrounding dots that were presented 400ms before or simultaneously with the search display. If RR benefits from accurate spatial orienting, it should be stronger when the placeholders indicated the item locations in advance. Yet, RR was unaffected by placeholder preview. Second, we provided a 100% valid pre-cue for the target location (a single set of four dots) at different points during the trial. Four conditions were examined: no cue, cue before first, cue before second and cue before third display. Participants used the cue successfully to find the target, but response times following a valid cue were still slower than those observed for RR with no cue. These results indicate that there is more to RR than efficient spatial orienting of attention, namely, RR reflects the confirmation of a perceptual hypothesis that has been formed during a previous look at the display.

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956 Efficiency of Visual Search are closely related with several properties of oval shape

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It was investigated how several properties of oval shape influence visual search process. We used oval stimuli as distracters and targets in visual search paradigm and performed three experiments. In experiment 1, we manipulated ratios of major to minor axes so that there were three ratios; 1:4, 2:4, and 3:4. It was conjectured that gradual changes of oval axes ratio influenced visual search process systematically. We found that there was no set size effect of ratio 1:4, whereas significant set size effect of ratio 3:4. Slopes of searching time changed systematically according to the ratios of major to minor axes. In experiment 2, we used concave and convex shapes of oval as distracters and targets. We conjectured that there existed search asymmetry because convex distracters might be organized more easily as background than concave distracters, and observed the proposed result. In experiment 3, we manipulated directional axes and convexity/concavity of oval shape. We found that the easiest search condition was a search of vertical convex target against horizontal convex oval distracters. It took more time to search a horizontal target than a vertical target. These results implied that grouping process are influenced by directions of oval object asymmetrically. Furthermore, concavity and convexity of objects also influence grouping process so that efficiency of visual search was changed. It is suggested that the familiarity of visual environment makes efficiency of grouping process of these elements asymmetrically.

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957 Optimal and Suboptimal Models of Oddity Search

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Signal detection and ideal observer models have been proposed to predict decreasing visual search accuracy with increasing set-size with a fixed target known to the observer (Palmer et al., 2000, Vision Research; Eckstein et al., 2000, Perception & Psychophysics; Verghese, 2001, Neuron). Here, we extend ideal observer and suboptimal models to oddity search, where fewer modeling attempts have been made (Santhi & Reeves, 2004, Vision Research). In an oddity search, the target is not known beforehand and observers must identify and find the target as the 'odd man out'. Methods: Three observers performed a 2IFC oddity orientation discrimination. Each interval contained N (2, 4, 8, or 16) Gabors (peak sf = 1.98 cpd, full width, half height = 0.798) presented on an imaginary circle (eccentricity=9.748). On each trial, a target and distractor orientation were randomly sampled from 10 possible orientations ranging from -458 to 458 in 108 steps. One interval contained N distractors, while the other contained N-1 distractors and a target; the observer judged which interval contained the target. The orientation of each element was perturbed with Gaussian noise (sd=128). There were two conditions, a target unknown (oddity search), and another with a cue giving the target orientation before each trial (target known). Results: For the ideal observer, set-size effects are more pronounced for the target known condition than the target unknown (oddity) condition, but not for a suboptimal model that does not use information about the target identity and only makes decisions based on element differences. Across both conditions, the suboptimal model best predicted performance for two naïve observers, and the ideal observer best predicted performance for the third observer (WS, author). Thus, with this novel extension of ideal observer models to the oddity search, we were able to assess that observers may differ in the amount of information used about target identity.

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958 Using models of visual search to design optimal interfaces

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Wolfe's (1994) Guided Search model was applied to a simple visual search task: looking for a store on a mall directory. The directory consisted of

eight stores represented as rectangles arranged from left to right. Each rectangle contained the store name and was one of three colors. The project involved two parts: fitting the model parameters to the environment and using the resulting model to create optimal directory designs. For parameter fitting, 600 different mall directories were generated with random assignments of store names and colors to positions. Observers viewed the directory and a target store and made a speed judgment on whether the target was in the directory or not. Sixty-nine observers in four groups each viewed 150 trials. Average RTs for the correct identifications of target present across each group were used with the directory features to identify the 15 model parameters that best fit the data. The model did a good job of fitting the data ($r=.721$). Running the same parameter fit technique with RTs randomly assigned to trials with different directory features did not lead to good fits (average $r=.053$). Next, we explored how to use the model to design an optimal directory that minimizes visual search time. Given a distribution of frequency searching for different stores in the directory, what is the assignment of colors to stores that minimizes average visual search time? The answer was found by examining all possible color combinations and for each one computing the average visual search time. For the directories we used, the model makes a counterintuitive prediction: color doesn't matter. The parameter fitting data found large effects of target position on RT, with a target in the middle of the directory being found fastest (closest to a pre-stimulus fixation point). Any effects of color were miniscule compared to the larger effects of target position. This finding is useful to a designer who might otherwise fret over how to assign colors to store positions.

959 Crowding degrades saccadic search performance

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An extensive body of literature shows that flanking elements make it more difficult to perceive target information (e.g. Bouma, 1970; He et al., 1996). We investigated whether this effect, known as crowding, affects the search time in a search task in which eye movements are required to inspect the whole display.

In a one-dimensional search strip, 6 subjects searched for an 'O' (gap 08) amongst 29 'Cs' (gap 0.338). One-dimensional 'mask' strips of Cs were added above and one below the search strip. Subjects were informed that these mask strips never contained the target. In three conditions, we increased the similarity of the masks (and not the search elements) to the target by decreasing the size of the mask gaps (0.338, 0.178, 0.038), thereby increasing crowding (Nazir, 1992; Kooi et al., 1994). A fourth condition did not contain mask strips. Eye movements were measured.

We validated our stimulus psychophysically. We confirmed that increasing target-mask similarity increased the crowding effect: the maximum eccentricity at which the target could be resolved was smaller when target and mask were more similar (i.e. smaller mask gap size).

Turning to the search experiment, with increasing crowding we found: longer search times, more fixations, shorter saccades and longer fixation durations.

From this we conclude that crowding is a bottleneck on saccadic search besides, for example, the distribution of spatial resolution and the scanning rate of attention. The adjustment of the saccade amplitude and the number of fixations is interpreted as due to decreasing visual span size with increasing crowding.

960 In search of segmentation

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We investigated object segmentation by means of a visual search task. Our aim was to investigate the role of object interpretations as opposed specific image properties. Three experiments are reported. In the first experiment,

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we manipulated inner and outer contours of connected versus disconnected objects. We found that the occurrence of search asymmetries depends largely on inner contours, not on outer contours. From this, we conclude that object interpretations, due to inner contours, are predominant. In Experiments 2 and 3, the segmentation due to T-junctions was investigated. More specifically, we designed stimuli in which various interpretations had differences in perceived connectedness. The results indicate that not the T-junctions but rather the interpretations, and with that the level of connectedness, are decisive with regard to the occurrence of search asymmetries. We conclude that, at least for our set of stimuli, segmentation based on specific image properties (like outer contours or T-junctions), can be overruled by object interpretations.

961 Feasibility of Feature-Based Contraband Detection in X-Ray Images

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Detection of illegal and prohibited items (contraband) passing through airports is a complicated and difficult task. The USDA uses x-ray inspection, interviews, and luggage and canine searches to keep our agriculture safe from foreign bugs & disease brought in through air traffic. Contraband includes, but is not restricted to, fresh fruits, plants, meat, soil, grain, and seeds.

X-ray inspection is relied upon because it is fast and allows for a non-invasive look into the contents of passenger baggage. Inspectors use the x-ray images to judge if a bag must be physically opened and searched for contraband. The drawback of x-ray inspection is that the images are monochromatic, compressed jumbles of lines and textures that must somehow be translated into presumed 3D representations that can be recognized as contraband items. This requires months of experience and is difficult to train for (there is no consistent vocabulary to describe "what to look for").

We are investigating a new image feature based (IFB) approach to improve inspection performance. Instead of looking for specific contraband (e.g. fruit), inspectors will look for particular patterns of curves or textures associated with contraband items. IFB is fast, adaptable, provides a consistent vocabulary, and does not require months of onsite training.

Contraband occurs in ~5% of bags. The number of bags that can be searched is limited by staff capacity, thus increasing the frequency of contraband-containing bags (CB) in that selection is desirable. Current max search capacity is ~10% of all x-rayed bags. X-ray inspection results in a CB frequency of 18% (vs 5%). However, 82% of the bags were searched unnecessarily, resulting in passenger delays and wasted manhours. Using IFB and pulling only 3.6% of the bags, CB frequency would be 10%. If IFB pulled 10% of the bags, we predict that CB would increase to ~21%. Training naïve observers in IFB and refinements of the feature set will be investigated next.

962 Both cognitive factors and local inhibition mediate the effect of a surrounding frame in visual search for oriented bars.

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It is easier to search for tilted line elements amongst vertical distractors than vice-versa (Treisman & Gormican, 1988, *Psychological Review*, 95, 15-48). When a vertical or tilted square frame surrounds the elements, there is an advantage for targets tilted relative to the frame. Treisman suggested two explanations: (1) the frame defines the orientation against which tilt is defined, and targets parallel to the frame lack a "tilt" feature, making them harder to find; (2) targets tilted relative to the frame have a unique orientation, making them more salient than targets parallel to the frame, which receive competition from it. Li (2002, *Trends in Cognitive Sciences*, 6, 9-16) proposed a saliency mechanism that explains these results using iso-orientation inhibition between nearby V1 cells: cells responding to an element parallel to the frame receive more inhibition than those responding to an element with a unique orientation. We ran several

experiments to test this model. In each stimulus, either the target or distractors were parallel to the left and right sides of the frame, and no element was parallel to the frame's top and bottom. In experiment 1 the left and right sides of the frame were constructed from elements oriented parallel to the frame's top and bottom; in experiment 2, the left and right sides were removed altogether. Both modifications caused the target to be uniquely oriented whether or not it was tilted relative to the frame and, in both cases, the frame effect was still present (but reduced in experiment 2). These results are not explained by the V1 model, and suggest a role for more cognitive factors. However, other results supported the V1 model, which predicts that inhibition decreases with increasing distance between receptive fields. We found that enlarging the frame, so that it was further from the elements, reduced its effect. In addition, a single line through the stimulus has the same effect as a frame only when the target is close to it.

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963 Spatio-temporal integration in grouping-based feature attribution

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By using a Ternus-Pikler display, we showed that features presented at one spatial location can be perceived at another one, in violation of retinotopic relations but in accordance with perceptual grouping (Herzog & Ogmen, VSS'05). Here, we extend these results by showing that features of elements presented at two distinct retinotopic loci can be combined. The stimulus consisted of a first frame (70ms) containing three vertical lines, an ISI (100ms), and a second frame (70ms) containing three lines shifted to the right. The second and third line of the first frame overlapped spatially with the first and second line of the second frame, respectively. With this set-up, group motion is perceived: the lines of the first frame are mapped onto corresponding lines of the second frame. We inserted a vernier offset to the central element of the first frame. An additional vernier offset of opposite direction was inserted to one of the remaining elements in the first or the second frame. Observers' task was to report the perceived direction of vernier offset (left of right) for a pre-designated line in the second frame. Naïve observers had no knowledge where vernier offsets were presented. Our results show that the integration of the vernier information across the two frames follows the rules of motion grouping; e.g. a vernier offset of the second element of the first frame is integrated with the vernier offset of the second element of the second frame- even though these elements reside at different spatial locations. The close relationship that we show between perceptual grouping and feature attribution suggests that the visual system violates retinotopic relations in order to maintain spatio-temporal contiguity of object identities in the perceptual space.

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964 The Perception of Order: Same-Different Paradigm Reveals a Relationship Between Goodness-of-Figure and Processing Efficiency.

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Information Theory defines statistical entropy in terms of the amount of information carried in a signal or event (Shannon, C.E., 1949). In general, more random strings take more information to represent, while less random strings take less information to represent. When describing arrays of visual objects, we may be tempted to refer to certain types of configurations as more 'ordered', 'organized', or 'structured' than others. Relating these types of subjective judgments to Information Theory predicts that visual configurations which are judged as more 'ordered' should take less information to represent and consequently, should result

in some benefit of processing over less ordered arrangements. Using the same/different paradigm, the present study investigates whether there is a correlation between subjective ratings of order and the speed at which participants determine whether two configurations are the same. Configurations were randomly generated to fill a 4 x 4 grid with an equal number of black and white cells. One group of participants made subjective judgments about how ordered each of 500 different configurations appeared. Participants decided which of two randomly paired configurations 'appeared more ordered'. Ratings were combined across participants to produce a distribution of relative judgments of order. A second group of participants performed a same/different task with these rated configurations. As predicted, there was a significant correlation between the subjective judgments of order and reaction time performance on the same/different task. Implications for the nature of perception of order are discussed.

965 Adaptation to invisible gratings in Troxler filling-in

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Under strict fixation, a stationary or slowly changing peripheral stimulus gradually disappears from awareness (Troxler 1804). This phenomenon is often attributed to early sensory adaptation at the level of retinal ganglion cells or LGN. Yet, evidence from binocular rivalry, motion-induced blindness, and induced disappearance indicates a cortical origin for disappearance. Here, we examined whether Troxler fading occurs before processing orientation information in V1. Six participants viewed two low-contrast peripheral (11.5 deg eccentricity) Gabor patterns for 15 s. Gratings drifted slowly (0.1 Hz) to reduce receptor adaptation. Observers monitored the visibility of one of the gratings by holding a key while it disappeared. On the average, the grating was invisible for 2.2 s. The second grating served as a control and was erased from the screen whenever the first was reported as invisible. After adaptation, a test Gabor pattern (with either the same or orthogonal orientation) appeared at one of the two locations, and observers were asked to report its location and alignment. Results: Orientation-selective adaptation was stronger when the adapting stimulus was physically present than when it was erased (48% vs. 64% correct detection for same orientation, $p < 0.01$). Subjects had little difficulty detecting an orthogonal grating in both conditions (89% vs. 90%, n.s.). Notably, the aftereffect was stronger in trials that observer reported fading during adaptation (42% vs. 56% for the same orientation, 94% vs. 82% for orthogonal). Thus, fading from awareness did not result in reduction of orientation-selective aftereffect compared to the control. We conclude that consistent with other disappearance phenomena, Troxler fading occurs at least in part after the site of orientation-selective processing. Results may be accounted for by attentional modulation of the visibility of peripheral targets.

966 Masking interrupts feedback processing

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In masking, a stimulus is rendered invisible through the presentation of a second stimulus shortly after the first. Although numerous accounts for masking have been given, an unequivocal explanation for this phenomenon remains elusive. However, neurophysiological studies from recent years indicate that visual perception depends strongly on cortico-cortical feedback connections from higher to lower tier visual areas. In macaque monkeys it has been shown that masking derives its effectiveness from interrupting these feedback processes. In this experiment, we used fMRI and EEG measurements to determine what happens in human visual cortex during detection of a texture defined square under masked and non-masked conditions. EEG derivatives that are typically associated with early feedback processing turn out to be absent in the masked condition. Moreover, preliminary fMRI results suggest that the masked stimulus still

evokes activation of visual cortex, with higher visual areas being activated more strongly than lower areas. This indicates that feed-forward processing is preserved, even when subject performance is close to chance. From these results we conclude that in humans, as in macaques, masking derives its effectiveness from interrupting feedback projections.

967 Within-field Advantage for Detecting Matched Motion Paths

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Purpose: Butcher & Cavanagh (VSS 04) demonstrated that subjects were faster and more accurate in detecting a pair of repeated letters, colors, or sizes when presented unilaterally (both elements in the same hemifield, left or right) than when presented bilaterally (one element in each hemifield). We now find that the within-field advantage also holds for detecting matched motion paths. Methods: Each trial began with 4 static white 1.5 deg. diameter disks on a gray background, placed at the vertices of an invisible 6 x 6 deg. square around fixation. After a short interval, the disks began to move at a speed of 3.25deg/sec. The display was present for 14 video frames on a 1024 x 768 monitor at 75hz. Each disk could move in one of the four cardinal directions, and maintained its direction of motion for the duration of the display. On target present trials, 2 of the 4 disks had the same motion direction. On target absent trials each of the 4 disks moved in different directions. Subjects reported the presence or absence of matched motions with a keypress. Results: Subjects were 72 ms faster detecting matched motions when the match occurred unilaterally versus bilaterally ($t(1,6) = 8.02$) $p < 0.001$). There was no evidence of a speed accuracy trade-off (mean misses: unilateral = 4%; bilateral = 8%). Conclusion: The results show that matched motion is more efficiently detected within hemifields than across fields. This suggests that the grouping process underlying the detection of the match operates in early retinotopic areas where the left and right hemifields are divided. This early grouping holds for these transient motion features as well as for the shape and color features reported previously.

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968 Neuronal correlates of Common Fate (spatial and temporal correlation) in retinotopic cortex

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According to the Gestalt Principle of Common Fate, objects that move or change together tend to be perceived as a unified group. Here we examined the neural correlates of common fate in retinotopic areas in a standard block design (GE 1.5T, 25 slices, TR=2.5s, n=12; retinotopy in a separate session). Experiment 1: Four equiluminant green disks (equated individually for each subject) on a gray background, one in each quadrant, turned on and off at random, but with equal probability in each location. Flickering was either independent, or the disks flicked in unison. Local statistics within a quadrant were the same in the two conditions. The only difference was global correlation. Results: V1 demonstrated a negative BOLD response in the uncorrelated condition and a positive BOLD response in the correlated condition. Also, V2d and V2v displayed a greater BOLD response in the correlated condition than in the uncorrelated one. Thus global correlation appears to lead to greater neural activity than baseline, whereas uncorrelated flickering leads to inhibition of neural activity in V1 relative to baseline. Experiment 2: Same as experiment 1 except now the disks were always visible, and each randomly changed position within an imaginary circular zone within one quadrant, either independently or in unison. The former case looked like four separate objects in motion, and the latter case looked like a larger square jumping about jerkily. Results: V1 and V2d demonstrated a positive BOLD response in the uncorrelated condition and a negative BOLD response in the correlated condition. These results contrast with

those of experiment 1, suggesting that V1 and V2 have different roles in determining grouping on the basis of spatial (motion-based) and temporal (flicker-based) correlation.

969 Object binding through motion

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The visual system is highly adept at segmenting scenes into regions based on cues such as color, luminance, texture, and boundary contours. It is also adept at determining which of these regions should be bound together as a single object. Work in infant visual development (e.g. Kellman & Spelke 1983, Slater & Johnson 1996) suggests that children are able to accomplish such object binding via dynamic cues of common fate within a few months of life. Our own work, as part of Project Prakash, with patients having low acuity (see E. Meyers abstract in this volume) also emphasizes the important role of motion in the binding of object parts. This pattern of results suggests that common-fate motion cues might comprise an important early mechanism for primitive object binding from which more robust heuristics based on other cues (e.g., junctions, texture, or Gestalt grouping principles) can be learned. Once these heuristics are in place in the developing infant, visual analysis of objects in static images can occur. Based on the experimental results on the primacy of common-fate motion cues for object binding and segmentation processes, we have developed a motion-based binding algorithm which extracts complex objects from video sequences. A key challenge that the algorithm addresses is binding despite the significant variability in the motion patterns of object parts. In other words, contrary to the simplistic notions of 'common-fate', the fates of visual entities that ought to be bound are often quite different. We shall describe how the algorithm accomplishes grouping even with not-so-common fate, and how its predictions compare with experimental data from human observers. This work is a key component of Project DYLAN (see P. Sinha abstract and B. Balas abstract in this volume), which seeks to computationally model the overall process of object concept learning in children.

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970 Temporal Information for Spatial Grouping: Structure or Synchrony?

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What visual cues promote grouping of local image features into global spatial form? Several previous studies suggest that synchronous stimulus changes support the grouping of spatially segregated elements, whereas asynchronous changes lead to stimulus segregation. However, these experiments often confound temporal synchrony (i.e., the precise timing of the changes) with temporal structure (i.e., the pattern or "rhythm" of the changes over time). In the current study, we investigate the extent to which spatial grouping from temporal cues can be attributed to structure versus synchrony. Observers viewed arrays of Gabor patches in which spatial frequency changed stochastically over time. The timing of the changes yielded two opposing perceptual organizations. One organization involved grouping those elements having the same point process (i.e., same temporal structure), but whose individual changes were delayed slightly relative to one another (i.e., asynchronous). The second organization involved grouping those elements that changed synchronously more often than not, but that changed according to different overall temporal patterns (i.e., different temporal structures). Perceived spatial organization proved to depend primarily on temporal structure, rather than temporal synchrony. That is, observers systematically grouped elements that changed according to the same general pattern over time, even though the changes themselves were asynchronous. Furthermore, different global patterns of change served as a consistent basis for segregation. These findings will be discussed in the

context of ongoing controversies concerning the role of temporal synchrony in stimulus binding.

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971 Neural correlates of edge detection and scene segmentation during inattentional blindness

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We studied the neural correlates of edge detection and scene segmentation, and to what extent these depend on attention. We used texture defined stimuli, that made it possible to distinguish between EEG activity related to texture boundary detection (TB) and activity related to texture surface segregation (SG). We presented these during three different conditions, a condition of inattention, a condition of non-attention and a condition of attention. Inattentional blindness (IB) was induced by presenting the target stimuli conjoint with a rapid serial presentation of letters that subjects had to focus on. We only analysed neural data from subjects suffering IB (50% of subjects did not see at least 200 targets). These subjects were presented with this paradigm again while they had to respond to the letters for a second time (the non-attention condition) and while they had to respond towards the target stimuli (attention). During inattention we observed both TB and SG activity. This activity is larger during the non-attention, and largest during the attention condition. We furthermore observed a temporal gradient in the SG activity, starting first in parietal channels, and appearing later in occipital channels, indicative of feedback processing. This was most strongly observed in the attention condition. We conclude that surface segregation signals do evolve independent of attention, yet at the same time are strongly influenced by it. It furthermore seems that these signals are strongly influenced by feedback from parietal to occipital cortex, which is consistent with a role of attention in surface segregation.

972 A regular grid imposes a city-block metric on visual space

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Purpose. To measure the metric imposed on visual space by the processes that group a grid of points into rows and columns. **Method.** On each trial the observer viewed (for 200 ms) a grid of small dots (Gaussian blobs), some of which were displaced from their expected locations. On any given trial, either 84 or 108 dots were perturbed, and the subject judged, with feedback, which type of grid had been presented. Dot perturbations all had length equal to 18.75% of the horizontal inter-dot distance but varied in direction over the 16 angles, 0, 22.5, 45, 67.5, 90, 112.5, 135, 157.5 deg. There were thirty conditions using different histograms of displacement directions, with prescribed displacements assigned randomly to grid-dots on a given trial. From the data we estimate the average impact (in multiples of d') exerted on judgments by displacements in different directions. We take these impacts to reflect the distances in visual space traversed by different displacements. In Expt. 1 the mean grid was 16 by 16, with equal horizontal and vertical spacing. In Expt. 2, the mean grid had 11 rows and 14 columns, with rows 1.25 times farther apart than columns. **Results & Conclusions.** In Expt. 1, the visual distance traversed by a displaced dot was found to be equal to the sum of the separate distances traversed by the dot in the horizontal and vertical directions. Thus, for example, a diagonal displacement exerted $\sqrt{2}$ times the impact of a vertical displacement. We conclude that a regular grid of points imposes a city-block metric on visual space. When rows were 25% farther apart than columns, displacements closer to horizontal than diagonal obeyed a city-block metric as observed in Expt. 1. However, displacements ranging from diagonal up to vertical did not: the visual distance traversed by such a displacement depended only on its vertical projection.

973 Surface convexity and extremal edges in depth and figure-ground perception

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Edges arising from depth discontinuities are powerful cues to figure-ground organization (FGO) in 2-D images. We studied psychophysically whether surface convexity and extremal edges (EEs) are effective cues to depth and FGO. EEs arise when a curved surface partly occlude itself such that the line of sight lies in the EE's tangent plane. An EE thus normally belongs to the curved surface, which is closer to the observer. It is much less likely that the curved object is occluded by a closer surface whose edge just happens to align with the EE.

If an EE is visible in a bipartite display containing a 2-D rendering of a curved surface and a flat surface, observers should tend to see the edge as belonging to the curved surface which should appear closer and figural. Displays of curved surfaces were rendered in 2D using shading gradients on one side and various flat surfaces on the other side that controlled for complexity, luminance, and other factors. As expected, the convex surface appeared closer and figural. To determine whether these results were solely due to surface convexity, we studied bipartite displays containing two orthogonal cylinders. The convex surface to which the EE belonged appeared figural more often than the other, equally convex side. We also studied bipartite figures in which one region was a surface of revolution with an EE and the other region had classical figural characteristics such as smaller size, edge convexity and/or greater meaningfulness. In most cases EEs appeared to be the stronger cue to FGO. Further experiments examined similar issues using texture gradients to render surface curvature. All preliminary experiments support the idea that surface convexity and extremal edges are powerful cues to FGO. Examples of our stimuli can be seen at <http://socrates.berkeley.edu/~plab/projects.htm>

974 The Effect of Skew Symmetry on Figure-Ground Assignment

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Symmetry is a salient cue for figure-ground (FG) assignment which was described by the Gestalt psychologists in the early 1900s. Perfect bilateral symmetry, however, is quite rare. If a viewer looks at a symmetrical region and is not perfectly aligned with its vertical midline axis, the image projected onto the retina is a skewed version of the symmetry. This skew symmetry, therefore, is likely to more often be experienced. Does skew symmetry also affect FG assignment? In Experiment 1 observers either viewed stimuli frontally or with the monitor swiveled and were asked to make FG judgments. In order to obtain a more objective measurement, Experiment 2 employed a short-term memory matching task in which observers matched contours to previously viewed FG displays. Experiments 3a and 3b addressed the possibility that observers may have used the orientation of the monitor as a cue as to the orientation of the stimuli. Skewed stimuli were presented on a frontally facing monitor. Observers performed the explicit FG report task from Experiment 1. Experiment 4 dealt with the possible confound of parallelism by making the edges of the stimuli nonparallel. All four experiments suggest that skew symmetry is used as a FG assignment cue.

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975 Local and global systems revealed in image segmentation during bistable percepts of three ambiguous figures: 'Schroeder's Staircase', the 'Rubin Face-Vase figure', and the 'Ebbecke Ring'.

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How the perceptual system segregates, sorts, and binds features of objects to form unified percepts from a complex visual world is a central question in vision research. Since the bistable percepts of ambiguous stimuli are purely subjective, they can be used to isolate mechanisms of perceptual binding from stimulus-dependent modulations. High resolution functional magnetic images, fMRI, (1.5x1.5x3mm) were acquired while subjects maintained one of the two-bistable percepts of 'Stroder's Staircase', the 'Rubin Face-Vase' figure, and the 'Ebbecke Ring'. A random-effects group analysis (SPM2) revealed a widely distributed global circuit including frontal, parietal, and occipital regions that was activated for all figures. Fusiform face area was significantly more active during the perception of the face versus the vase percept for the Face-Vase figure. Furthermore, distinct regions of the right inferior parietal lobule were more active while viewing one percept of a figure over the other. These results were consistent across all 3 ambiguous figures suggesting a generalized mechanism for image segmentation, and lead to two important conclusions: (1) high-level mechanisms are involved with the maintenance of a percept of bistable figures (2) activity in distinct local populations of neurons in the inferior parietal lobule are involved in perceptual grouping and binding of visual input.

976 The determination of visual figure and ground in dynamically transforming shapes.

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Figure/ground assignment is a critical step in early visual analysis, upon which much later processing depends. Previously identified cues to figural assignment exclusively involve static geometric factors such as convexity, symmetry, and size in non-moving images. Here, we introduce a new class of cue to figural assignment based on the motion of dynamically deforming contours. Subjects viewing an animated, deforming shape tended to assign figure and ground so that articulating curvature extrema, i.e. 'hinging' vertices had negative curvature. This bias is present when all known static geometrical cues to figure/ground are absent or neutral in each of the individual frames of the animation and instead depends on a preference with regard to dynamic contour motion. In addition, this bias for certain deformation properties even seems to override a number of well-known static cues, including smaller area and convexity, when they are in opposition to the motion cue in the same display. We propose that the phenomenon reflects the visual system's inbuilt expectations about the way shapes will deform specifically, via the articulation of rigid parts at concave part boundaries. This preference is consistent with the underlying structure of biological organisms consisting of rigid limbs, formed over skeletal segments, connected at axial joints. These results point to a novel role for shape partitioning at negative minima and, more generally, suggest a prominent, and largely overlooked, role of dynamic factors in shape and object perception.

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977 Electrophysiological correlates of contour integration in human visual cortex

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Integration of local features into global shapes has been studied in a contour integration paradigm. We investigated the neural bases of contour integration with the help of event related potentials (ERP). Observers had to either detect an egg-shaped contour (DET), or discriminate between to directions that the egg-shaped contours were pointing at (DIS). In both conditions the same stimuli were used: closed contours composed of Gabor patches on a background of randomly positioned and oriented

Gabor patches. Task difficulty was varied by gradually rotating the contour patches from the predetermined path of the contour, that resulted in six levels of difficulty, and undetectable contours in about half the trials. We repeated both tasks at high and low contrast values for the Gabors. While subjects performed 360 trials for each condition we obtained ERPs (recorded from 23 channels, positioned according to the 10-20 system). DET and DIS trials were recorded in separate blocks. Difference waves were constructed by subtracting ERPs for undetectable from that of for detectable contours. Contour integration (as reflected in the difference wave) was characterised by a more negative wave between 200 and 300 msec. This difference is generated by a smaller P2 (at around 200-220 msec) and an enhanced N2 (at 260-280 msec) at occipito-temporal electrodes. Increased attention to the shape of the figure in the DIS condition only slightly increased the magnitude of this effect. Reducing the contrast of the images also led to an increase of the effect between 200 and 300 msec, and extended the difference to the N3 (at 350-380 msec) component of the ERP. The time course of these results is consistent with earlier findings in the monkey cortex (e.g. Zipser et al, 1996, Bauer and Heinze 2002), suggesting the relevance of a later, 'tonic' response phase within the early visual cortex in the integration of orientation information across the visual field.

978 A Neural Network Model of Gestalt-like Visual Processing.

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The perceptual phenomena evidenced by Gestalt theory can be explained by assuming the existence, within perceptual space, of a suitable vector field. The latter would act upon the single stimulation elements, by organising them into wholes, endowed with properties of global nature. The contours of perceived patterns would coincide with suitable lines of force associated to the equilibrium configurations of this field which, in turn, should depend on the form of the boundaries of perceptual space itself. Stadler proposed to detect these lines of force by resorting to a task in which a subject must graphically reproduce on an empty sheet of paper a point previously observed on another sheet. The displacement between the reproduced and the observed point lets us individuate the direction and the magnitude of the tangent vector to the line of force at a given position.

In this work we introduce a neural network model able to reproduce the performance of human subjects in the task quoted above and to represent Gestalt-like properties of spatial pattern processing. This model is based on a general architecture consisting of: a retina receiving input pattern, a spatial memory designed to process retinal output values, and a system of filtering networks designed to detect the domains of the spatial scene whose properties are the most important for the task to be done by the whole system. Our model includes also a motor network describing motor action issued by subjects as a consequence of their spatial memory content. Model's performance has been tested through a comparison of its motor output with the one of human subjects on visual pattern reproduction.

The findings obtained from the latter evidenced that the majority of lines of force thus individuated crossed in a small number of points, to be identified with the attractors of the perceptual field. We found clear evidence for the presence of two attractors located near the two corners on the upper part of the sheet.

979 Neural signals in monkey primary visual cortex that predict direction and latency of saccades.

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When in the brain is a decision made? In the visual domain, a behavioral outcome of a decision is a saccade, which is a fast shift of gaze towards a

target in the visual scene. Making a saccade includes a sensory phase where a target is located and identified and a motor phase where an eye movement is prepared and executed. Current neurophysiological data and reaction time models show that saccadic reaction times are determined by the build-up of activity in motor-related structures. Here we show, using a delayed figure-ground detection task that sustained activity in the sensory visual cortex (V1) predicts saccadic reaction time. This predictive activity is part of the process of figure-ground segregation and is specific for the saccade target location. These observations show how sensory signals can provide information for the decision when and where to look.

980 Statistical Basis for the Perception of Contrast, Orientation, Spatial Frequency and Color

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The visual perceptual qualities of contrast, orientation, spatial frequency and color are strongly and complexly affected by the relationship between any given target and its context. For example, the perception of surface brightness is determined by the luminance contrast, orientation, spatial frequency and spectral characteristics of a target and these same parameters at every point in the rest of the scene. It remains unclear how interactions among these basic stimulus features are represented in the visual brain, and why target and context features affect each other in such extraordinarily complicated ways.

Here we suggest that, as a means of contending efficiently with the full range of naturally occurring visual stimuli, the human visual system encodes the probability distributions of the co-occurrence of these basic visual features in typical scenes. An advantage of this strategy of vision is that it makes use of the full coding capacity of the system in any typical situation. Since specific values of stimulus qualities such as luminance contrast, orientation, spatial frequency and spectral distribution co-occur to different degrees in different natural contexts, the pertinent representations of any one of these characteristics should, in these terms, be based on the conditional probability distribution of the relevant characteristic at one location, given the probability of occurrence of the possible values of all these other features at both the same and other locations.

To test the merits of this concept of vision, we analyzed a database of natural images, thus obtaining the relevant probability distributions of co-occurring contrasts, orientations, spatial frequencies and spectral distributions. We show that these probability distributions can indeed account for the wide range of target-context effects apparent in the perception of contrast, orientation, spatial frequency and color, supporting a wholly statistical basis for these perceptual phenomena.

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Faces 3

981 Image Warping Does Not Model Variation in Facial Masculinity

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Differences in facial appearance between women and men (facial masculinity/femininity) have been proposed to account for variance in perceived attractiveness of faces. Studies of men's facial attractiveness show that, in many cases, masculine faces are preferred to feminine faces. However, some studies show the opposite, particularly studies that used image warping to masculinize or feminize images of men's faces. We propose the terms masculinity (variation in unaltered faces) and

masculinization (images warped to be more masculine-appearing) to differentiate the methods.

We altered men's images with image warping and found masculinity to be positively - but masculinization negatively - associated with judgments of men's attractiveness. To understand how masculinity and masculinization differ, we used a computational model to determine whether they are subsets of the appearance differences between men and women. Once trained to differentiate images of men and women, the model moderately predicted masculinity judgments of unaltered men's face images. The model did not predict masculinity judgments of masculinized images of men. We also demonstrate that the ways in which appearance variation in unaltered and warped images predicts masculinity judgments are remarkably distinct.

Thus, warping produces images that do not parallel natural variation in masculinity. At least two reasons explain the incongruity. First, growth and differentiation are unlike a single deformation. Second, warping methods generally don't model the pigmentation differences between men and women.

Warping is useful to isolate sources of facial variation for experimentation, so we suggest a guideline to its use. If warping is used to produce representations of the results of 'real-world' processes such as growth, the burden of proof is on the experimenter to carefully demonstrate that the altered images represent valid variants.

982 Sensitivity to the Spacing of Features in Novel Objects after Learning Individuals vs. Categories.

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Adults appear to be more sensitive to configural information, including the spacing of features, in faces than in other objects (reviewed in Maurer, Le Grand, & Mondloch, 2002). This difference arises even when adults are simply primed to perceive 4 blobs (placed in the position of two eyes, nose, and mouth) as facial features rather than points of the letter Y (Nishimura, Maurer, & Mondloch, 2004). The difference may arise because spacing information plays a greater role in learning to identify individual exemplars of an object category (e.g. faces: Bob vs. John) than in learning to identify objects at the basic level of categorization (e.g. table vs. chair; Gauthier & Tarr, 1997). We simulated this learning difference by having two groups view the same stimuli but learn to label them only at the categorical level or at both the categorical and individual levels. One group (n=9) was trained to label three categories of ambiguous stimuli: bobos formed from 4 blobs, tikas formed from 6 blobs, and pelis formed from 7 blobs. The other group (n=9) was trained, in addition, to use different labels for the three individual bobos, each of which has a slightly different spacing of its constituent blobs. The two groups were matched based on a pre-test of sensitivity to spacing differences in a different set of bobos. On a post-test with novel bobos, the group trained to label individual bobos was significantly more accurate (M=71.1%) in detecting changes in the spacing of the constituent blobs than the group that learned only the category labels (M=64.8%; $p = .03$, one-tailed). The spacing changes were of the magnitude that naturally exists among human faces. The findings are consistent with the hypothesis that we become more sensitive to the spacing of features in faces than in other objects because we have more experience identifying individual faces than identifying individual members of non-face categories.

983 Matching Complementary Faces and Blobs in the Gabor Domain by Novices, Experts, and an Ideal Observer

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Many of the phenomena associated with face (vs. object) recognition can be understood in terms of a representation for individuating faces that retains aspects of the original spatial filtering, as posited by Malsburg's Gabor Jet model (Biederman & Kalocsai, 1997). Objects, in contrast, may be

represented by a structural description specifying explicit relations among view-invariant properties of edges of simple parts. To test whether the representation of faces, but not objects, retain characteristics of the original spatial filtering, subjects matched faces and blobs in a two-alternative, match-to-sample task. The blobs were smooth, asymmetric volumes (harmonics of a sphere resembling teeth) that, like faces, varied in the metrics of their surfaces. Each stimulus was filtered by a jet of Gabor wavelets at 5 scales and 8 orientations, with each jet positioned at the vertices of a 10*10 grid. On half the trials, the correct choice was the identical image as the sample; on the other half it was a complement of the sample. Complementary pairs of images were produced by assigning every other scale and orientation component to one member of a pair and the remaining components to the other. Consistent with the hypothesis that face representations specify the original spatial content, matching complements of faces resulted in greater error rates than matching identical images for both novices and experts. No such costs were apparent when matching blobs, a result consistent with prior findings in the Fourier domain with faces, chairs, and blobs. A pixel-based ideal observer analysis showed that faces and blobs had equivalent complementary costs, indicating that the greater cost in matching complementary images of faces compared to blobs was not due to intrinsic differences in the stimuli.

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984 The Distinctiveness Effect Reconsidered: Poorer Recognition of Distinctive Face Silhouettes

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A recognition advantage for distinctive versus typical faces has been widely reported (e.g., Valentine, 1991, Deffenbacher et al., 2000). The effect is robust and appears as both an increased hit rate for distinctive targets and a reduced false alarm rate for distinctive distractors. Because distinctive faces lie in a sparse, peripheral region of face space, the recognition advantage could potentially be due entirely to the fact that they are more dissimilar than typical faces to any randomly chosen set of distractor faces. To control for target-distractor distances, we constructed a parameterized space of silhouetted face profiles. A previous set of studies validated the parameterized silhouettes as genuine face stimuli. In this study, we used a 3-AFC delayed match-to-sample paradigm to test whether distinctive faces retain their processing advantage over typical faces when target-distractor distances are matched for the two types of faces. In the first condition, a set of typical and distinctive silhouettes were constructed to lie on concentric hyper-spheres in silhouette face space. In the second condition, typical and distinctive silhouettes were constructed to occupy regions of equal size in silhouette face space. In both conditions, the recognition advantage normally associated with distinctive items disappeared. In fact, we observed a recognition *disadvantage* for distinctive silhouettes. We consider a simple explanation for this "reverse distinctiveness effect" in terms of norm-based coding and perceptual learning.

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985 The role of reflectance and shading in face recognition

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Aim: To investigate the role of shading and reflectance information in the recognition of real images of human faces. **Methods:** Pictures of human faces were taken with a calibrated digital camera and subjected to a reflectance-shading separation algorithm similar to that described by Olmos & Kingdom, Perception, 33, 2004. Subjects were presented with nine possible combinations of original, reflectance-only and shading-only

faces in various forced-choice, test-versus-comparison combinations. Subjects were required to indicate on each trial whether the test and comparison faces were from the same face or not. Results: Removing either the reflectance or the shading components from an original face impaired recognition. Subjects found it more difficult to judge whether a reflectance-only and shading-only pair were from the same face, compared to pairs that included the original face. Subjects found it more difficult to compare two shading-only faces compared to either two reflectance-only, or two original faces. Conclusion: Although both shading and reflectance information appears to be important for face recognition, shading may be less important than previously thought.

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986 Face pigmentation and sex classification

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Research into sex differences in faces has focused primarily on shape rather than pigmentation. What work has been done on pigmentation has focused on 1-D signals, such as overall hue (Tarr et al. 2001) and albedo (e.g. Frost 1988). The current study sought to investigate whether there are other more complicated sex differences in pigmentation, and to determine whether these differences are actually used to perform sex classification. Two images, produced by averaging 22 male and 22 female Caucasian faces, were distorted such that the two average faces had the same androgynous shape. With the images spatially registered, we can determine where the average faces differ from one another in terms of luminance and hue. The male average is darker than the female average everywhere but the eyes and lips, which are equally dark across the sexes. Thus, there is greater contrast about the eyes and lips of the female than the male. A subsequent investigation of 36 male and 32 female Caucasian faces found these differences to be statistically significant. The same pattern of results was found with a comparable set of East Asian faces. For an experiment, faces were manipulated to increase or decrease the luminance contrast between the eyes, lips, and the rest of the face. Subjects were more likely to report a face as being male when the contrast between the eyes, lips, and the rest of the face was decreased, and more likely to decide a face was female when the contrast was increased. In another experiment, for female faces a significant, positive correlation was found between a measure of contrast and the rated femininity, while for male faces a significant, negative correlation was found between contrast and rated masculinity. Together, these findings provide evidence that there are spatially organized sex differences in face pigmentation, and that people use these differences to determine the sex and degree of masculinity or femininity of faces.

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987 Sensitivity to the Geometric Variability of Faces in Infants

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Purpose. Face perception research has suggested that 2-month-olds can perceive face-like stimuli as a unique configuration of features. The parameters of the face configuration necessary for infants to discriminate between faces, however, has not been examined. To investigate the configurational parameters of face stimuli that support discrimination, synthetic face stimuli (Wilson et al., 2002), both frontal view and 20-degree side view, that equate faces on all parameters except geometric variability were used. More specifically, this study was designed to determine how much geometric variation between faces is necessary for infants to discriminate them. Methods. A cueing paradigm was used in which 6- to

7-month-olds saw picture sequences in which mean face cues predicted plus sign targets appearing on one side of the screen, and face cues that geometrically varied from the mean by either 5 or 10% predicted plus sign targets appearing on the other side. Eye movements were analyzed for correct anticipatory eye movements to the targets in response to which face cue had been presented. Results. When seen in frontal view, infants exhibited above chance correct anticipations for all face comparisons. When seen in the side view, infants exhibited above chance correct anticipations only for the mean vs. 10% variability comparison. Thus, infants discriminate as little as a 5% change in the overall configuration of a face when seen from the front, but need 10% change to discriminate faces seen from the side. Conclusions. These results indicate that by 6-7 months of age infants rely on the overall geometric variability in configuration to discriminate between individual faces. Moreover, these findings are consistent with those obtained with adults (Wilson et al., 2002) in both the amount of variability necessary for discrimination and that less variability is needed to discriminate frontal than side view faces, perhaps suggesting the recruitment of the same neural mechanisms.

988 Effect of contrast on face perception: application to ophthalmology (amd patients).

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Objective: Age related Macular Degeneration (AMD) is a major cause of blindness in people over 50 years. AMD patients display difficulties in reading and recognizing faces. Our Study is designed to understand the effect of loss in contrast sensitivity and high spatial frequencies on face recognition in patients with AMD and healthy observers.

Method: Healthy subjects were tested in three tasks requiring different types of processing: (1) discrimination face/non-face, (2) discrimination of gender and (3) discrimination of known/unknown faces. The contrast of gray-level photographs of faces was manipulated in order to simulate the loss in contrast sensitivity of AMD patients. From each original photograph the contrast was divided by 2, 4, 8, 16, and 32 for healthy participants and divided by 2, 4, 8 and enhanced (2, 4, 8) for patients.

Results: For healthy subjects the results show that: (1) the decrease in contrast does not affect the face/non-face discrimination task, (2) gender discrimination requires 9% of the original contrast and face recognition requires at least 16% of the original contrast. For patients performance increases when the contrast is multiplied at least by two.

Conclusions: Our results indicate that difficulties in face recognition in patients with AMD are to a large part due to their loss in contrast sensitivity and its consequences on the perception of high spatial frequencies.

989 The effects of external contour of face on gaze perception.

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Purpose. We have found in our past study that the characteristics of gaze perception for stimuli with only two eyes differ from those with whole-face stimuli. In this study, we first compare the effects of low-pass filtering on gaze perception for whole-face and eye-only stimuli, then, we examined the effect of adding the external contour of face to the eye-only stimuli. Our past results have indicated that low-pass filtering of whole-face images has no effect on gaze perception performance.

Methods. The stimuli were real-size color digital pictures of two young persons with eyes shifted in 11 steps between 15 deg to the right and to the left from the center. The eye-only stimuli were created by cutting the eye areas from the original picture and placing them on a background of the average color/luminance of the face. For the low-pass-filtered stimuli, the two types of pictures were low-pass filtered with 3 cut-off frequencies ranging from 1.4 to 5.6 c/d. These pictures were presented on a CRT

screen with a random order and subjects were asked to adjust the marker on the string running horizontally right in front of their face.

Results. For the whole-face stimuli, although there was a tendency to overestimate eye deviation for larger deviation angles, no effect of low-pass filtering was found regardless the cut-off frequencies. However, a clear effect of low-pass filtering was found for the eye-only stimuli. The overestimation increased as cut-off frequency was lowered. This effect of low-pass filtering remained even when the external contour of the face was added as a black line drawing.

The present results indicate that gaze perception relies on the measurements of the dark part of eyes relative to facial parts other than eyes themselves. Since the external contour of the face does not have much contribution, the internal features of face such as eyebrows, nose or mouth seem to have important role in accurate gaze perception.

990 A visual search advantage for faces learned in motion

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Recently there has been growing interest in the role that motion might play in the perception and representation of facial identity. Most studies have considered old/new recognition as a task. However, especially for non-rigid motion, these studies have often produced contradictory results. Here, we used a delayed visual search paradigm to explore how learning is affected by non-rigid facial motion. In an incidental learning phase, two faces were sequentially shown for an extended period of time. One face was presented moving non-rigidly and the other as a static picture. After a delay of several minutes observers (N=18) were asked to indicate the presence or absence of the target faces among unfamiliar distractor faces, using identical static search arrays. Although undegraded facial stimuli were used at both study and test and the search arrays were identical, faces that had been learned in motion were identified almost 300 ms faster than faces learned as static snapshots. In a second experiment we examined a familiar kind of rigid motion. Stimuli consisted of 3D heads from the MPI database, placed on an avatar body. The figures were animated so as to approach the observer in depth. In this experiment we explicitly compared performance on visual search and old/new recognition tasks (N=22). Again with visual search, observers were significantly faster in detecting the face of the individual learned in motion. Using several variants of old/new recognition tasks, we were unable to detect a difference between moving and static conditions. Taken together the visual search results of both experiments provide clear evidence that motion can affect identity decisions across extended periods of time. Additionally, it seems clear that such effects may be difficult to observe using more traditional old/new recognition tasks. Possibly the list-learning aspects of these methods encourage coding strategies that are simply not appropriate for use with dynamic stimuli.

992 The use of spatial frequency through time in face identification

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Face perception has received much attention since it became obvious that something special characterizes this stimulus class (e.g. Bodamer, 1947; Farah et al., 1998; Yin, 1969). One promising avenue for the study of face perception involves psychophysical procedures that can determine the information effectively used by human observers. Here we studied the effective use of spatial frequency information through time in face identification using Bubbles (Gosselin & Schyns, 2001; Vnette, Gosselin & Schyns, 2004). We submitted five subjects to 3000 dynamic grayscale faces (6 x 6 deg of visual angle x 180 ms) sampled by dot multiplying their Fourier spectrum with a 2D white Gaussian noise convolved with a Gaussian function (Std's = 0.156 of the Nyquist frequency and 79 ms). The

subjects performance was maintained at 75% of correct identifications by adjusting, on a trial by trial basis, the surface under the sampling noise. Using multiple linear regression on response accuracy and sampling noise, we revealed that subjects tend to use a narrow band of low spatial frequency (about 5.8 cycles per face) throughout and, from 100 to 150 ms after stimulus onset, a broader frequency band centered on 15.6 cycles per face. These results suggest that face identification occurs in a two-step process: an initial sweep mainly interested in low spatial frequencies and a later one focussing on mid to high spatial frequencies, which appears particularly important for the efficient resolution of the perceptual task. This two-sweep process is compatible with the proposal of Liu, Harris and Kanwisher (2002) that face identification at an individual level follows a more global categorization of the stimulus as a face. Results are also in agreement with studies that showed a natural bias in face perception for spatial frequencies between 5.62 and 22.5 cycles per face (e.g. Nasanen, 1999; Schyns, Bonnar & Gosselin, 2002; Vuilleumier et al., 2003).

3D Processing: Motion and Texture

993 Interpolation of occluded surfaces in structure from motion

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Consider two vertically adjacent random dot surfaces twisted 208 around the vertical axis and undergoing a 108 oscillation around the same axis during a period of 1/2 second. The rotation of the surfaces is perceived as rigid when they amodally unified behind a horizontal occlusion. Conversely, when the surfaces are interpreted as separated objects, they are perceived as undergoing a rotation of a different magnitude (see Domini, Caudek and Proffitt 1997). This effect suggests that spatial unification may affect the process of recovering depth in structure from motion stimuli by maximizing rotation coherence between joinable surfaces.

To test our claim we measured the threshold for perceived rigidity of twisted surfaces in 4 conditions resulting by the combination of 2 factors: occlusion (present vs. absent) and surface-similarity (congruent vs. incongruent). Both the simulated slant of the lower surface and the amount of rotation were kept constant at 108. The simulated slant of the upper plane was varied in a constant stimuli fashion. Observers were required to judge if the twisted pair of surfaces appeared to rotate rigidly or not.

The stimulus is perceived as being a rigid structure for a wider range of slant differences when an occlusion is present. The difference between occlusion-present and occlusion-absent conditions is noticeably reduced when the degree of connectivity between surfaces is lowered by introducing surface dissimilarity. These results support the idea that the surface interpolation process interferes with perceived rigidity of structure from motion stimuli. The amount of perceived rotation is modulated to maximize the coherence between joinable parts in order to achieve a smooth unification of misaligned surfaces (see Fantoni, Gerbino and Kellman 2004). Moreover, perception of surfaces that requires interpolation with torsion is possible with a limited range of twist angle.

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<http://www.cns.bu.edu/Profiles/Grossberg>

994 Depth-order violation in structure from motion

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Humans can recover structure from motion (SFM) based on the projected 2D motion field of a rotating or translating object. Recovery of SFM from rotation has been studied almost exclusively in the condition where the axis of rotation lies in the frontoparallel plane. Here we assess the ability to

recover SFM in the general case, where the axis of rotation may be tilted out of the frontoparallel plane.

Subjects observed simulated elliptical cylinders whose cross-section was constant along the axis of rotation. The cylinders were defined by short-lived random-dots to minimize depth cues from changing dot density; occluders masked the cylinders' borders to eliminate cues from boundary shape. Subjects adjusted a comparison cross-section so it matched the perceived cross-sectional shape of the test cylinder. We found that subjects accurately matched the simulated shape of the cylinder regardless of the inclination angle of the axis of rotation. This result is surprising: the cylinder's shape should depend on the perceived axis of rotation, but using an independent measure we show that subjects do not perceive the axis of rotation veridically.

The results suggests that SFM is computed in two stages. The first stage uses only velocity components perpendicular to the projected axis of rotation. It computes relative depth as if the axis were in the frontoparallel plane. The second stage transforms this depth representation to take into account the angle of inclination. The model predicts that depth order violations can occur when shape changes along the axis of rotation. We tested this prediction in a second experiment using circular cylinders whose radius changed along the axis of rotation. Depth order violations were found. We propose a physiologically plausible implementation of the two-stage model for computing SFM for the general case of arbitrary axis of rotation.

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995 Extra-retinal signals in motion parallax: Support from eye movement asymmetries in strabismus

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The asymmetric horizontal pursuit and optokinetic response (OKR) eye movements found in some strabismic observers (Tychsen & Lisberger, 1986; Demer & von Noorden, 1988; Westall et al, 1998; Levi & Schor, 1984) provide an excellent opportunity to explore the role of an extra-retinal eye movement signal in the perception of depth from motion parallax (MP). We have found that elevated MP thresholds in strabismus (Thompson & Nawrot, 1999) are linked to a pursuit anomaly (Nawrot & Frankl, 2004). Specifically, MP thresholds are elevated when the observer is making abnormal, low-gain nasal-temporal (NT) pursuit eye movements. Conversely, MP thresholds are normal when the observer is making the opposing, normal-gain temporal-nasal (TN) pursuit eye movements. Since strabismic observers often have asymmetric OKR, in addition to asymmetric pursuit, we explored the role of extra-retinal information through a novel MP display that relies on opposing pursuit and OKR eye movement signals. In this display a depth-sign-ambiguous motion parallax stimulus (Rogers & Graham, 1979) is presented with a large, horizontally translating, high contrast, square-wave grating background. This translating background is well known for eliciting OKR. However, translation of this background also disambiguates perceived depth in the MP display, presumably by eliciting both an OKR signal and a countermanding pursuit signal, with the latter disambiguating perceived depth from MP. We found that in strabismic observers asymmetric OKR and pursuit are linked to asymmetric MP thresholds with this stimulus. MP thresholds were lower (more normal) when the background translated in a direction of low OKR gain, opposite the direction of normal pursuit. We interpret this result to mean that a normal pursuit signal is required to disambiguate the perceived depth order in an otherwise ambiguous MP stimulus, further supporting the role of an extra-retinal eye movement signal in MP.

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996 Depth from stereo-motion: estimating the Intrinsic Constraint Line

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Retinal velocities and horizontal disparities produced by the projection of a rigidly rotating object are linearly related. This relation identifies a one-dimensional subspace in the disparity-velocity space. A recent model proposed by Domini and Caudek (2004) predicts that the visual system derives 3D structure from stereo-motion signals by means of a two-stage process: a) in the first stage it estimates the direction of this subspace (defined as Intrinsic Constraint (IC) line) by performing a principal component analysis, and b) in the second stage it derives 3D properties from the IC line. Purpose of this work was to test the first hypothesized stage. In two experiments the observers binocularly viewed a rotating 3D cloud of dots and judged when a probe dot at the center of the structure appeared to be aligned in depth with two nearby target dots having both the same velocity and disparity (i.e. same simulated depth). In six conditions (four in the first experiment and three in the second experiment) we independently perturbed the disparity and velocity signals of the surrounding dots so to produce a noisy relationship among these signals (i.e. a noisy IC line). We reasoned that if the visual system recovers the IC line before estimating depth, then these perturbations should also influence the observers' task, even though it only concerns matching the velocity and disparity of the unperturbed probe and target dots. In fact, we found that different levels of noise (experiment 1) influenced the accuracy with which the observers' task was performed. Moreover, we also found that the noise distribution - and not only the noise level - in the velocity-disparity space influenced the observers' accuracy (experiment 2). These findings are compatible with a model that performs a Principle Component Analysis in the disparity-velocity space and recovers depth from the resulting lower-dimensional space.

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997 A Neural Model of 3D Shape-from-Texture: Multiple-Scale Filtering, Cooperative-Competitive Grouping, and 3D Surface Filling-In

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A neural model is presented of how cortical areas V1, V2, and V4 interact to convert a textured 2D image into a representation of 3D shape. Two basic problems must be solved to achieve this end: (1) Transform spatially discrete 2D texture elements into a spatially smooth surface representation of 3D shape. (2) Explain how changes in the statistical properties of texture elements across space induce the perceived 3D shape of this surface representation. The percepts of a fronto-parallel plane, a slanted plane, a cylinder and a sphere, viewed under perspective projection, are simulated for the case of regular-dot surface textures. The sphere example is generalized to the case of prolate ellipsoids where 3D perception as a function of eccentricity is simulated. Results clarify properties of psychophysical data (Todd and Akerstrom, 1987, *J. Exp. Psych.*, **13**, 242). In the model multiple spatial-scale filters process the 2D image. Several filters can respond to the same texture features, but to different degrees. The model clarifies how this ambiguous representation of shape is disambiguated using cooperative and competitive boundary interactions that carry out scale-sensitive perceptual grouping within and between filter scales. Across-scale interactions realize a near-to-far depth asymmetry, which has elsewhere been used to explain data about figure-ground separation. These processes take place within multiple, depth-selective boundary webs before the boundary representations regulate the filling-in of a smooth 3D surface representation.

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998 Phase Dependent Local Energy mediates Effects of Phase Scrambling on Shape Perception from Texture

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Models of 3D shape perception from texture often consider local Fourier amplitude spectrum of an image but ignore the phase spectrum. Last VSS we reported that phase scrambling impairs shape perception for blob but not contour textures. The present study was designed to investigate why phase scrambling affects shape perception for some textures but not for others. We used five texture patterns [random polka dots (dots), dots organized in horizontal-vertical (dotgrid) or diagonal (dots45) directions, and lines organized in horizontal-vertical (grid) or horizontal-vertical-diagonal (grid90-45) directions] and their phase-scrambled counterparts. Observers viewed 20 degree optical projections of ellipsoidal cylinders homogeneously textured with each of our 10 textures, and judged the apparent cross-section in depth of each surface by adjusting the shape of an elliptical arc presented on a separate monitor. Observers' depth perception decreased with phase scrambling for 'dots' and 'grid90-45', but remained unchanged for 'dotgrid', 'dots45' and 'grid'.

To further examine influence of phase scrambling on shape from texture, we calculated phase dependent local energy (Morrone & Burr, 1988) for images of various surface patches differing in slant. Local energy was computed as the sum of weighted responses of a bank of 5 spatial x 6 orientation-tuned quadrature pairs of filters (Kovesi, 1999). The subsequent comparison of filter responses between unscrambled and scrambled texture patterns revealed high correlations of filter responses for cases where 3-D shape perception was hardly affected by phase scrambling ($r^2 > .91$). On the other hand, correlations of filter responses were much lower when shape perception was reduced by phase scrambling ($r^2 < .56$). Local amplitude spectra did not differentiate between 'good' and 'bad' scrambled textures. The results suggest that mechanisms underlying 3D shape from texture are sensitive to both amplitude and phase of local Fourier spectra.

999 A Gradient Based Heuristic for the Perception of 3D Shape from Texture

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Previous research has shown that human observers are quite accurate at judging the locations of local depth extrema in monocular images of smoothly curved surfaces with polka dot textures (Todd, Oomes, Koenderink & Kappers, 2004). One possible source of information on which these judgments could be based involves the relative spatial frequencies of the projected texture patterns in different local regions. For surface textures that are physically isotropic, local depth extrema (i.e. maxima or minima) in any given direction will be optically specified by local minima in the spatial frequency of the projected image texture in that direction. This correspondence between local depth extrema on a surface and local minima of spatial frequency in an image does not necessarily occur, however, for surfaces with anisotropic textures. Thus, in an effort to evaluate the extent to which observers rely on this information, the present research was designed to investigate how texture anisotropies in different orientations influence the apparent positions of local depth extrema on smoothly curved surfaces. The displays depicted randomly shaped objects with volumetric blob textures. The textures were created by carving each object from a volume of small blobs, which could be stretched in different directions to create systematic patterns of anisotropy. Observers judged the ordinal depth on each object by marking local maxima and minima along designated scan lines. The results revealed that that the perceived locations of local depth extrema were more highly correlated with the positions of local spatial frequency minima in the projected image texture, than with the locations of the actual depth extrema on the depicted surface. These findings suggest that the perception of 3D shape from random blob textures may be based on an implicit assumption that the physical texture on a surface is spatially isotropic.

1000 Perception of slant-from-texture for textures with oriented symmetry

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When a surface with a regular texture is viewed in perspective, the projected texture is systematically distorted, providing information about its 3D structure. Regularities along different texture dimensions (eg size, shape, anisotropy) potentially provide separate 3D cues. Previous work has focused primarily on texture foreshortening, and gradients of texture size and spacing. When a texture has an oriented symmetry, another potential cue is *perspective convergence*: symmetry lines that are parallel along a surface project to lines that vary in orientation in an image (eg converging lines in a linear perspective picture). The experiments reported here test whether this regularity contributes to perception of slant from texture, particularly in the case of surfaces oriented near the frontal plane, when other texture cues provide weak information. Stimuli simulated slanted planar surfaces covered with uniform dots. In one condition, dots were positioned by a random isotropic process. In the other conditions, dots were positioned on a hex grid, oriented so that rows were either at 0 deg and ± 60 deg relative to the tilt direction (aligned grid), or at ± 30 deg and 90 deg (perpendicular grid). Subjects performed a forced-choice slant-nulling task. In experiment 1, textures were presented monocularly, and in experiment 2, textures were presented binocularly with stereo information conflicting by ± 5 deg. Discrimination thresholds from texture alone were higher for isotropic textures than for either hex grid texture, and were higher for the perpendicular grids than for the aligned grids. In the stereo conflict experiment, subjects gave greater weight to texture information in the aligned grid condition than in either of the other conditions. Both results support the conclusion that the visual system uses perspective convergence to perceive slant, and that symmetries aligned with the tilt direction are most effective for conveying slant from convergence.

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1001 Spatial Induction of Changes in Perceived Elevation and Verticality by Global and Local Orientations of Sets of Lines

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Two different "orientations" present in a linearly-oriented array of parallel, equilength lines were separated and independently manipulated: The common orientation of the individual lines defines a "Local Orientation"; the orientation of the implicit straight line through the centers of the parallel lines defines a "Global Orientation". The present experiments measure the relative contributions of Global and Local Orientations in inducing changes in perception of two spatial dimensions: (1) The dimension of elevation as measured by the subject's setting of a small circular visual target that appears to lie at eye level (VPEL); (2) orientation in the frontal plane as measured by the subject's setting of a short line to appear vertical (VPV). Subjects monocularly viewed in darkness two simultaneously-presented inducing arrays (68° -long), centered at $\pm 25^\circ$ horizontal eccentricity, of 25 parallel equilength lines that were either 1° -long or 3° -long. To obtain large influences, the two inducing stimuli were bilaterally-symmetrically-oriented for VPEL trials and were parallel for VPV trials (Spatial Vision, 1994). In the first experiment the roll-tilt of the Global Orientation of the arrays was varied over a $\pm 10^\circ$ range around true vertical with Local Orientation fixed at either horizontal or vertical, or was identical to the Global Orientation. In the second experiment, Global Orientation was fixed at vertical and Local Orientation varied over a $\pm 10^\circ$ range around true vertical. Both VPEL and VPV changed systematically with Global Orientation; Local Orientation had at most a small influence. This is not consistent with a model in which the orientation responsible for induction is set by orientation-selective neural units in V1 since those units select for Local line Orientation and not Global Orientation. We suggest

that the retinotopic location information in V1 is passed on to higher level neural units for construction of Global Orientation.

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Attentional Selection

1002 Temporal Properties of the Polarity Effect in Crowding

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The identification of a peripheral target is severely impaired by flanking distracters, but the extent of this crowding effect is reduced if the target contrast is opposite to that of the distracters (e. g., a white target flanked by black distracters, Kooi, Toet, Levi, & Tripathy, 1994). We explored the temporal properties of this polarity advantage by rapidly flickering target and distracter contrasts during each trial. In the out-of-phase condition, the target polarity was the opposite of the distracter polarity on each frame (white target among black distracters and then black among white). In the in-phase condition, target and distracters had the same polarity and again alternated on each frame (white among white, then black among black). At low temporal rates, the contrasts of the target and distracters were visible in each frame and were seen to reverse polarity from frame to frame. At higher rates, however, the letters were seen not as individually light or dark but all seemed to be flickering equivalently: the individual states and phase relations were no longer apparent. We varied the target-distracter spacing across trials and estimated the critical spacing that gave 62.5% performance from the resulting psychometric functions. We found the polarity effect at low frequencies: the critical spacing was as much as 59% smaller in the out-of-phase condition (i. e., showing less crowding) than in the in-phase condition. However, at frequencies of 7.5 Hz and higher, the polarity effect was lost suggesting that the instantaneous target and distracter polarities were no longer available to the mechanism responsible for crowding effects. It is known that attention has a coarse temporal resolution (6 - 8 Hz) whereas lateral masking operates at much higher frequencies. The findings of this study suggest that attention plays a role in the phenomenon of crowding.

1003 Competition Between Stimuli in Opposite Visual Fields

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We investigated the effect of unilateral and bilateral displays on visual processing of a spatially lateralized target using fMRI. Stimuli consisted of a high contrast visual target appearing either alone or with a visually similar distractor in the opposite visual field. The location of the target was randomly assigned on each trial to either the left or right visual field. No spatial cue was available prior to the onset of the display, resulting in spatial uncertainty that precluded anticipatory attentional enhancement of visual areas associated with an expected target location. Target-side specific contrasts of the two display conditions produced symmetrical and focal activations in the superior occipital gyrus contralateral to the target; Visual stimuli in unilateral displays produced stronger activation in these occipital sites than the same stimuli in bilateral displays, suggesting that distractor competition reduced associated BOLD activation in sensory cortex. Moreover, within bilateral displays, activations associated with target and distractor stimuli displays did not differ significantly from each other. Consistent with the existing literature on attentional control structures, we also found extensive frontal and parietal activations associated with processing of bilateral compared to unilateral displays, particularly in left and right intraparietal sulcus (IPS). Additionally, activation in both of these IPS sites was more correlated with activation in the left middle frontal gyrus in the bilateral than the unilateral condition reinforcing the notion of a frontal-parietal network in selective attentional processing. Furthermore, within attentional control structures, the right angular gyrus showed a specific interaction pattern such that there was

repetition suppression for spatially repeated targets in bilateral but not unilateral displays suggesting a special role in spatial selection.

1004 Gender differences in selective attention: Evidence from a spatial orienting task

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Selective attention is considered a central component of cognitive functioning. While a number of studies have demonstrated gender differences in cognitive tasks, there has been little research conducted on gender differences in selective attention. To test for gender differences in selective attention we tested 80 undergraduates using a spatial orienting task with an endogenous (centrally located arrow) cue. While males and females showed similar benefits across four cue-target intervals, females showed greater costs at 500 ms stimulus-onset asynchrony. The potential role of an inhibitory deficit in males is proposed as a possible explanation for these results.

1005 Hue-contrast is Invariant with Attention

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Background: Transient covert attention enhances contrast sensitivity and spatial resolution, and alters both apparent contrast and spatial frequency. We have shown that transient attention also changes apparent color saturation (Fuller et al., VSS 2004). Here we examine whether attention affects hue-contrast sensitivity. Hue discrimination thresholds are a function of angular separation in color space, independent of saturation (Sankeralli & Mullen, 1999). We hypothesized that attention enhances the saturation of two simultaneously presented hues without changing the subjective hue difference between them.

Method: Observers performed a 2AFC orientation discrimination task, reporting the orientation (45° right or left tilt) of one of two stimuli presented simultaneously at 4° eccentricity on the horizontal meridian. The stimuli were 2° Gabors modulated in hue (polar angle in color space) with fixed luminance and saturation. Hue modulation was identical for both patches in each trial, with tilt varying independently. We employed a range of hue modulations to elicit a psychometric function. Stimulus presentation (50 ms) was preceded by a brief (60 ms) uninformative precue appearing at the center fixation point (neutral cue) or adjacent to one of the stimuli (peripheral cue). At stimulus offset, a central arrow indicated the stimulus for which the observer was to report orientation.

Results: The psychometric function did not change with cueing condition, indicating that sensitivity to hue difference is invariant with attention, and that hue remains independent from saturation. This result differs from previous findings regarding the effect of attention on the appearance of contrast and spatial frequency. For color, whereas attention affects saturation, it does not affect hue.

1006 Responding to the second of two events: The farther away, the better

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It is well known that a sudden luminance change (cue) captures attention, and that stimuli appearing near the cue after short stimulus-onset asynchronies (SOAs) are responded to more quickly than stimuli that appear far away (Posner & Cohen, 1984). We have found the opposite pattern using a similar paradigm. In our task, responses are slower to targets that appear nearer to the cue. We hypothesize that our task forces subjects to inhibit processing of the cue (in order to avoid making an anticipatory response) and that this inhibition carries over to targets that

appear near to the cue. We have shown that the putative inhibition is not mediated by apparent motion between the cue and the target. It also does not spread to the target from the cue via the intervening placeholders. Instead, we suggest that the angle between the cue and the target (as subtended at fixation) plays a determinant role in the magnitude of the hypothesized inhibition effect.

1007 Effects of Color-based Selective Attention on Feedforward Sensory Processing

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Attentive selection can be constrained by simple features, in addition to locations and objects. Using fMRI, Saenz et al [Nature Neuroscience, 5, 2002, 631-632] showed that task-irrelevant stimuli in the attended color receive facilitated processing even when presented at an ignored location. However, this result appears to conflict with previous ERP studies in which clear modulations of feedforward sensory processing (i.e., modulations of P1 amplitude) have been observed only for spatial attention and in which nonspatial attention effects have been observed only at attended locations. To resolve this discrepancy, we recorded ERPs in a paradigm modeled after that used by Saenz et al (2002). Random dot patterns consisting of a mixture of isoluminant green and red dots moved randomly within a circular aperture in one visual field. Participants were instructed to attend to either red or green in separate blocks and to make a button response whenever they detected a luminance change of the attended color. This was a demanding task that required subjects to attend selectively to one color and ignore the other color. In the opposite visual field, task-irrelevant random dot patterns (probes) with either green or red dots were flashed every 400-800 ms. Participants were instructed to fixate a central point and EOG recordings were used to ensure compliance. The task-irrelevant probe in the attended color elicited a larger contralateral P1 component (with an onset at 125 ms) than the probe in the ignored color, even though the probes were presented at an unattended location. The same effect was observed, but with an onset latency of approximately 105 ms, when the stimulus contrast was increased. Thus, color-based selective attention influences feedforward sensory processing as indexed by P1 component, even at unattended locations.

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1008 Standing out in a crowd: Item discriminability increases attentional resolution

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Background: Intriligator and Cavanagh (2001) reported that it is difficult to walk one's attention through densely crowded arrays of similar items. Here we test the hypothesis that it is less difficult to do so when the items within the array differ from each other. **Methods:** Observers walked through arrays of discs that were presented at 11.8 deg eccentricity. The discs were all the same color (gray) or differed in color. Density was 9, 13, 17 or 25 items in each hemifield. Observers walked their attention through the arrays in response to tones that were presented every 750 msec. Walk distances were 0, 5, 7, and 9 steps. A change in tone indicated the end of the walk, at which point the discs (whether gray or colored) changed color. The task was to report the color of the attended disc at the end of the walk. **Results:** For the 0-step condition, accuracy varied as a function of density, ranging from 92% in the density-9 condition to 54% in the density-25 condition; there was little difference, however, between the gray and the colored conditions (both 79%). For the attentional-walk conditions, performance was better in the colored condition than in the gray condition (60 vs. 52%, averaging across the 5-, 7-, and 9-step conditions). However, this effect was driven entirely by the two intermediate density conditions (density-13 and density-17). When the task was quite easy (density-9) or

quite difficult (density-25) accuracy did not differ across gray and colored conditions. **Conclusions:** Attentional walks within a differentiated display appear to be easier than attentional walks within a homogenous display. The decline in performance in the 0-step condition suggests that observers have difficulty not just moving their attention among closely-spaced items, but moving their attention to a single item within similarly dense displays. An explanation of how these two factors interact requires further research.

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1009 Determining Salience for Complex Objects

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Purpose: Our overall objective is to determine how salience - the visual system's assessment of relative biological relevance, on which attention allocation is thought to be based - is computed for complex objects. In this initial experiment, we sought to determine whether the detectability of such objects carries the signature of object-based attention; that is, that multiple feature dimensions are processed independently, by default. **Methods:** A 20x20 'Vasarely' array of Gabor patches was presented to observers, with an embedded 4x4 object. Background elements were governed by a 3D Gaussian (in feature-space; spanned by the dimensions of color, orientation, and spatial frequency), as were object elements. The object, however, was defined by virtue of having either a higher mean or variance along one, two or three dimensions. **Results:** Not surprisingly, detection rates increase monotonically with greater differences in the means of the object and background distributions, or with greater variance differences. As expected too, as means or variances are changed along two dimensions, detection thresholds drop; with 3D manipulations, thresholds are lowest. Critical though, is whether we reach expectations based on independent treatment of the dimensions (this would be shown if detection rates were 1 minus the probability of missing the object's, say, mean difference along one of the manipulated dimensions times the probability of missing it along the other). This pattern of results is exactly what we found, for both mean and variance increases, for all pairwise dimension manipulations. **Conclusions:** With respect to detection, the feature dimensions of statistically-defined, complex objects are treated independently; we feel this is a key piece of support for emerging object-based models of salience.

1010 Does Response Type and Stimulus Duration Influence When Compatibility Interference Occurs?

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Previous research shows that planning and withholding an action to a stimulus (X1) can delay the response to a second stimulus (X2), if X2 is response compatible (requires the same response hand) with X1 (compatibility interference, CI). To explain CI, Stoet and Hommel (1999) proposed the Code Occupation Hypothesis (COH) which suggests that action planning may temporally integrate all components controlling planned actions, preventing any one of these action components from being readily available for another action until the current plan is executed/abandoned. CI occurs when responses to X1 and X2 are based on stimulus identity, and when X2 appears briefly. However, it is unclear whether CI occurs when the response to X1 is based on stimulus identity and the response to X2 is based on ego location. It is also unclear whether CI occurs when X2 is present when its corresponding response is executed. The present study tested the assumptions of COH by determining whether CI generalizes from identity-based actions (that require key presses) to location-based actions (that require pointing to a stimulus location on a touch screen). The presentation duration of X2 (250 ms vs. viewed until response) was also varied to determine if CI occurs independently of X2 duration. Observers planned a response to X1 and a response to X2 that required either the same hand (compatible) or different hands

(incompatible). CI occurred when responses to X1 and X2 were identity based and the duration of X1 was 250 ms (Exp. 1). CI did not occur when the response to X2 was based on ego location (Exp. 2 & 4) or when X2 remained present during its corresponding response (Exp. 2 & 3). These findings conflict with the assumptions of COH. CI may occur only when both responses are identity based (and hence utilize the ventral stream) and/or when verbal recoding and rehearsal of the X2 response is required to accurately respond to X2 (Exp. 1).

1011 Attention can be guided to the relevant feature category

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When the visual system is challenged by distractor heterogeneity and target-distractor similarity, can search be sped up by guiding attention to the relevant feature category, i.e., one that selectively promotes the target, and inhibits the distractors? Previous studies measuring reaction time suggest that for small feature differences between the target and distractors, search is inefficient when the target is flanked by distractors in feature space (D'Zmura, *Vis Res* 1991;31(6):951-966). This has been widely demonstrated in size (Treisman & Gelade, *Cog Psy* 1980;12:97-136), orientation (Wolfe et. al, *J Exp Psy* 1992;18(1):34-49) and color (Bauer et. al, *Vis Res* 1996;36(10):1439-1465). A widely accepted inference from these studies is that attention cannot be guided to a category, otherwise search for the medium target would be efficient. But this inference need not be true. We verified through eye tracking methods that despite inefficient search for the medium target (in size and color), a significantly higher number of fixations landed on items in the medium category than less or high categories. Our results suggest that indeed attention can be guided to a category. To reconcile previous results with our data, we propose a new computational mechanism which suggests that feature dimensions are encoded in cortex by broadly tuned "categorical" channels and that top-down influence can selectively boost the relevant category. Hence, inefficient search for the medium target occurs due to increased overlap between target and distractor categories, so that boosting the relevant medium category may falsely activate some distractors that belong to overlapping categories.

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1012 How many locations can you select at once?

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Performance across several visual attention tasks, such as multiple object tracking, change detection across visual memories, or rapid counting, often seems to suggest that the visual system can handle a fixed number of objects at once. These fixed capacities, often of about 3 or 4 objects, are often taken as strong constraints on possible architectures of visual attention. However, for each of these tasks, there is debate over whether capacities are truly fixed, or rather vary according to factors related to task difficulty.

In two experiments, we asked whether there is a fixed limit on the number of spatial locations that can be selected concurrently in a task. Subjects searched for a target through a cued set of search items. These items were spatially interleaved with similar looking search items that could never be the target, minimizing the potential for 'chunking' several cued items together into a single location. Cues either disappeared before the search, or remained throughout a trial. We determined capacity for selecting locations by finding the cued subset size where memorized cues could no longer serve visual search as efficiently as those still visible in the display.

In Experiment 1, observers could search through 5 or 6 spatial locations before response times indicated that search strayed to known distractor

locations. In Experiment 2, which used denser displays with more items, subjects could only maintain about 3 or 4 locations. These results suggest that our capacity for selecting locations is not fixed. Instead, there may be a tradeoff between the number of locations that can be selected, and the precision with which their positions are encoded. These results parallel other work using multiple object tracking tasks, showing a tradeoff between the number of tracked items and the precision with which their positions are encoded (Alvarez & Franconeri, *VSS* 2005).

1013 Temporally gradual modulation of attention in the RSVP

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It is known that observers' preparations for a task cannot be perfect until the task onset, which hinders their RTs (the preparation cost, Rogers & Monsell, 1995). Our study focuses on the nature of the preparation cost to grasp transitions of the state of attention through the task. To examine temporally sensitive profile of attention, the RSVP task would be optimum. In the RSVP task, which requires observers to identify a feature-defining target (e.g., a white letter) inserted in the rapid distractor stream (e.g., blue letters), we can directly observe transient changes in target-detection performance with manipulating when the target appears. Indeed the past RSVP studies have postulated that only a target inserted in the stream can be fairly detected whenever it appears, but the present study tested hypothesis that observers make preparations for the task at the very beginning of the RSVP sequence, which hinders their detection of the target at that time. EXP.1 evidenced that the detection of a target at the beginning of a sequence was dramatically low and recovered as it appeared later, that is, the preparation cost and its recovery process were observed in the RSVP task. EXPs. 2-4 asked what triggers the preparation for the task. The results showed that the preparation was triggered neither by the fixation onset (EXP. 2, in which the duration of the fixation point was extended) nor by mere the beginning of the rapid presentation (EXP. 3, in which the fixation point blinked at the same rate as the task sequence), but was triggered by the beginning of the rapid presentation of the task similar stimuli (EXP. 4, in which some signs, such as "#", "%", etc., were sequentially presented just before the task sequence). Our results indicated that the preparation cost that was directly observed in the RSVP task would reflect that observers gradually modulated their temporal attention to a rapid sequence with task relevancy in order to well extract a target from the temporally congested stream.

1014 Spatially-mediated attentional interference degrades shape processing

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Purpose: Localized attentional interference (LAI) occurs when selection of one item within the visual field degrades processing of nearby stimuli (e.g., Mounts, 2004; McCarley, Mounts, & Kramer, 2004). Competitive network accounts of attention explain this as the product of competition for control of extrastriate neural responses, whereby the selected object alone drives activity across an assembly of neurons. Under this conceptualization, the effect of LAI should be to degrade the observer's ability to organize stimulus properties into structured object representations. The current study tested this prediction by examining the effects of LAI on processing of emergent structural properties (Prinzmetal, 1989). **Method:** Subjects made speeded same-different judgments of colored target pairs embedded within arrays of gray distractors. Control stimuli were carets comprising a vertical line segment attached to a left- or right-oblique segment. Experimental stimuli were identical to control stimuli, except that a redundant horizontal segment was added to each item to produce either an arrow or a triangle. Spatial separation between attended items varied. Hypothesis was that localized interference between attended items would be greater for stimuli distinguished by structural differences than for control stimuli. **Results and conclusions:** Data showed substantial LAI for

stimuli distinguished by emergent structural features, while control stimuli showed no LAI. A series of additional experiments revealed LAI for stimuli distinguished by shape but not those distinguished by orientation. Results indicate that spatially-mediated interference degrades processing of shape information, and suggest that such interference may emerge only when stimuli are distinguished by features that can be processed in parallel. Findings suggest spatial limits on the ability to form object representations in parallel.

1015 Inhibition of Novel Distractors

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Inhibiting distractors can decrease interference from these competing distractors. To measure the effect of distractor inhibition, a negative priming paradigm is usually used (Tipper, 1985).

Recently, negative priming was found to be contingent on stimulus repetition (Malley & Strayer, 1995; Strayer & Grison, 1999). That is, a distractor was inhibited only when it was a highly repeated stimulus.

Consider the ecological validity; both repeated and novel distractors exist in daily life. It is critical to examine if distractor inhibition can be applied to both kinds of distractors, or it can be applied to familiar distractors only. The current study was hence conducted.

In the first set of experiments, negative priming for novel stimuli was examined. Response-to-stimuli-interval, word frequency, and location of the probe target were manipulated. No reliable negative priming was found. With the same procedure, negative priming could be observed with repeated stimuli. Therefore, it appeared that only repeated distractors were inhibited.

Two explanations existed for the failure to observe negative priming with novel stimuli. First, novel stimulus might be not inhibited at all, as Strayer and his colleagues suggested. We postulated another. Novel stimuli could not trigger the inhibitory mechanism, but could be inhibited when the inhibitory process was triggered.

To test the hypothesis, an experiment with three items in a trial was conducted. One of these three items was a target while the other two were distractors. Moreover, one distractor was a repeated item while the other distractor was a novel item. The results confirmed our hypothesis. With the presence of a repeated distractor, negative priming for novel distractors could be observed.

In summary, a novel distractor has difficulty in triggering the inhibitory mechanism. However, if the inhibitory process begins due to the presence of other competing distractors, a novel distractor can be inhibited.

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1016 Object-substitution masking: The identity of the mask does matter!

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The current experiment extends a previous study completed by Olds and Weber (VSS '04), in which a traditional object-substitution masking (OSM) task was combined with a shape manipulation. The design closely resembles that of Enns and Di Lollo's (1997) experiment, in which 4 dots, presented around one of three modified-diamond targets (diamond shapes missing a corner either on the left side or on the right side), trail in the display after target offset; in the present study, the 4-"dot" mask consisted of 4 smaller modified-diamonds (all missing a corner on the left side, or all missing a corner on the right side). The delay between target onset and mask onset (stimulus-onset asynchrony, or SOA) was 80 ms. Our previous study found an effect of target-mask similarity: when the modified-diamond target, and the modified-diamonds of the mask, were

the same shape, accuracy was much higher than when the target and mask were different shapes. The present study manipulated the proportion of trials with masks missing corners on the left, versus trials with masks missing corners on the right, to determine whether the effect of mask identity could be attributed to re-entrant processing or simply to a response bias. The present study showed that the effect of target-mask similarity (replicated here) was not attributable to response bias, for these 80-ms SOA trials. Furthermore, in addition to this 80-ms-SOA condition (traditional OSM), a common-onset condition (mask duration 300 ms; trials intermixed with OSM trials) allowed us to compare effects of re-entrant processing with effects of interruption by a transient mask. Performance was lower in the common-onset condition than in the 80-ms-SOA 'OSM' condition; in addition, a response bias was evident in the common-onset condition, along with very poor performance when target and mask were different shapes (indicating that observers were responding to the mask rather than the target, on common-onset trials).

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1017 Attentional Inhibitory Surrounds in Orientation Space

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The consequences of attending to points in orientation-space are examined in two experiments. Subjects are cued to attend to lines of a particular orientation, and cue validity (Experiment 1) and probe orientation (Experiment 2) are varied. Performance is directly related to the difference between attended and presented/probed orientations. Performance is superior when these values are coincident, most adversely affected when the presented/probed orientation is near the attended orientation, and intermediate for presented/probed orientations far from the attended orientation. As has been observed in the spatial domain, these results indicate that an inhibitory surround exists when attention is directed to a point in orientation space. These results are discussed in the context of the Selective Tuning Model and the Biased Competition Model.

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1018 Fruitful visual search: Inhibition of return in a virtual foraging task

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Inhibition of return (IOR) has long been viewed as a foraging facilitator in visual search. The current research sought to investigate the foraging hypothesis of IOR in a naturalistic foraging task and to examine how the context of visual search modulates inhibitory effects. Participants in a fully immersive virtual reality environment manually searched beneath an array of leaves for a piece of fruit. On each trial, participants used a virtual wand to select and inspect locations in their search for the target; unlike typical IOR paradigms, location searches were slow (taking seconds instead of a few 100 ms). Participants were instructed to make a speeded response when they detected a flashing leaf that was 1, 2, or 3 positions back in the search sequence or a distance-equated leaf that had not been searched. Reaction times to detect the presence of a cued leaf in this display were slower when the cued leaf had previously been searched than when the cue appeared at an unvisited location, irrespective of distance. These results support the foraging hypothesis, generalizing this phenomenon to a realistic foraging setting. A second experiment showed that this IOR effect can be modulated by search context and task demands, and does not occur automatically.

1019 Observer expectation as a determinant of inhibition of return: Some limiting factors

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Inhibition of return (IOR) is indexed by slower reaction times to targets presented at previously attended locations (location-based IOR) or on previously attended objects (object-based IOR). Both location-based and object-based IOR can be found in response to moving objects. Jefferies, Wright, and Di Lollo (submitted) used a moving object that became occluded during its motion path to demonstrate that observer expectation is a powerful determining factor in IOR. Specifically, IOR to a moving object that becomes occluded occurs both at location-based and object-based coordinates only if the observer expects the object to continue to exist behind the occluder. If the observer expects that the object ceases to exist at the end of the motion sequence, IOR does not occur at either coordinate. The present series of experiments investigated the limits of this critical expectation. Experiment 1 examined the effect of disconfirming the observers' expectation that the object continued to exist behind the occluder. This was done by moving the occluder away from its initial location to reveal that the object had not persisted underneath it. We found that IOR was much diminished under these conditions. In Experiment 2, we asked whether a memory representation of the occluder, as opposed to a perceptual representation is sufficient to mediate IOR. We found that a memory representation of the occluder is as effective as its continuing presence on the screen in mediating IOR. In Experiment 3, we examined whether independent expectations can be developed simultaneously for separate objects, or whether once an expectation is developed, it applies to all objects present on the screen. Collectively, the outcomes of the present experiments buttress the claim of Jefferies, Wright, and Di Lollo that two factors, object continuity and observer expectation, mediate IOR.

1020 Simulation of inhibition: Do I simulate your stopping?

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Research into the basic mechanisms of human social interaction suggests that simulation of other peoples' actions provides an important principle. In particular, it has been shown that observing another person carrying out an action activates the same network in the brain that is activated when this action is carried out by oneself. But how general is this simulation mechanism? Is there also simulation of inhibition? For instance, is there simulation of another person's stopping of an action? Using the stop-signal paradigm, we investigated whether imagining, perceiving, or actually evaluating another person's stopping has similar effects on performance as has one's own stopping.

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Color Vision 2

1021 Peripheral Chromatic Sensitivity for Rectified Stimuli in Each Cone-Opponent System

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Aims: To determine the presence of asymmetries in cone contrast sensitivity between the two poles of each of the L/M and S/L+M cone opponent systems across the human visual field.

Methods: We used chromatic rectified stimuli modulated in the following directions in cone contrast space: an isoluminant +L-M cardinal direction (red), an isoluminant +M-L direction (green), +S (blue) and -S (yellow). The stimulus was a spatial and temporal Gaussian blob on a gray background (49.7 cd/m², (x, y) = (0.275, 0.293)) with a fixed spatial sigma of 0.5 deg in the horizontal meridian, and a sigma in the vertical meridian

that varied from 0.5 to 1.8 deg with eccentricity, determined by the magnification factor in V1. (Temporal sigma = 0.125 sec). Stimuli were presented from 0 to 20 deg in the nasal visual field in 5 deg steps. Cone contrast thresholds were measured using a standard 2AFC staircase procedure.

Results: The results show a much steeper decline in sensitivity of the L/M compared to the S-cone opponent system. The L/M system shows an asymmetry with ÅggreenÅh cone contrast sensitivity decreasing more than the ÅgredÅh at eccentricities over 10 deg. Little or no asymmetry is found in the S-cone opponent system.

Conclusions: Our results showing the asymmetry of cone contrast sensitivity in the L/M cone opponent system support those of Stromeyer et al., *Vis. Res.*, 1992 and extend them to a wider range of conditions. They add to other evidence showing a rectification in the L/M cone opponent system. The lack of asymmetry found in the S-cone opponent system indicates that the underlying cause of the asymmetry is unique to the L/M cone opponent system.

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1022 Mapping Cone Specific Activity in Primary Visual Cortex

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We are investigating how cone inputs are mapped across the cortical surface using intrinsic signal optical imaging in the dichromatic tree shrew. We determined an empirical short wavelength (S-) cone isolating stimulus using color-exchange during extracellular recordings of multiunit sites. In these experiments, the blue CRT gun contrast was held constant at 0.8 (80%), while the green gun contrast varied from 0 to -0.8, with the green and blue modulation 180° out of phase. This produced heterochromatic blue/green gratings with a spatial frequency of 0.4 cycles/deg drifting at 8 Hz. A prediction of color-exchange is that a particular value of blue:green modulation will produce no net change (a null) in response from the dominant middle-long wavelength (ML-) cones. At this modulation ratio, only S-cones produce a differential response, so this stimulus isolates the contribution from the S-cones. The color-exchange experiments yielded a mean response minimum at a green gain of -0.19±0.03 (s.d.), with most sites giving a response null at or below the spontaneous firing rate. An ML-cone-isolating stimulus of approximately the same cone contrast as the S-cone-isolating stimulus was calculated from the known tree shrew S-cone spectral sensitivity. We then performed optical imaging experiments while presenting full-screen drifting sinusoidal S- and ML-cone isolating gratings of varying orientation and spatial frequency. The spatial tuning for S-cone activation peaks at lower spatial frequency with more high frequency attenuation than the ML-cone response. In addition, S-cone isolating stimuli produce activity that is roughly half the magnitude of ML-cone isolating stimuli of equivalent cone contrast. The map of orientation tuning is comparable in orientation preference, but has broader tuning with S-cone isolating stimuli. These results suggest that although the S-cone mediated signals are lower in spatial frequency resolution, they are able to drive orientation specific responses in V1.

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1023 Non-isometric Colour Similarity.

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This paper presents the findings obtained in an experimental study of metric underlying the perceptual colour space. Previous studies evidenced that, in tasks of evaluation of colour similarity, the subjects don't refer to the most general category of "colour", but rather rely on the introduction of subordinate categories containing all variations of a colour. Besides,

categories related to different colours can sometimes overlap. This forces to conclude that perception of colour variations is not isometric, but is rather weighed in different ways for different colours.

In order to detect the metric of colour space we performed an experiment with multiple conditions within the subjects, designed to determine the form of the function that ties the independent variable (tonality of colour) with the dependent variable (similarity judgement). To each subject we presented simultaneously a pair of images, the target one and another differing from the target only for its colour (a suitable perturbation of the tonality). The subject task was to rate the similarity of the second image with the target. The frequency distribution of similarity judgments for each colour gave a qualitative description of how the different colours are represented at the cognitive level. We applied to the observed frequencies a unidimensional scaling procedure to obtain a precise measure of the distance between the variation steps for each colour. We were allowed to choose a single dimension because we limited the study only to the variation of tonality. The scaling was applied separately to each colour scale.

The results showed that different colours were associated to different measure scales. Besides, once chosen a particular colour, its measure scale itself was depending on the direction of variation chosen for its tonality during the experimental presentation. We can conclude that the geometry of colour space looks very complicated and not reducible to familiar mathematical concepts.

1025 Spatial summation of chromatic information

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Purpose: We investigated the extent and the shape of the receptive fields of chromatic detectors by observing the detection thresholds for spatial patterns with different size, shape and chromaticity.

Method: The stimuli were either Gabor patches (4c/deg, sine phase, horizontal) or Gaussian spots. The contrast detection thresholds were measured as a function of the length and the width of the Gaussian envelope to determine the size and the aspect ratio of the detector. The scale parameters ('standard deviation') of the Gaussian envelope varied from 0.01 to 0.45 deg in either vertical or horizontal direction or both. The chromaticity modulated either in L-M, S or L+M cone contrast directions. The threshold was measured with a 2AFC paradigm and QUEST adaptive threshold seeking algorithm.

Result: For Gaussian stimuli in all color directions, the threshold decreased with the length or the width from 0.01 and 0.15 deg. with a slope -0.5 on a log-log plot. The threshold then reduced slowly as the length further increased. The threshold for the L+M Gabor patch revealed an elongated property as the detection threshold function leveled at a greater extent in length than in width. The threshold for the L-M or the S-cone modulated Gaussian showed an isotropic property with the threshold curve leveled at about the same point for both length and width.

Conclusion: While the luminance contrast detectors are elongated, the chromatic detectors are isotropic. In addition, the spatial extents for Gaussian and Gabor summation are about equal. It suggested a second order envelope detector involved in the chromatic contrast detection.

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1026 Neural Bases of Surface Perception from Color

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One critical role of color vision is to segment scenes into distinct surfaces. The mechanisms that allow patches of color to be unified into a percept of a single colored surface remain largely unknown. We used fMRI to identify regions in cortex that contain neurons responsive to colored surfaces. Subjects viewed a novel dynamic stimulus comprised of an array of 59 x 44 small adjoining square elements whose colors were updated

every 100 msec. Upon each update, squares were randomly assigned to be either surface or noise. Surface elements were all a fixed gray level and noise elements were randomly sampled from a uniform distribution of gray levels between the monitor's minimum and maximum. The surface color and ratio of surface to noise elements varied between trials. In pilot behavioral work, subjects reported perceiving a uniform colored surface behind the dynamic noise at surface-to-noise ratios above approximately 40%. Subjects in the fMRI experiment viewed stimuli at four surface-to-noise ratios, chosen to be symmetric around the mean threshold transition point from the pilot behavioral data. Stimuli were presented once every 5 secs for a duration of 2 secs, and interleaved with presentations of a static version of the same stimulus, but at 100% noise. Stimulus conditions were ordered using an m-sequence. Neural responses for each surface-to-noise ratio were estimated using ordinary least-squares, and amplitudes of the estimated responses were computed by fitting functions to the estimated response time course. Primary visual cortex responded more strongly to noise than to surfaces; response amplitudes decreased as the surface-to-noise ratio increased. Conversely, later visual areas responded more strongly to surfaces than to noise; amplitudes increased as the surface-to-noise ratio increased. These later areas likely contain neurons that integrate color information across relatively large areas in the visual field.

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1027 Dichromatic judgments of surface color under different illuminants on natural scenes

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The aim of this study was to test dichromats' ability to judge surface color under different illuminants on natural scenes. Stimuli were simulations of natural scenes presented on a high-resolution color monitor with 10-bit resolution per gun. Twenty-two scenes (which included rocks, foliage, and buildings) were obtained with a hyperspectral imaging system (Foster et al., 2004, *Visual Neurosci.*, 21, 331-336). Illuminants were drawn from the daylight locus. In each trial, two images were presented in sequence, each for 1 s, with no interval: in the first image, the correlated color temperature of the illuminant was 25000 K or 4000 K, in the second, it was 6700 K. The spectral reflectance of a surface in the second image was changed randomly, from trial to trial. The size and position of the test surface, which was indicated to the observer, varied with the scenes tested. The observer's task was to decide whether the test surface in the successive images was the same. Six deuteranopes, eight protanopes, and two tritanopes participated in the study.

A preliminary analysis suggested that deuteranopes could judge surface colors about as well as normal trichromats for about half of the natural scenes tested; with protanopes it was for rather fewer scenes, and with tritanopes fewer still. The two tritanopes' overall performance was also more variable than that of red-green dichromats. Why tritanopes might be particularly disadvantaged is unclear, since similar experiments with Mondrian-like patterns of Munsell surfaces (Foster et al., 2003, in *Normal & Defective Colour Vision* Eds J D Mollon, J Pokorny and K Knoblauch (Oxford: Oxford), pp 218-224) suggest that short-wavelength-sensitive cones make only a small contribution to surface-color judgments.

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1028 Complex effects of test-surface color on surface-color judgments with natural scenes

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Observers can readily discriminate between illuminant changes and surface-color changes in images of natural scenes, but performance varies with scene content (Amano *et al.*, 2004, *Perception*, 33, Suppl. 65), and, in particular, may be affected by the color of a test surface used to probe surface-color judgments. To address this issue, test-surface color was varied systematically in a discrimination experiment. Images of natural rural and urban scenes were presented on a computer-controlled color monitor with 10-bit resolution per gun. The scenes were reproduced from data obtained with a high-resolution hyperspectral imaging system (Foster *et al.*, 2004, *Visual Neurosci.*, 21, 331-336). Test-surface color was manipulated so that, in separate sessions, it was initially neutral, reddish, bluish, greenish, and yellowish. In each trial, two images of a pattern were presented in sequence, each for 1 s with no interval, under two different daylight illuminants: the first with correlated color temperature 25000 K or 4000 K, the second 6700 K. The spectral reflectance of the test surface in the second image was changed randomly from trial to trial. The images, viewed at 100 cm, subtended approx. 178 x 148. Observers had to decide whether the test surface in the successive images was the same. Performance by 8 observers with normal color-vision was quantified with a standard constancy index (Arend *et al.*, 1991, *J. Opt. Soc. Am. A*, 8, 661-672). Performance was generally high, but varied over scenes from 0.40 to 0.95 (with 1.0 representing ideal performance). Test color interacted significantly with direction of illuminant change ($F(4,64)=3.8$, $p=0.01$). Interestingly, a neutral test surface did not give best performance uniformly across scenes (Nascimento *et al.*, 2004, *Visual Neurosci.* 21, 337-340), suggesting a more complex interaction between surface colors in determining surface-color perception in natural scenes.

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1029 Contrast perception and discrimination of chromatic temporal modulations

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INTRODUCTION. Color desaturates and detection sensitivity to chromatic modulations deteriorates as temporal frequency increases (1-10 Hz, heterochromatic flicker photometry). Here we ask whether the apparent contrast and contrast discrimination of color stimuli, measured at suprathreshold contrast levels, also deteriorate over this temporal frequency range.

EXPT.1. Observers matched the perceived contrast of a chromatic flicker (S- or (L-M)-cone, 2° dot) and a spatiotemporally equivalent luminance flicker ((L+M)-cone). At 1 Hz, the detection thresholds and perceived contrast matches shared a single scaling ratio roughly as (L+M):(L-M):S = 1:0.2:3 (Switkes and Crognale, 1999). As temporal frequency increased to 8 Hz, the detection thresholds significantly changed, reaching a ratio of (L+M):(L-M):S = 1:0.5:10. The perceived contrast matches at suprathreshold contrast levels, however, remained roughly unchanged across this temporal frequency range.

EXPT.2. Contrast discrimination thresholds were measured using a forced-choice staircase design. On each trial observers compared two stimuli that differed only in contrast and decided which one had higher contrast. For all color directions tested (S-, (L-M)- and (L+M)-cone), discrimination thresholds at suprathreshold contrast levels remained roughly invariant with temporal frequency. For example, the discrimination thresholds for 25% contrast S-cone flickers were 3% at both 1 and 8 Hz. Over the same frequency range, S-cone detection thresholds changed by a factor of three (3%, 1 Hz; 10%, 8 Hz).

CONCLUSION. Unlike color saturation and chromatic detection sensitivity, contrast perception and discrimination of suprathreshold chromatic modulations do *not* deteriorate as temporal frequency increases (1-10 Hz). The preservation of contrast perception and discrimination for

chromatic modulations in this frequency range has applications to the design of video coding algorithms as well as the interpretation of cortical neuronal responses.

1030 A colour-specific deficit in visual working memory and imagery

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Although there have been several documented cases of dissociations between colour perception and imagery, we present here what may be the first evidence for a selective deficit in colour working memory and imagery, affecting only particular hues. At the time of testing, our patient, QP, was a 36-year old woman who had experienced a brief period of achromatopsia following a severe concussion at age 17. Although her colour perception gradually normalized, she has experienced persisting problems with memory for colour, and colour imagery. During the present assessment, we verified that QP's estimated verbal intelligence was in the high-average range, and that her immediate and delayed recall of both verbal and visual form information (faces, designs) was also in the high-average range. Performance on tests of spatial span and spatial imagery was well within normal limits, and short-term memory for visual texture was also intact. Despite performing normally on tests of colour naming and discrimination, when recalling colours after an 8 s delay she scored below the 95% confidence interval for red, but not blue, hues. Similarly, in a test requiring her to visualize named objects and compare their colours, QP's reaction times exceeded the 95% confidence limit when the objects' hues were reddish, but not bluish. Together, these data suggest that QP's deficit does not simply reflect a general problem with maintaining visually-encoded information in working memory, or with generating a visual image within a working memory buffer. Instead, the present data suggest that, just as category-specific recognition impairments indicate separation in the neural representations of different categories of objects (e.g., living vs. nonliving) within the temporal lobe, QP's particular colour-specific impairment suggests that different colour categories may be represented separately in the brain.

1031 Chromatic induction and perspective distortion

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A pattern presented by Robertson (1996), consisting of yellow and blue square waves with red squares superimposed on either the blue or yellow bands give rise to assimilation effects similar as in the White illusion. The red squares on the yellow bands appear more blue, and the red squares on the blue bands appear more yellow. Varying the position and orientation of the pattern in space changes the effect. For example, slanting the pattern or increasing the distance to the pattern in space increases the effect. But rotating the pattern by 90 degrees and slanting it, nearly eliminates the effect. These changes in color appearance can be explained as the result of averaging in receptive field of extended size.

Due to perspective distortion, the area of the pattern in space mapping to an image patch changes with the position and orientation of the pattern. A computational simulation, implementing the distortion from 3D space to image space, followed by a color segmentation (k-means clustering) gave the same color distortion and segmentation as perceived. Thus the effect seems to be simple an artifact of sampling which causes averaging or smoothing with some filters.

We propose the hypothesis that chromatic induction, which takes the two forms of chromatic contrast and assimilation, results, because the system samples with large fields and following in the segmentation stage attempts to compensate for the averaging effects in neighboring regions

1032 Expansive and contractive size perception with color patches

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Empirically, changing the color of an object modulates its perceived size; e.g., clothes in a particular color make you look thinner. In order to quantify this effect, we systematically examined the effects of object and background color on size perception. Subjects viewed a pair of solid square patches on a computer display and were instructed to report which patch subjectively appeared larger. The color and size of one of the two patches were varied (test patch), while those of the other patch were constant (sample patch). The effect of isoluminant colors of the test patch on its perceived size was assessed as a shift in the psychometric function in which the percentage of trials perceiving the test patch as larger was plotted against the actual size of the test patch. The psychometric functions for some isoluminant colors were shifted in either direction along the abscissa, indicating that patches with some particular colors expanded or contracted in perceived size. The colors with expansive or contractive effects were consistent across subjects. The results indicate that chromaticity (hue and saturation) of the stimulus affected size perception. To determine whether perceived size depends on the background color, we tested various combinations of patch and background colors. Larger chromatic contrasts between the patch and background resulted in larger size percepts, while smaller chromatic contrasts led to smaller size percepts. As in the isoluminant test, larger luminance contrasts between the test patch and background resulted in larger size percepts. Our results suggest that the chromatic and luminance contrasts between the patch and its background, rather than the chromaticity and luminance of the patch itself, determine the perceived size. The neural mechanism modulating perceived size might involve cortical neurons that modulate their size tuning with chromatic and luminance contrast (Solomon et al. 2004; Sceniak et al. 1999).

1033 Simultaneous color contrast in 4 months old infants is revealed by a temporal modulation paradigm

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When a test stimulus is embedded in a chromatic surround, adult subjects report that temporal modulation of the chromaticity of the surround induces a corresponding temporal modulation of perceived color of the test stimulus, in phase with the surround modulation. This modulation can be nulled by modulating the test stimulus, in phase with the surround. We use this phenomenon to address the question of simultaneous color contrast in infants.

In a pilot study, adult subjects viewed a modulating test field in a surround that modulated in purity from 38% purity Blue-Green (BG) to white at 1.2 Hz. They determined the modulation of the test field, required for the test to appear unmodulated. Tnull modulated from white to 15% purity Red.

Two experiments were carried out on 23 4-mo-old infants. In both experiments, the infants viewed a display in which two circular 108 test stimuli were embedded 108 to the right and left of center in a 488 by 648 surround. The stimuli were Tw, stationary white, and Tnull, defined above. The luminances of the tests and surrounds were 15 and 20 cd/m² respectively. In Expt1, the surround chromaticity was constant at 19% purity BG. In Expt2, as in the adult pilot study, the surround was modulated from 38% purity BG to white, in phase with the modulation of Tnull. The two surrounds had equal time-average chromaticity.

If infants simply prefer to look at the stimulus that is physically flickering and maximally different from the surround, they should prefer Tnull over Tw in both experiments. However, if infants have adult-like simultaneous color contrast, the temporally modulated surround should decrease the

perceived modulation of Tnull, and thus decrease the infant's preference for Tnull.

The results show a significant decrease of preference for Tnull in Expt2 (Delta = 14% +/- 2%), consistent with the conclusion that 4 months old infants have simultaneous color contrast. Additional experiments will be discussed.

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Object- and Space-Based Attention

1034 The different properties of object-based and spatial attention revealed by SSVEPs

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We investigated how the average SSVEP power spectra in stimulus-driven frequency bands varied with stimulus location (overlapping or separated stimuli), contrast, frequency, and attention. Blocks where Os attended to overlapping stimuli ('object-based') or to spatially separated stimuli were counterbalanced. For object-based attention, the central stimuli (8 radial arms, arranged as a + and x) were flickered at different frequencies. For spatial attention, the bull's eye stimulus in each visual hemifield was flickered at a different frequency. A counter-phase flicker (black-white against mid-gray) was used to prevent afterimages. Os maintained central fixation for the duration of each 4.8-second trial and attended to the +/x or the left/right stimulus throughout a trial. Contrast was varied randomly within each block of trials. Across blocks, stimulus frequency and attention conditions were counterbalanced. Spatial attention boosted amplitudes of SSVEPs within the same areas as were activated by the stimuli. In contrast, object-based attention modulated responses in areas that differed from those activated by the stimuli. Specifically, attending to 16.7 Hz or 12.5 Hz components boosted activation in largely complementary areas even when the same shape was attended. These results suggest that attention mechanisms may use topographically-segregated frequency-coding to support object-based attention; attention appears to segregate different frequencies into separate cell assemblies. The effect of spatial attention clearly demonstrated response gain in contrast response functions for all subjects. In contrast, object-based attention produced individual differences. For example, Os who demonstrated topographically-segregated frequency-coding of the attentional modulation showed a response-gain pattern. In the absence of this topographical segregation, attentional modulation of the contrast response function was better characterized by contrast gain.

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1035 Object-based curve tracing in the upper and lower visual fields

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Observers can use attention to trace along a visible path. This curve tracing operator requires more time to trace longer paths (e.g., Jolicoeur et al., 1986; Roelfsema et al., 1999), suggesting an analog-like index of attention. Grouped array accounts of object-based attention would suggest that perceptual grouping cues (e.g., good continuation) influence the allocation of spatial attention in curve tracing tasks. One prediction of the grouped array account is that factors affecting spatial attention should also affect object-based attention. Recent research has shown that spatial attention has different resolutions in the upper and lower visual fields (He et al., 1996). We asked if object-based curve tracing exhibited a similar attentional resolution difference and hypothesized tracing into the lower visual field (LVF) would be faster than tracing into the upper visual field (UVF). Observers viewed pairs of curves, which crossed one another (0-2

times) as they went into the LVF or UVF. Observers were instructed to report which curve's end was connected to the fixation (e.g., Roelfsema et al., 1999). In Experiment 1, the curves were presented until participants responded and eye movements were monitored. Tracing into the LVF was faster than tracing into the UVF. In Experiment 2, curves were only presented for 200 ms. The error data replicated the reaction time data in Experiment 1. In Experiment 3, we examined if these field differences were due to attentional resolution. The two curves were colored differently, thus providing a featural difference between the curves and minimizing the need for focal attention. The differences between the LVF and UVF were reduced, suggesting object-based resolution differences between the fields. The results of these experiments suggest that the attentional resolution differences in the LVF and UVF impact the curve tracing operation, demonstrating the close relationship between space-based and object-based attention.

1036 Conjunction Benefits Can Occur For Dimensions Within An Object But Not Between Objects

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Conjunction benefits refer to the case in which discriminating the presence of multiple features within an object (feature conjunctions) can be faster than discriminating the presence of the less discriminable feature alone (Fournier et al., 1998, 2000; 2004). An asynchronous priming model assumes that conjunction benefits result from early partial decision activation by more discriminable features that are combined with activation by less discriminable features to meet a single decision criterion. Conjunction benefits occur if task-relevant dimensions differ in discriminability and features on the task-relevant dimensions are consistently mapped to a response. However, it is unclear whether they occur when task-relevant dimensions occur across two different objects (or parts of an object). This study investigated whether conjunction benefits can occur for feature discriminations across two conjoined, 2-D objects. Observers judged whether one or two features were present or absent in a stimulus consisting of a geometric object bisected by a line. There were three dimension judgment conditions: object shape and/or line orientation (between object), object shape and/or line color (between object), line color and/or line orientation (within object). Discriminability difficulty between the task-relevant dimensions was varied in each condition. Results showed that conjunction benefits occurred only for dimensions within the same object. This suggests that decision activation from features within an object, as opposed to across different objects, can asynchronously prime a common response decision in parallel. When relevant dimensions occur across objects, attention may be serially allocated to each dimension, preventing response decisions from activating a common decision in parallel. The implications of these results for visual attention models, as well as the asynchronous priming model, will be discussed.

1037 Shifting Attention Into and Out of Objects: Evaluating the Processes Underlying the Object Advantage.

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Purpose: The response advantage for shifts of attention within compared to between objects is thought to reflect either an advantage for shifts within objects or a disadvantage for shifts between objects. We examined the object advantage in terms of engage and disengage operations of the object- and location-based attention systems by comparing conditions where attention shifted within, between, out of, and into objects, as well as between locations (loc), using one and two object displays. Responses were expected to be slowest for shifts between and out of objects because only they would require object-based attention to disengage from an object before shifting. *Method:* Objects were bars (Exp 1: vertical; Exps 2 & 3: diagonal). Cues and targets appeared inside (at a bar end) and outside objects (opposite the bar in one object displays) at one of four positions

equidistant from fixation. On 20% of the trials no target appeared. When a target appeared, cues were valid on 60% of the trials and invalid on the rest. Of the six invalid cue conditions (names indicate where attention shifted from cue-to-target), two had two objects (within-obj & between-obj) and four had one object (within-obj, obj-to-loc, loc-to-obj, & loc-to-loc). Observers responded to target onset. *Results:* RTs were always faster on valid than invalid trials. RTs were the same for invalid conditions where object-based attention did not have to disengage from an object to shift (within-obj, loc-to-obj, & loc-to-loc). RTs were slowest, and no different from each other, for the invalid conditions where object-based attention had to disengage from an object before shifting (between-obj & obj-to-loc). *Conclusions:* Disengage operations associated with object-based attention are the primary cause for the object advantage in cuing studies. The object advantage is more accurately described as a disadvantage associated with object-based attention having to shift out of, or away from, an object.

1038 Object-Based Attention: Interactions Between Stimulus Features

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Abrupt onset of a visual stimulus automatically captures attention at the expense of older stimuli at other locations (Yantis & Jonides, 1996). Reynolds et al (2003) reported that such attentional capture occurs not only for spatial locations, but also for simple perceptual objects: when a rotating surface (a colored dot field) was abruptly superimposed upon a counter-rotating (and differently colored) surface, motion judgments of the older surface were impaired relative to those of the newer one. This result was interpreted as revealing object-based cueing of the newer surface. In those experiments, however, object newness covaried with feature duration (of color and motion).

We asked whether feature duration could account for the observed performance bias via mechanisms unrelated to object-based attention (e.g. adaptation). To dissociate rotation duration from object newness, we reversed rotation directions in the middle of each trial. We found that performance still favored the newer surface. In a second experiment, we removed the color difference between surfaces. Performance, without rotation reversals, again favored the newer surface. Neither surface, however, held an advantage when rotation directions were reversed in the absence of a color difference.

We conclude that neither motion nor color individually accounts for the original effect. Rather, we find interactions between these attributes, supporting the conclusion that the performance advantage yielded by delayed onset is indeed object-based. These interactions, moreover, clarify the role of these stimulus factors in maintaining perceptual continuity of an object as its attributes alter over time.

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1039 Feature-based Attention Is Also Object-based

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Feature-based attention has been revealed as a global enhancement of attended visual features throughout the visual cortex. Object-based attention was shown as better performance when concurrently discriminating two features of the same object compared to two features of different objects. We used high field strength (4T) functional MRI to investigate whether feature-based attention is also object-based, i.e., does cortical enhancement of attended features result from subjects treating two features as a single same object? The stimuli were two drifting Gabor patches presented bilaterally to the central fixation cross. Subjects performed orientation discrimination using a two-interval forced-choice paradigm on one side and ignored the stimulus on the other side. The

ignored stimulus was always vertical (V) and drifting slowly (S) and the attended stimulus either was identical (VS) or horizontal (H) and drifting faster (F). We compared visual cortical enhancement of the ignored stimulus when subjects attended on the other side to either the identical (VS) or a different (HF) stimulus in two conditions: either the Gabor stimuli on both sides appeared to belong to a same object (with both Gabors simply displayed on a normal gray background), or as two separate objects (each Gabor displayed in a grey box appearing on top of a textured background, with cast shadows effects around the boxes). Results showed that in the single-object condition all three subjects consistently had significant enhancement of the ignored stimulus (SPM T-values $T_1=4.43$; $T_2=4.24$; $T_3=3.93$ with $P(\text{uncorrected}) < 0.001$, $tr=3s$, Voxel size= $3 \times 3 \times 3 \text{mm}^3$) in area MT+, which confirmed previous observations of feature-based attentional modulation. But this enhancement disappeared (no significant enhancement) when stimuli appeared as two different objects. These results indicate that feature-based attentional modulation is also object-based, i.e., only occurs when between features that belong to a same object.

1040 Contributions of feature-based attention to object perception

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Recent evidence suggests that attention helps in perceiving 'low-level' visual features, such as luminance, motion and orientation. It remains unclear, however, whether and how attention enhances 'higher-level' vision. Here, we studied attentional contributions to the processing of proto-objects of intermediate complexity. - We probed perception of loops that consisted of edge segments, luminance-defined gabors, using a dual-task design. Two concurrent rapid serial presentation streams of arrays of scattered gabors appeared in the left and right visual hemifield, respectively. On the primary task side, as indicated by a fixation arrow, subjects made quick responses in one of two conditions, (a) when a subset of gabors was oriented to form the contour of a loop, or (b) when the loop was defined by rotating gabors. These 'primary loops' appeared twice per trial, and coinciding with either of them, another loop was presented on the secondary task side. Perceptual thresholds of this 'secondary loop' were determined in a two-alternative-forced-interval fashion by adding different amounts of orientational noise to the gabors. We found that perception of the secondary loops was better when the primary loops were easier to detect, as measured in pretests. Moreover, the condition mattered: perception was better when subjects attended to contour-defined primary loops rather than motion-defined loops. Is this advantage due to more symmetry between the primary and the secondary task? - We replaced the primary loops by s-shapes. Again, secondary loops were easier to perceive when the primary s-shapes were contour-defined rather than motion-defined. Our results suggest that feature-based attention enhances not only low-level vision but also perceptual processes that require grouping simple image structures into more complex ones. This possibly involves enhanced collateral activation of neurons in higher-level visual areas with increased cross-talk between the visual hemifields.

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1041 Object-based attentional selection modulates the spatial gradient surrounding the object

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Many theories of object-based attention implicitly assume that the facilitation is limited to locations within the borders of the attended object and fail to address the attentional consequences for locations surrounding the object. In a series of experiments utilizing standard object-based target detection and discrimination paradigms, we show that the object as a whole, and in particular distance from its center of mass, is critical in determining the facilitation of locations in the surround. First, we compared detection times to two invalid targets, equidistant from the cue,

which appeared in the space surrounding a cued object. Interestingly, the target closer to the object's center of mass was detected faster and this advantage held across several object locations and orientations. By probing targets at systematically varying distances we established that the facilitation of targets in the surround is a linear function of distance from the object's center of mass. Finally, we directly manipulated the center of mass while holding all target locations constant, demonstrating that discrimination times for these targets was dependent on distance from the center of mass. Taken together these results indicate a close coupling between space- and object-based attention, whereby attending to an object has implications for the spatial distribution of attentional facilitation throughout the scene. These results are consistent with a distributed account of the attention mechanism in which information across multiple levels of representation interacts to form an attentional gradient which reflects the overall representation of the attentional locus.

1042 The Spatial Distribution of Object-based Attention

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Attention operates not only over spatial locations but also over perceptual objects. One of the hallmarks of object-based attention is that following an invalid peripheral cue, perceptual judgments are more efficient when the target appears in the same object as the cue versus in a different object. However, the manner in which attention is oriented to and within objects is not well understood. We investigated a core issue in object-based selection: the spatial distribution of attention within an object. We manipulated the within-object distance between the cue and target. Evidence of spatial distance effects within objects would support grouped-array theories of object-based attention (Vecera, 1994), in which object perceptual structure serves to constrain the spatial distribution of attention.

We modified the object-based task developed by Egly et al. (1994), using more realistic, three-dimensional stimuli with cues and targets intrinsic to the objects. Two curved, 'tube' objects were used so that all points on each object were equally distant from fixation. In the first experiment, we replicated the Egly et al. same-object detection advantage. In the second experiment, we manipulated the distance between cue and target within an object. On each trial, the target appeared at one of three possible locations: at the cued location, at a near location within the cued object, or at a far location within the cued object. Targets were detected more efficiently at the cued location than at either of the uncued locations. In addition, targets were detected more efficiently at the near location within the object than at the far location within the object. These results demonstrate that object-based selection is inherently spatial and that attention has a spatial profile across the extent of an attended object. These results support grouped array models of object-based attention.

1043 Modulation of object-based and space-based attention by cue validity

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We used the double-rectangle cueing paradigm of Egly, Driver, and Rafal (1994) to examine the effect of cue validity on object-based and space-based attention. This paradigm has the advantage that both the spatial cueing effect (i.e., shorter RT at the cued location than at the uncued location) and the same-object effect (i.e., shorter RT for the cued object than for the uncued object), which are indicative of space-based and object-based selection respectively, can be demonstrated in the same task. However, in previous studies the cue informativeness is almost always varied with respect to the objects and to the locations. We dissociated the two kinds of cue informativeness by controlling the cue validity of the locations while manipulating that of the objects, or vice versa. Results from the two experiments with the object configuration in the display were compared with two control experiments in which the object configuration

was removed to reveal the pure space-based attentional effect. Results showed that when the target appeared at all possible locations with equal probability, the cue validity of different parts within an object is additive. When the target appeared at the two objects with equal probability, however, response to locations with different validity was modulated by the object configuration. These results suggest that the effective cue of the same-object effect is a cue which predicts a high probability that sums the cued part and the uncued part of an object. Object configuration constrains the extent to which the location-based probability is of use.

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1044 Attentional capture by new object sudden-onsets can be modulated by top-down control

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In attentional capture research it is a robust finding that suddenly appearing stimuli or 'sudden-onsets' can capture attention in a purely exogenous or bottom-up manner. While some theorists (e.g. Yantis & Hillstrom, 1994) propose that this is because sudden-onsets represent new perceptual objects, it also seems plausible that subjects may be 'set' to attend to such dramatic changes, and that these endogenous or 'top-down' control settings are responsible for capture (e.g. Folk, Remington, and Wright, 1992). One impediment to evaluating these explanations has been that demonstrations of top-down modulation of sudden-onset capture have involved changing pre-cues, while demonstrations of the strongly bottom-up nature of sudden-onset capture have involved new objects appearing in locations previously unoccupied by placeholders. In two experiments we investigate the extent to which top-down modulation of attentional capture by new object sudden-onsets is possible. In Experiment 1 we found that the extent to which new object sudden-onset pre-cues capture attention is affected by a subject's task-set. Experiment 2 evaluated the impact of a constantly changing task-set in a task-switching paradigm, and once again modulation of new object sudden-onset capture was found. While these findings support the notion that some component of attentional capture by sudden-onsets is top-down in origin, the relatively small effects obtained still suggest a large role for an exogenous mechanism activated by new objects.

1045 Structure-based modulation of inhibition of return: Implications for theories of object-based selection

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A fundamental issue in understanding visual object perception is how we are able to select and attend to individual objects in the environment. One relevant source of evidence has come from studies of inhibition of return (IOR). With this paradigm, it has been shown that detection latencies can be longer for targets presented on previously attended, rather than on unattended, objects independently of their spatial location. This finding has been taken as evidence for the existence of an object-based selection mechanism. The present study describes a new empirical observation showing that the magnitude of object-based IOR can be modulated by object-internal structure. We show that structure-based modulation arises at a level of shape representation that makes explicit surface, but not volumetric, part structure. Furthermore, this structure-based modulation effect occurs at a level of shape representation computed after preattentive image segmentation.

1046 Modeling Feature Sharing between Object Detection and Top-down Attention

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Learning, Brain and Cognitive Sciences, and Mc Govern Institute, Massachusetts Institute of Technology, Cambridge, MA, USA

Visual search and other attentionally demanding processes are often guided from the top down when a specific task is given (e.g. Wolfe et al. Vision Research 44, 2004). In the simplified stimuli commonly used in visual search experiments, e.g. red and horizontal bars, the selection of potential features that might be biased for is obvious (by design). In a natural setting with real-world objects, the selection of these features is not obvious, and there is some debate which features can be used for top-down guidance, and how a specific task maps to them (Wolfe and Horowitz, Nat. Rev. Neurosci. 2004).

Learning to detect objects provides the visual system with an effective set of features suitable for the detection task, and with a mapping from these features to an abstract representation of the object.

We suggest a model, in which V4-type features are shared between object detection and top-down attention. As the model familiarizes itself with objects, i.e. it learns to detect them, it acquires a representation for features to solve the detection task. We propose that by cortical feedback connections, top-down processes can re-use these same features to bias attention to locations with higher probability of containing the target object. We propose a model architecture that allows for such processing, and we present a computational implementation of the model that performs visual search in natural scenes for a given object category, e.g. for faces. We compare the performance of our model to pure bottom-up selection as well as to top-down attention using simple features such as hue.

1047 What changes to objects disrupt object constancy?

Jason H. Wong (jwong.cogsci@gmail.com)¹, Anne P. Hillstrom¹, Yu-Chin Chai²; ¹George Mason University, ²University of Texas at Arlington

This study examines what changes to objects disrupt object-based (OB) attention in order to understand the nature of object representation. The experiments reported here used the Egly, Driver, & Rafal (1994) cueing paradigm, in which displays contain 2 objects. Responses to a target that appears at an invalidly cued location are faster when the target is in the object containing the cue than when the target appears equidistant but in a different object; this is the result of OB attention. We used more realistic looking objects and examined what changes occurring between cue and target disrupt OB attention. When OB attention is disrupted, we expect to see space-based (SB) attention: that all targets equidistant from the object are detected equally fast, regardless of which object they are in. We assume that changes that disrupt do so because the representation has changed radically enough that attention is disengaged from the pre-change object representation. Changes between cue and target, which occurred over 3 frames and 150 ms, included morphing of an object to a new identity; disappearance/reappearance of an object; rotation of an object 180 degrees in the picture plane; and translation of an object in a very small circle, maintaining its original orientation. Morphs and disappearance were expected to disrupt object constancy, resulting in SB attention, whereas rotation and translation, being events that should not affect object constancy, were expected to demonstrate OB attention. Translation also controlled for the frame to frame masking found when an object morphs. Results show that morphing, disappearance, and translation all resulted in SB attention, whereas rotation and a no-change condition resulted in OB attention. That translation disrupted OB attention leaves us unclear whether morphing disrupts because of identity change or because of masking effects. Future experiments aim to resolve this issue.

1048 Cohesion as a Principle of Object Persistence in Infants and Adults

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A critical task for vision is to represent objects as the same persisting individuals over time and visual change. How is this accomplished?

Across several areas of cognitive science, perhaps the most important principle is thought to be cohesion: objects must maintain single bounded contours. Infants, for example, fail to represent complex stimuli that undergo cohesion violations, such as pouring sand, as persisting individuals. Here we explore the role of cohesion in object persistence by examining such violations in their simplest form: a single object splitting into two. We first demonstrated a role for cohesion in adults' visual perception, by showing that splitting (but not similar control manipulations) yields severe performance costs in 'object reviewing' tests of persistence (Mitroff, Scholl, & Wynn, 2004, *Psych. Sci.*). To explore whether such simple cohesion violations affect infants' perception of persisting objects, we used a forced-choice crawling task with 10- and 12-month-olds. In the control condition, infants were shown one cracker hidden in one location and two crackers hidden in a second location. In the splitting condition they were shown a single cracker hidden in one location and then a larger cracker split into two, with the two resulting pieces hidden in a second location. Infants selectively crawled to the two-cracker location in the control, but they failed to do so in the splitting condition. Even though both conditions involved the same ultimate presentation of one vs. two crackers, the infants were unable to represent the two crackers as 'more' when they resulted from a 'split'. Together, these results with adults and infants suggest that even simple cohesion violations play a key role in the representation of objects as persisting individuals.

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1049 Implicit discrimination of visual arrays by number in rhesus macaques

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Research suggests that animals, including humans, internally represent number as an analog magnitude on a subjective 'number line'. The internal representation of number is thought to be less precise with increasing magnitude, accounting for the size and distance effects on numerical judgments consistent with Weber's law. A critical prediction of Weber's law is that discriminability of two numbers depends on their ratio, regardless of actual magnitude. To test this prediction, we trained a monkey to perform an implicit visual numerical discrimination task which varied the number of elements in a visual array, while holding their ratios constant and controlling for element size and density. Specifically, midway through the delay period of a visually-guided saccade task, an array of n elements flashed briefly (300ms) in the hemifield opposite the saccade target. On the majority of trials the number of elements in the array was 'standard' (e.g. 8), and correct saccades were followed by a small reward (100ms juice delivery). On remaining trials, an array with an 'oddball' number of elements (e.g. 4 or 16) was presented and a large reward (300ms juice) followed correct saccades. The values of the standard and oddball arrays were varied across blocks of trials. Task execution was thus independent of the number of elements in the array, while differences in reward value encouraged attending to the array. Saccade reaction time differed on oddball trials, suggesting that the number of elements in the array was processed implicitly. This task thus provides a powerful paradigm for investigating implicit visual numerical processing and its neurophysiological correlates in the primate brain.

Talk Sessions

May 11, 2005 – Wednesday AM

Binocular Rivalry (1050-1055), Perceptual/Object Learning (1056-1061), Motion; Form from Motion (1062-1068), Visual Attention, Learning, and Memory (1069-1075)

Binocular Rivalry

8:30 - 10:00 am

Hyatt North Hall

Moderator: Marcia Grabowecky

1050 Exogenous and endogenous attention influence initial dominance in binocular rivalry

Sang Chul Chong (sangchul.chong@Vanderbilt.Edu), Randolph Blake¹; Department of Psychology, Vanderbilt University

What governs initial selection of one stimulus over the other in binocular rivalry? A previous study (Mitchell et al, 2004) showed that exogenous attention could determine dominance in binocular rivalry. We replicated their finding with different stimuli, extended the results to endogenous attention and quantified the strength of attention's effect on dominance. In experiment 1, superimposed +/- 45 deg gratings were viewed dioptically for 3 seconds, followed by a brief contrast increment in one of the gratings to direct exogenous attention to that grating. A blank screen was presented for 250 ms (to prevent temporal summation), and then dichoptic stimuli were presented for various durations (100 ~ 700 ms). Exogenous attention strongly influenced which stimulus was initially dominant in binocular rivalry, consistent with the finding of Mitchell et al (2004). We next measured the strength of exogenous attention by varying the contrast of one of two rival gratings when exogenous attention was previously directed to that grating. The contrast of the attended grating had to be reduced ~ 50% relative to the unattended grating to counteract attention's boost to initial dominance. In experiment 2, endogenous attention was manipulated by having participants track one of two oblique gratings both of which independently and continuously changed their orientations and spatial frequencies during a 5 sec period. The rest of the procedure was as same as in experiment 1. The initially dominant grating was most often the one whose orientation matched the grating correctly tracked using endogenous attention. The strengthening effect of endogenous attention on initial dominance was smaller than the effect of exogenous attention. Evidently both exogenous and endogenous attention can influence initial dominance of binocular rivalry, effectively boosting the stimulus strength of the attended rival stimulus.

1051 Laminar Cortical Dynamics of Binocular Rivalry

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One of the interesting aspects of binocular rivalry is its time dynamics, which have been used to evaluate models of binocular rivalry. Blake and Mueller (1989) introduced a novel method to modulate the time dynamics of binocular rivalry using contrast modulation either in synchrony or inde-

pendent of a percept switch. Those data supported a reciprocal inhibition oscillator as a rivalry mechanism. A laminar cortical model of 3D vision, called 3D LAMINART (Grossberg and Swaminathan, 2004), quantitatively simulates rivalry percepts of real images that obey the duration-contrast relations reported by Blake and Mueller, both the slope sign and slope value of linear regressions. Key model mechanisms are binocular perceptual grouping circuits in layer 2/3 of V2 interacting with orientational competition and habituated synapses. The model clarifies how these mechanisms control visible rivalrous surface percepts in V2 and V4, and modulate cell responses in V1. These mechanisms have elsewhere explained perceptual and brain data about stable cortical development and 3D perceptual grouping, notably data about 3D figure-ground separation, transparency, neon color spreading, perception of slanted and curved surfaces, Necker cube, perceptual learning, and object attention. Thus the model shows how rivalry can emerge from brain mechanisms that carry out other perceptual tasks. The model can also reproduce the gamma distribution of dominant phase duration (Levelt, 1967), mixed phase output (Ngo et al., 2000), why feature-based rivalry (Diaz-Caneja, 1928; Alias et al, 2000; Lee and Blake, 2002) rather than eye-based rivalry can take place, consistent with the fact that the location of rivalry is higher than monocular loci (Leopold and Logothetis, 1996; Sheinberg and Logothetis, 1997). The model also explains the Logothetis, Leopold, and Sheinberg (1996) demonstration that swapping two half-stereopairs between the two eyes with the rate of 3 Hz does not affect the time dynamics of rivalry.

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<http://web.mit.edu/bcs/schillerlab/oss>

1052 Independent binocular rivalry processes for form and motion

David Alais (alaisd@physiol.usyd.edu.au), Amanda Parker¹; Department of Physiology, University of Sydney

Aim: To test whether binocular rivalry suppression entails low-level, non-selective eye suppression, or higher-level feature-selective suppression. **Methods:** Subjects (n=4) viewed 88x58 rival stimuli, either faces (one tinted red, the other green, equal luminance & RMS contrast) or global motions (expansion vs. contraction, 150 dots, 100% coherence, 6.58/s). During dominance (and suppression), thresholds were measured for two kinds of brief (100 ms) probe, cross-faded faces (identity discrimination) and rotary motions (direction discrimination). The ratio of dominance to suppression thresholds quantifies rivalry suppression depth (1=no suppression, 0=max suppression). Rivalry coherence was also measured (proportion of 5 min period in which one or other image was exclusively visible). **Results:** For rivalry between two faces, suppression was deep for face probes (.27) while global motion probes were not suppressed at all (~1). The converse was true: rivaling global motions deeply suppressed global motion probes (.30), but not face probes (~1). For mixed rivalry pairs (global motion/face), suppression was shallow for both global motion probes (.64) and face probes (.74). Rivalry coherence measures showed face pairs (.85) of

global motion pairs (.83) rivalled coherently, with little piecemeal rivalry. Coherence for mixed rivalry pairs was lower (.53). Conclusions: (i) Rivalry between stimuli represented in extrastriate areas (e.g., global motions; faces) is deep. (ii) This deep suppression is limited to the processing stream or area representing the rival stimuli. (iii) Sensitivity to probes not represented in the rivaling area is unaltered, during dominance and suppression. (iv) Shallow suppression observed for mixed global motion/face stimuli is consistent with the Highest Common Denominator hypothesis (Alais & Melcher 2005). (v) Rivalry suppression does not affect an entire eye- it is selective for stimulus attributes and leaves others unaffected.

1053 Sources of long-term speeding in binocular rivalry

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We previously demonstrated long-term speeding of binocular rivalry (VSS 2004). We further investigated how the rate of perceptual alternations changed with both short- and long-term experience. During each 20 s trial, Os reported perceptual alternations between "+" and "x" shapes. When Os viewed the rivalry stimuli for the first time, alternations were slow, but they rapidly speeded, stabilizing after only 3-5 trials. Following this rapid initial speeding, alternation rates remained stable (at least across 40 trials) within a day, but gradually speeded across days, reaching an asymptote in 15-30 days. The initial rapid speeding transferred across visual hemifields, but was asymmetric; initial experience in the RVF produced slower asymptotic alternations in the LVF. In contrast, the long-term speeding was specific in position, orientation, luminance polarity, and eye of origin. To begin to identify the source of this speeding, we presented Os with subsets of the rivalry experience. To determine whether experience of rivalry is critical, we had Os experience pattern alternations (e.g., + in the left eye alternating with x in the right eye) which simulated the dynamics of actual rivalry. For long-term speeding, actual and simulated rivalry produced similarly stimulus-specific speeding, suggesting that the speeding was due to modifications of post-rivalry processes. Interestingly, the initial speeding appears to require experience of rivalry. Additional experiments determined contributions of experiencing: (1) transitions without speeding, (2) binocular stimulus transitions, or (3) stimuli without transitions. Overall, these results suggest that the rate of binocular rivalry is determined by at least two separate processes, (1) processing that resolves binocular conflict that is fast adapting, stimulus general, and hemisphere asymmetric, and (2) post-rivalry pattern processing which is slow adapting (potentially sleep dependent), stimulus specific, and hemisphere symmetric.

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1054 Interactions between binocular rivalry and depth in plaid patterns

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In binocular rivalry produced using orthogonal diagonal gratings, if a matching diagonal grating is added to one eye then rivalry is eliminated. We found that in fact rivalry is not eliminated for certain spatial frequency combinations for matched and rivalrous diagonal patterns involving differences of one octave or more. We investigated whether this effect generalizes to plaids which are the sum of: (1) rivalrous orthogonal diagonal gratings and (2) identical vertical gratings in the two eyes. Over 100 s trials, observers pressed one key when the left grating predominated, or another key when it was not visible. For 2 and 4 cpd patterns, rivalry occurred if the spatial frequency of the vertical gratings was more than 0.4 octaves above or below that for the diagonal gratings (or 0.35 octaves for 8 cpd gratings).

Following these measurements for the bandwidth for rivalry, we investigated the interaction between rivalry and depth. Similar plaids were used, with the additional manipulation that depth was produced in the vertical components using three methods: (1) an orientation disparity of plus or minus 4 degrees was used to produce tilt forwards or backwards; (2) slant

was produced using a spatial frequency difference between the two eyes; (3) a phase offset in the vertical grating was used so that the top and bottom of the image were in different depth planes. Observers performed a match for the apparent depth of the vertical components in the plaids using the method of adjustment. In all cases depth and rivalry coexisted when the spatial frequency difference between the vertical and diagonal gratings was greater than 0.8 octaves, but neither depth nor rivalry was present for smaller differences. These results place constraints on models of stereopsis and rivalry.

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1055 The third percept in bistable perception

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Introduction. 'Bistable perception is the phenomenon that when faced with ambiguous visual input, one experiences a percept alternating between two interpretations.' Sentences like this form the starting point of myriad papers on the subject, but bistable perception as a two-state process is a simplification: between dominance phases of percept A and B there are phases during which neither prevails. This has been noted before¹ but is routinely ignored. We try to clarify how this is possible and study the features of the transition stage in a binocular grating paradigm.

Methods. Due to the transition stage's short duration we cannot rely on subjects' key presses to report it, but use a novel method based on synchronisation and cueing. Synchronisation means that we force the onset at t_0 of a dominance phase, using the flash suppression effect. Then after a chosen time lag, by replacing the gratings by a mask, we cue subjects to report what they saw the instant before mask appearance. By repeating this at various lags, we get probability distributions of percepts as a function of time after t_0 . Subjects were tested twice: first we instructed them to report the percept to be either A or B; the second time we added the option of reporting a transition percept.

Results. Subjects easily executed the two-alternative choice experiment. Still, with the option of reporting a third phase, its mean duration was 300-1100 ms: 0.2-0.7 times that of a dominance phase (the duration of an entire cycle was unaffected). Concluding, reports of putative bistable perception do not prove the absence of a transition percept; merely that subjects were not asked to report it. Instead, the transition stage is a substantial part of the alternation cycle, that models of bistable perception should incorporate. We are presently studying its characteristics, e.g. its duration distribution, its dependence on stimulus features and associated detection thresholds.

Ref. 1: Mueller & Blake, Biol. Cybern. 61, 1989.

Perceptual/Object Learning

8:30 - 10:00 am

Hyatt South Hall

Moderator: Jozsef Fiser

1056 Contrast effects in rapid learning of a visual detection task.

Craig K. Abbey (abbey@psych.ucsb.edu), Binh T. Pham¹, Steven S. Shimozaki¹, Miguel P. Eckstein¹; Dept. of Psychology, UC Santa Barbara

Purpose: Some studies of learning have found that easier tasks enhance the learning process (e.g. Ahissar & Hochstein, Nature 1997). We investigate the influence of signal contrast on very rapid learning effects using an experimental paradigm in which an ideal observer learns from trial to trial. The framework allows us to compare the amount of learning in human

observers to maximal learning assessed by the ideal observer across stimulus contrast. **Methods:** We conducted 8-alternative forced-choice localization experiments over contrasts of 12% to 17%. Each experiment consisted of blocks of four trials in which one of four possible signals (oriented bright or dark Gaussians, embedded in noise) was chosen at random and used throughout the block. Within a block, signal location was randomized, but signal identity was constant, allowing observers (human and ideal) to use previous trials within the block to 'learn' the signal profile and thus improve their strategy for localization. The ideal observer allows for the computation of statistical efficiency. In addition, learning efficiency can be determined by comparing contrast thresholds (matched to human observer performance) of the ideal learner with an observer that is ideal except that it does not use information from previous trials (and hence is unable to learn). **Results:** We observed performance improvements of 3% to 16% in percent correct over the four learning trials. In general, statistical efficiency was relatively constant across learning trials, but as the stimulus contrast increased, it increased by 30% to 50%. Over this same range of contrasts, learning efficiency was highest at low contrast and fell off as contrast increased. **Conclusions:** Higher signal contrasts - which we have used to manipulate task difficulty - lead to a general improvement in statistical efficiency. However, in terms of learning efficiency, our results indicate that observers learn relatively more in difficult tasks than easy ones.

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1057 Motion-based orienting, segmenting and tracking in a model of object learning

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Most current computational models of object learning rely on labeled, pre-normalized collections of static images to guide the process of extracting features that are diagnostic of an object class. From the standpoint of the developing visual system, these approaches are deeply problematic. An infant has no reliable labels to attach to newly observed objects, there is no guarantee that objects will be observed at a consistent scale or orientation, and, an infant's visual world is dynamic rather than static.

A growing body of results from Project Prakash, and also from studies with infants, points to the profound significance of motion information in the early development of visual object concepts. But, precisely how do dynamic cues contribute to object learning? Here we address this question in the context of a comprehensive model of object learning named 'Dylan' (Dynamic input based Learning in Artificial and Natural systems). Specifically, we show how dynamic information can be used to orient towards, segment and track potential object candidates, without the need for pre-normalization or labeling of input data. Interestingly, the three processes can be implemented via qualitatively similar computations involving clustering of motion vectors, operating over progressively longer time-scales. By tracking a candidate proto-object over many frames of a video sequence and recording its appearance continuously, we can construct a temporally extended model of that object's appearance. This series of images can then be used as the starting point for various feature extraction techniques, and to build up tolerances to variations of scale and illumination. Our system can also be selectively compromised to more closely approximate the perceptual limitations of the developing visual system, providing a useful means for understanding the influence of poor acuity and color sensitivity on high-level object representations.

1058 The neural correlates of perceptual learning and deterioration: a role for attention?

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We have previously shown that repeated, within-day testing on a perceptual task produces performance deterioration. But, an inter-test sleep epi-

sode (e.g. daytime nap) leads to performance improvement. Both phenomena demonstrate specificity to retinotopic position and to stimulus features (Mednick et al. 2003, Mednick et al submitted).

In the present study, we investigated the neural correlates of sleep-dependent, perceptual learning and deterioration, and the particular role attention plays in these performance changes. We compared changes in fMRI BOLD response in retinotopically defined visual areas (V1, V2, V3, V4) to changes in performance on a texture discrimination task (Karni & Sagi, 1991). Performance was measured as the threshold inter-stimulus-interval (ISI) between the target and masking stimulus. Subjects (n=20) trained outside the scanner for one hour on the task twice in one day (9AM & 5PM). An fMRI session immediately followed each test session in which subjects performed the task inside the scanner. In the scanner, the task alternated every 20 seconds between performing the texture discrimination in the trained and the untrained hemifield. Stimulus-driven and attention-driven brain responses were measured separately. Half the subjects took a 1.5-hour, polysomnographically-recorded nap in between test sessions (1-3PM).

Our behavioral results replicate previous findings of nap-dependent performance improvement compared to deteriorated performance in non-nappers. The fMRI BOLD response showed an increase in response across the visual areas in the second session in nappers compared with non-nappers. Further, fMRI responses in early visual areas were reversed between the groups. These results demonstrate the neural correlates of performance changes due to task training and sleep. Reversals in BOLD response found between nappers and non-nappers may reflect changes in the ability of top-down mechanisms to suppress the masking stimulus.

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1059 The Development of Visual Sensitivity to Words in Ventral Occipito-Temporal Sulcus

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INTRO Left ventral Occipito-Temporal Sulcus (OTS) responds more powerfully to visual words than to checkerboards (Cohen et al., 2003). We have shown that BOLD response to words in this region decreases with increasing amounts of noise. In this study, we ask how early this sensitivity develops.

METHODS We measured BOLD signals while 7-12y children with varying reading skills viewed word stimuli in an implicit reading task. Subjects judged the color of a fixation cross in the center of each word. Word visibility was parametrically manipulated by forming a convex sum of the word with a phase scrambled version of itself. Stimuli were presented in 12s (6 items) blocks, alternating with fixation blocks. Twenty-six 2.5x2.5x3 mm axial slices were acquired (3T GE Signa, spiral acquisition) covering occipito-temporal cortex. To assess the spatial distribution of noise sensitivity, we computed a GLM and created contrast maps for the high visibility vs. low visibility conditions in each brain. We measured the size of the BOLD response to words as a function of noise level within left OTS, defined anatomically and functionally by contrasting word conditions vs. fixation.

RESULTS We found robust activation in left OTS in 20 out of 22 children (some as young as 7y) for high vs. low visibility words. ROI analysis revealed that individual response functions in this region decreased with increasing amounts of noise, but the shape of this function varied between subjects. Response decrease to added noise was not found in early visual areas (V1/2/3).

CONCLUSIONS Sensitivity for words in visual noise develops as early as age 7, and manifests in similar brain regions as in the adult reader. This is in agreement with behavioral data showing a 'viewing position effect' for words in children at the end of the first grade (Aghababian and Nazir,

2000). Correlating individual response functions with behavioral reading measures will further elucidate the functional significance of this early perceptual sensitivity for words.

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1060 Right hemisphere processes dominate the initial phase of visual statistical feature-learning

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Is there a hemispheric asymmetry in the implicit learning of new visual features? New visual features represent spatial structures based on perceptual grouping (a right hemisphere, RH, task), but they also lead to conceptual knowledge of the feature (a LH task). We contrasted the performance of 16 normal subjects with that of a split-brain patient. During practice, subjects viewed displays of seemingly random arrangements of simple shapes in a 3x3 grid, with each of the multi-shape scenes presented for 3 s in either the right or left visual fields. Unbeknownst to the subjects, the shapes were organized into 2 horizontal, 2 vertical and 2 oblique base-pairs. Each display was composed of three base-pairs in various grid positions (the elements of a base-pair always appeared together), and each of the base pairs could appear during practice only in the right or the left visual field while subjects maintained their fixation in the center of the screen. A 2AFC post-exposure test revealed that normal subjects could easily discriminate base-pairs from randomly combined shape-pairs when presented in either the left or right visual fields, regardless of where the pairs appeared during practice [71%, $p < .0001$]. In contrast, the performance of the split-brain patient was random when the test displays were presented in the right visual field (LH), but significantly above chance when presented in the left visual field (RH) [59% and 78%, respectively], with pairs appearing on the same side during practice and test. Performance in both visual fields was at chance with pairs appearing on the opposite sides during practice and test. These results suggest that the initial phase of statistical learning of new visual features is dominated by processing mechanisms in the RH, and they predict how the fMRI activation pattern in LH and RH might change as subjects' perception shifts from an initial phase of naïve observation to a knowledge-based interpretation of visual scenes.

1061 An Increased BOLD Response for Trained Objects in Object-selective Regions of Human Visual Cortex

Hans P Op de Beeck (*hop@mit.edu*), Chris I Baker¹, Sandra Rindler¹, Nancy Kanwisher¹; McGovern Institute for Brain Research and Department for Brain & Cognitive Sciences, Massachusetts Institute of Technology, Cambridge, MA

Little is known about how intensive experience in discriminating exemplars from an object class changes the processing and representation of these objects in human visual cortex. Physiological studies in macaque visual cortex have reported effects of discrimination training on both the strength and the selectivity of neural responses. We investigated the effect of object discrimination training on the BOLD response in several regions of the human visual cortex. We trained 9 subjects during 10 daily sessions on the discrimination of shaded 3D objects from one of three novel object classes: 'smoothies', 'spikies', and 'cubies'. All subjects showed an improvement of discrimination ability over training. Subjects were scanned using an 8-channel coil in a 3T scanner before and after training. During scanning, subjects performed an orthogonal task, detecting changes in object color. A comparison of the pre- and post-training scan sessions revealed that training increased the BOLD response ($p < .001$) for the trained object class relative to the response for the untrained classes in object-selective voxels (LOC). No consistent training effects were seen in other visual regions such as the right fusiform face area and early visual cortex. The training effect was restricted to a subset of the voxels in LOC. The localization of the training effects seemed to depend on the selectivity

of voxels before training and on subjects' strategies. In conclusion, object discrimination training increases the BOLD response in object-selective regions of human visual cortex.

Motion; Form from Motion

10:15 - 12:00 pm

Hyatt North Hall

Moderator: David Whitney

1062 The efficiency of biological motion perception

Jason M Gold (*jgold@indiana.edu*)¹, Susan C Cook¹, Duje Tadin², Randolph Blake²; ¹Indiana University, Bloomington, ²Vanderbilt University

Purpose: Human observers easily extract information (e.g., gender and identity) from point-light biological motion sequences. A common assumption is that point-light displays are highly impoverished relative to full-figured bio-motion. Our ability to easily perceive point-light sequences is then taken to suggest highly efficient use of available information. We used ideal observer analysis to test these assumptions by a) quantifying the relative information contained in full-figured and point-light biological walker displays and b) determining how efficiently human observers use the available information contained in each of these displays.

Methods: In two conditions, observers discriminated between a left and a right walking bio-motion sequence. In the FULL condition, bio-motion sequences were depicted by a dark silhouette of an actor walking on a treadmill. In the POINT condition, bio-motion sequences were depicted by a point-light walker stimulus that was generated by tracking 13 body coordinates from the FULL walker sequences. Gaussian spatiotemporal pixel noise was added to the walker and discrimination thresholds were obtained by varying the walker contrast. FULL and POINT thresholds were measured in separate blocks, with the order randomized across subjects. Ideal observer thresholds were measured for the same two conditions.

Results & Conclusions: Surprisingly, ideal observer performance was indistinguishable in the FULL and POINT conditions, indicating that each carried the same amount of discriminative information. However, human performance was up to 7 times worse in the POINT than the FULL condition, indicating that human observers used information far less efficiently in the point-light displays. Efficiency (ideal/human threshold) ranged between 0.4-0.6% in the POINT condition and 2.2-3.0% in the FULL condition. We are currently using response classification analysis to investigate this relatively inefficient use of information in point-light displays.

1063 Detection of direction in scrambled motion: a simple 'life detector'?

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Spatially scrambled point-light displays of humans or animals in locomotion contain unambiguous information about the direction in which the agent is facing. Observers are well able to retrieve this information, but only if the displays are presented right-side up. Even though spatial integrity is not required for direction discrimination the temporal relations between dots may still be important. Here, we report the results of an experiment in which we manipulated the temporal integrity of spatially scrambled point-light displays in two different ways. In the first condition we apply random offsets to the phase of the single dots. Whereas this manipulation changes the 'beat' of the pattern which defines the particular gait of the agent, it leaves its general rhythmicity intact. In a second condition, we also changed the playback speed individually for each dot, which results in completely uncorrelated dot movements.

The results show a small but consistent effect of the temporal integrity on the strength of the inversion effect. As the degree of temporal scrambling increases the inversion effect decreases. Even though temporal integrity apparently plays a role, observers can still determine the direction of the upright, fully scrambled point-light agent with an accuracy that is still much higher than the spatially and temporally intact, but inverted walker.

The results can be modeled by means of a simple linear model and they are discussed in terms of a basic, yet reliable and form invariant visual filter designed for the general detection of animate motion in the visual environment.

1064 Structure-from-Transients: hMT/MST Mediates Figure/Ground Segmentation

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Transient changes may be considered as the 'elemental events' structuring dynamic visual scenes. Previously we established that synchrony/asynchrony in a spatiotemporal pattern of transients was the critical factor in novel illusions of contextual motion (Likova & Tyler, JOV 2003; SPIE 2003). Now we report strong image segmentation from transient asynchronies in fields of featureless visual noise. We term this phenomenon 'Structure-from-Transients' (SFT). BOLD fMRI (GE Signa 3T, spiral acquisition, 23 coronal slices 3 mm³) was used to reveal cortical mechanisms involved in SFT. The stimuli were random dot fields (RDF) of 30x40 deg, replaced by uncorrelated dots every 500ms. Asynchronous updates in subregions of the RDF results in SFT. Figure/ground organization was generated in the test stimuli by transient-asynchrony between an elongated horizontal region (figure) and its surrounding area. The transient changes between these areas in the null stimuli however were synchronized, generating no SFT. Thus the global percepts switched from figure/ground (test) to a homogenous RDF (null) every 9 sec, in 36 blocks per scan. Exp 2: Figure/ground organization was eliminated by SFT-segmentation of the RDF into equal horizontal stripes. In Exp 3, the SFT stripes were defined by unidirectional but asynchronous apparent motion of the noise. Our data show dramatic reorganization of the cortical activation pattern with manipulation of the perceptual SFT organization. Consistent figure/ground-specific activation was seen only in hMT/MST, while surround-specific suppression occurred in V1 (Exp 1). Both were abolished by eliminating the figure/ground organization (Exps 2&3) - the activation shifted to higher retinotopic areas. The results support a view of a recurrent architecture with inhibitory feedback from hMT/MST to the V1 surround projection. We suggest that this cortical network mediating the perceptual reorganization may be activated for figure/ground in dynamic structures in general.

Acknowledgment: NIH EY 7890

1065 Background stripes affect apparent speed of rotation

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A gray line that rotated at constant speed against a stationary background of vertical stripes appeared to double in perceptual speed as it rotated through the vertical position and was momentarily aligned with the background. Two stimulus features might be at work: landmarks, where the tip of the moving vertical line moves horizontally across the maximum number of stationary stripes, and moiré intersections between stripes and moving lines, which move most rapidly when the line is near vertical. To isolate the contribution of landmarks, a white ring was as placed over the grating, and short radial lines ran around this ring. This provided landmarks but no intersections, and the illusion disappeared. To isolate the contribution of intersections, a slit in a virtual black occluder rotated in front of the grating, which was thus seen only through the slit. This provided moiré intersections but no landmarks, and the illusion increased. We conclude that the moiré intersections are entirely responsible for the

perceived speed changes. Consistent with this, we find that when a line rotates on a plain grey background, dots that run back and forth along the length of the line can modulate its perceived speed, which indicates a failure to decouple radial from tangential velocity components.

Acknowledgment: SA: Visting Fellowship, Pembroke College, Oxford. HI: Grant-in-Aid for the 21st Century COE Program, Kyushu University.

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1066 Fractal Rotation Stimulus Activates Human MT/V5

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We constructed a novel stimulus that appears to rotate yet contains no local translational motion. The stimulus is constructed by applying a band-pass orientation filter to a noise image. On each consecutive frame, the filter is rotated about the Fourier domain origin and reapplied to the original image. The stimulus elicits a strong rotational motion percept within any arbitrary window, and is opaque to traditional computational models of motion processing. For example, when an extended gradient model is applied to the stimulus (Johnston, McOwan & Benton, 1999, Proc. R. Soc. London, Ser. B, 509-518), no coherent motion is detected. We examined whether our stimulus activates human MT/V5 using a blocked fMRI design. We compared the BOLD response evoked by the following four stimuli: (a) fractal rotation stimulus, (b) frame shuffled fractal rotation stimulus, (c) rigid rotation of a single frame from the fractal rotation stimulus, and (d) a frame shuffled version of our rigid rotation stimulus. For frame shuffled versions we permuted the order in which frames were presented. An examination of the response in human MT/V5 for our 10 subjects showed that both the fractal rotation stimulus and rigid rotation stimulus evoked similar (and significant) increases in response compared to their frame shuffled counterparts. Indeed we find no significant difference in MT/V5 activation between our fractal rotation and rigid rotation stimuli. Using standard psychophysical procedures, we then investigated whether our stimuli elicited motion aftereffects. As expected, the rigid rotation stimulus evokes both a static and dynamic motion aftereffect. We found no such aftereffects with our fractal rotation stimulus. We take our results to demonstrate the existence of a feature tracking mechanism that inputs to human MT/V5. The lack of a motion aftereffect may well imply this process to be fundamentally different to standard low-level motion analysis.

1067 Measuring motion capture with a Vernier task

Bettina Friedrich (bettina@psy.gla.ac.uk)¹, Pascal Mamassian^{1,2}; ¹University of Glasgow, Glasgow, UK, ²CNRS, Université Paris 5, France

DeValois and DeValois (1991) have shown that motion within a stationary aperture leads to its perceptual displacement in the direction of motion. This distortion in localizing objects due to motion signals is not limited to the motion field itself, but occurs also for objects that are flashed in its vicinity (e.g. Whitney & Cavanagh, 2000). In earlier experiments we measured the size of this motion capture by comparing the perceived position of two targets flashed simultaneously on either side a moving Gabor (Friedrich et al., VSS '03), and by comparing the perceived position of a target flashed once during the motion and again after the motion has stopped (Friedrich & Mamassian, VSS '04). Problems with these methods were that when using two targets at different positions around the Gabor, we must know the size of the shift for one of the targets to use it as a reference. For the double-flashing of the same target, we have to take into account a possible motion aftereffect. To avoid these problems, we designed a Vernier alignment task. Three targets were vertically positioned and each one was placed next to a moving Gabor. The outer two Gabors were placed on one side of the targets (e.g. right) while the middle one was placed on the other side (left). In addition, the outer Gabors moved in a direction opposite to the middle one, so all three targets had the same position relative to the motion fields, either in front or behind. This configuration produced a per-

ceptual misalignment of physically aligned targets. Targets were laterally shifted to find the shift leading to perfect perceptual alignment. For each observer, we took into account their baseline bias to localize the targets when the Gabors were stationary. For both targets in front and behind the motion fields, we found significant target shifts in the direction of motion. We extend this technique to measure motion capture for targets placed at various locations around a motion field.

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1068 Global motion from form in the human visual cortex.

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Implied motion, that is the perception of motion in static images that contain no real motion, demonstrates an interesting interaction between motion and form information that are often assumed to be processed along largely separate pathways. Previous neurophysiological studies have shown that areas MT and MST are involved in implied motion perception. The aim of this study was to investigate whether implied motion processing in the human brain is confined to the motion pathway or entails interactions between motion and form areas. We used dynamic Glass patterns that contain no coherent motion. In these patterns motion is implied by the alignment of oriented dot pairs along a common trajectory. We used an event-related fMRI adaptation paradigm, in which decreased responses after repeated presentation of a stimulus compared to stronger responses (rebound) after a change in a stimulus dimension indicate sensitivity of the measured neural populations to the changed dimension. We observed sensitivity for changes in the global structure of Glass patterns in hMT+/V5, consistent with the previous neurophysiological studies. That is, stronger fMRI responses were observed when two different Glass patterns were presented in a trial (e.g. concentric followed by radial) than when the same pattern was presented repeatedly. Similar rebound effects were observed for real-motion patterns. These rebound effects for Glass and real-motion patterns were observed in motion areas V3, V3a and KO, but also the Lateral Occipital Complex (LOC), that is implicated in form analysis. Interestingly, adaptation effects were observed in motion areas when a Glass pattern was followed by a real motion pattern of similar global structure, suggesting that overlapping neural subpopulations encode real and implied motion patterns. In sum, our findings implicate both motion and form areas in the processing of global motion from form.

Visual Attention, Learning, and Memory

10:15 - 12:00 pm

Hyatt South Hall

Moderator: Ed Vogel

1069 Effects of video game playing on visual processing across space

C. Shawn Green (csgreen@bcs.rochester.edu)^{1, 2}, Daphne Bavelier^{1, 2}; ¹Department of Brain and Cognitive Sciences, University of Rochester, ²Center for Visual Science, University of Rochester

Using several different measures of the spatial characteristics of visual attention, we show that video game play enhances attentional resources over space, and test the hypothesis that it may do so by increasing the spatial resolution of vision. We first used the flanker compatibility effect to establish that video game players have increased visuo-spatial attention, and to confirm that this increase is not only observed at peripheral locations but also in central vision. To unambiguously establish the facilitatory effects of video game play on the deployment of attention over space, we used a visual search task (Useful Field of View task - Ball et al, 1988),

which requires participants to localize a briefly presented target amongst a field of distractors while performing a challenging central task. VGPs far outperformed NVGPs on all aspects of this test, further supporting the hypothesis of an enhancement in visual attention over the whole field in VGPs. Finally, we investigate the possibility that such improvements in visuo-spatial attention may be explained, at least in part, by an increase in the spatial resolution of vision, or more exactly the spatial analysis of a target in the context of nearby pattern elements. It is well known that recognition is impaired when a to-be-recognized target is flanked with distractor shapes. This phenomenon, termed crowding, is believed to be at the root of our ability to identify objects in cluttered scenes. Using a procedure similar to Toet & Levi (1992) we measured the distance between target and distractor that resulted in 79% correct target discrimination. VGPs showed a decrease in this critical distance, establishing an enhancement of visuo-spatial resolution. Critically, in both the UFOV and crowding paradigms, similar effects were observed in NVGPs that were specifically trained on an action video game, thus establishing a causative relationship between video game play and augmented visuo-spatial abilities.

1070 Learning Blinks During the Attentional Blink

Christine Lefebvre (christine.lefebvre@umontreal.ca)¹, Aaron Seitz², Takeo Watanabe³, Pierre Jolicoeur¹; ¹Centre de Recherche en Neuropsychologie et Cognition, Université de Montréal, ²Harvard Medical School, ³Boston University

In our previous studies (Seitz and Watanabe, 2003, *Nature*; Watanabe et al., 2001, *Nature*), subjects learned a motion stimulus through a reinforcement procedure in which the motion was subliminally presented as an irrelevant feature during an attentionally demanding letter task. Here we offer evidence that the bottleneck believed to be responsible for the decrease in correct report for the second target (T_2) in the attentional blink (AB) effect encompasses processes critical to this perceptual learning. In our experiment, participants trained on the identification of two target digits presented within a rapid serial visual presentation of letters. When a short stimulus onset asynchrony (SOA) separated the two targets, T_2 was less likely to be reported correctly, indicating an attentional blink effect. This condition is referred to as the 'AB' condition. When the SOA was long, T_2 was reported correctly most of the time, indicating the absence of a blink effect ('No AB' condition). Irrelevant, unattended moving dots, with 5% motion direction coherence, were presented peripherally during the task. A particular direction was associated with targets presented in the 'AB' condition and another direction was paired with targets presented in the 'no AB' condition. Participants were tested on an identification of motion direction test before and after training in the dual target RSVP task. Results show that the motion direction associated with the no blink condition was learned, but not the direction associated with the blink condition. This suggests that the same lack of resources that are responsible for the incomplete processing of T_2 affects the reinforcement process by which perceptual learning occurs.

Acknowledgment: This work was supported by grants NSF 0418182, NIH R01 EY015980-01 and Human Frontier Foundation RGP18/2004 to Takeo Watanabe and NSERC funds to Pierre Jolicoeur

1071 Maintaining visual short-term memory representations across new object onsets

Edward K Vogel (vogel@darkwing.uoregon.edu)¹, Andrew W McCollough¹, Jason A Fair¹, Geoffrey F Woodman²; ¹University of Oregon, ²Vanderbilt University

The storage capacity of visual short term memory (VSTM) for simple objects is known to be very small (around 3-4 items). This severe capacity limitation necessitates control mechanisms that restrict access to it. These control mechanisms may work to select new relevant items for storage in VSTM, as well as to protect representations currently being maintained in memory from being disrupted by new object onsets. Here, using a sustained event-related potential (ERP) measure of the number of items currently held in VSTM (contralateral delay activity), we examined how new

object onsets impacted the maintenance of existing representations in memory. In the first experiment, task-irrelevant probes were briefly presented during the retention interval of a VSTM task. The presence of the probe temporarily disrupted the sustained activity related to maintaining the memory items. This delay activity returned 40 ms later with a loss in amplitude of approximately 20%. These results suggest that under these conditions, orienting attention to a new irrelevant stimulus may temporarily disrupt existing memory representations, but these memories may be quickly regained with some loss in fidelity. In a second experiment, task-relevant memory items were presented during the retention period of a VSTM task and subjects were asked to add or 'append' these two new items into memory along with the original two memory items. The amplitude of the contralateral delay activity initially reflected the original memory items (2 items), but 200 ms following the onset of the second set of items the amplitude rose to that equivalent to that of four items presented simultaneously. These results suggest that new objects that are task-relevant may be added to VSTM without causing significant disruption of existing memory representations.

1072 Attention and automaticity in visual statistical learning

Nicholas B. Turk-Browne (nicholas.turk-browne@yale.edu), Justin A. Junge¹, Brian J. Scholl¹; Yale University

We typically think of vision as the recovery of increasingly rich information about individual objects, but there are also massive amounts of information about relations between objects in space and time. Recent studies of visual statistical learning (VSL) have suggested that this information is implicitly and automatically extracted by the visual system. Here we explore this possibility by evaluating the degree to which VSL of temporal regularities (Fiser & Aslin, 2002) is influenced by attention. Observers viewed a 6 min sequence of geometric shapes, appearing one at a time in the same location every 400 ms. Half of the shapes were red and half were green, with a separate pool of shapes for each color. The sequence of shapes was constructed by randomly intermixing a stream of red shapes with a stream of green shapes. Unbeknownst to observers, the color streams were constructed from sub-sequences (or 'triplets') of three shapes that always appeared in succession; these triplets comprised the temporal statistical regularities to be learned. Attention was manipulated by having subjects detect shape repetitions in one of the colors. In a surprise forced-choice familiarity test, triplets from both color streams (now in black) were pitted against foil triplets composed of shapes from the same color. If VSL is preattentive, then observers should be able to pick out the real triplets from both streams equally well. Surprisingly, however, they only learned the temporal regularities in the attended color stream. Further experiments that improved learning of the attended stream failed to elicit commensurate improvements for the unattended stream. We conclude that while VSL is certainly implicit (because it occurred during a secondary task), it is not a completely data-driven process since it appears to be gated by selective attention. The mechanics of VSL may thus be automatic, with top-down selective attention dictating the populations of stimuli over which VSL operates.

Acknowledgment: Supported by NSF #BCS-0132444

1073 Visual memory interference with preview search: VSTM and visual marking

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Visual search for a conjunction target is greatly facilitated by giving observers a preview of half the distractors before the target and the remaining items appear. Previous studies have shown that this preview advantage in search is diminished if participants engage in a secondary task when the preview is present. Here we examined the effects of different secondary tasks, contrasting verbal and spatial memory loads. Both forms of memory load decreased search efficiency in preview search com-

pared with baseline (no preview) search conditions, but the effects of the spatial load were more severe and, unlike the verbal load, did not diminish by given observers more time to encode the pattern. The data indicate that preview search is modulated by spatial memory for the first set of distractors, consistent with the idea that search is made efficient by inhibitory visual marking of a memory representation of the old items. Other accounts of preview search fail to explain these selective interference effects.

1 Watson, D.G. & Humphreys, G.W. (1997). Visual marking: Prioritising selection for new objects by top-down attentional inhibition. *Psychological Review*, 104, 90-122.

2 Humphreys, G.W., Watson, D.G. & Joliceur, P. (2002) Fractionating visual marking: Dual task decomposition of the marking state by timing and modality. *Journal of Experimental Psychology: Human Perception and Performance*, 28, 640-660.

Acknowledgment: MRC, BBSRC

1074 The Costs of Visual Working Memory

Alan Robinson (robinson@cogsci.ucsd.edu)¹, Alberto Manzi², Jochen Triesch¹; ¹Dept. of Cognitive Science, UC San Diego, ²Dept. of Psychology, Second University of Naples

While the capacity of visual working memory has been extensively characterized, little work has investigated how occupying visual memory influences cognition and perception. Here we show a novel effect: maintaining an item in visual working memory slows processing of visual input during the maintenance period.

We measured the speed at which subjects could determine the gender of human faces in a dual task paradigm. For the memory task subjects memorized computer generated faces or abstract 3D objects, and then after a 4 second delay, determined if an image was the same or different as the one memorized earlier. For the gender task subjects reported the gender of hairless human faces. The two were combined by inserting the gender task into the delay portion of the memory task. The question was how speed on the gender task would change as a function of the surrounding memory task. In EXPERIMENT 1 gender recognition was slower when another human face had to be maintained in memory than when an abstract 3D object was maintained in memory. In EXPERIMENT 2 we verified that this effect was due to visual memory usage by adding a phonological loop interference task to prevent subjects from using any verbal encoding.

We interpret this effect as interference between memory and perception, caused by the visual similarity between ongoing perceptual input and items already encoded in visual memory. This interference is likely due to a neural overlap in the areas that recognize faces, and the areas that maintain faces in working memory. Thus, using visual memory has perceptual costs, which may explain the limited use of working memory found in research on natural tasks. Thus, everyday behavior may involve a complex trade-off between memory usage and efficient perception.

1075 The type of working memory load influences the magnitude of distractor interference in a selective attention task

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Loading cognitive control processes such as working memory decreases performance in response conflict tasks by making it harder to prioritize targets over distractors (deFockert et al., 2001). Here we test whether the loss of cognitive control is dependent on how working memory is loaded. Specifically, if working memory is occupied by items that draw capacity away from either targets or distractors in a selective attention task, then we should observe different patterns of dual-task interference effects. Subjects performed a matching task while maintaining items in working memory. The primary matching task was to make a same/different judgment for two face targets, each occluding the center of a larger house distractor, presented side-by-side. The subjects only performed face matching, but the

background house distractor pair was either congruent or incongruent to the face target responses (same/ different). These response conflict trials were performed with three types of concurrent working memory tasks: face memory, house memory and no memory. In face memory blocks, subjects maintained two faces in working memory while performing the matching task. In house memory blocks, subjects maintained two houses in working memory. The main result of interest was the response time difference between incongruent and congruent trials that reflect response conflict elicited by the house distractors. Significant response conflict was observed overall. Interestingly, this response conflict was reduced when subjects were maintaining houses in working memory compared to when they were maintaining faces or nothing at all. This suggests that the house working memory load reduced the capacity for perceptual processing of house distractors, attenuating response conflict. Thus, distractor interference does not always increase with increased working memory load, but is rather dependent on whether memory items share the same resources with targets or with distractors.

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3D Processing: Motion and Texture

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3D Space Perception

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Adaptation

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Binocular Rivalry

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Natural Images

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Object Recognition

Posters, (737-748) Monday, May 9, 8:30 - 2:00 pm

Objects: Cortical Mechanisms

Talks, (910-914) Tuesday, May 10, 2:00 - 3:15 pm

Orienting and Eye Movements

Posters, (692-702) Monday, May 9, 8:30 - 2:00 pm

Perception and Action

Talks, (383-388) Sunday, May 8, 10:15 - 11:45 am

Perceptual Learning 1

Posters, (710-716) Monday, May 9, 8:30 - 2:00 pm

Perceptual Learning 2

Posters, (863-874) Tuesday, May 10, 8:30 - 1:30 pm

Perceptual Organization 1

Posters, (340-354) Saturday, May 7, 2:00 - 7:00 pm

Perceptual Organization 2

Posters, (963-980) Tuesday, May 10, 2:00 - 7:00 pm

Perceptual Organization,

Talks, (497-503) Sunday, May 8, 3:45 - 5:30 pm

Perceptual/Object Learning

Talks, (1056-1061) Wednesday, May 11, 8:30 - 10:00 am

Performance and Attention

Posters, (155-173) Saturday, May 7, 8:30 - 1:30 pm

Reading and Print

Posters, (806-820) Tuesday, May 10, 8:30 - 1:30 pm

Scene and Layout Perception

Posters, (63-79) Friday, May 6, 5:30 - 8:30 pm

Scene Perception and Inattentive Blindness

Talks, (791-797) Tuesday, May 10, 10:30 - 12:15 pm

Sensory Integration

Talks, (646-652) Monday, May 9, 10:30 - 12:15 pm

Sensory Integration: Vision and Hearing

Posters, (875-890) Tuesday, May 10, 8:30 - 1:30 pm

Sensory Integration: Vision and Touch

Posters, (749-759) Monday, May 9, 8:30 - 2:00 pm

Spatial Vision 1

Posters, (174-192) Saturday, May 7, 8:30 - 1:30 pm

Spatial Vision 2

Posters, (475-489) Sunday, May 8, 8:30 - 1:30 pm

Spatial Vision

Talks, (227-232) Saturday, May 7, 1:30 - 3:00 pm

Target Mislocalization

Posters, (202-208) Saturday, May 7, 8:30 - 1:30 pm

Temporal Processing

Posters, (760-771) Monday, May 9, 8:30 - 2:00 pm

Visual Attention, Learning, and Memory

Talks, (1069-1075) Wednesday, May 11, 10:15 - 12:00 pm

Visual Cortex: Receptive Fields

Talks, (80-86) Saturday, May 7, 8:30 - 10:15 am

Visual Cortical Organization

Posters, (891-909) Tuesday, May 10, 8:30 - 1:30 pm

Visual Disorders and Blindsight

Posters, (284-303) Saturday, May 7, 2:00 - 7:00 pm

Visual Memory

Talks, (915-919) Tuesday, May 10, 2:00 - 3:15 pm

Visual Neurons: Properties

Posters, (429-435) Sunday, May 8, 8:30 - 1:30 pm

Visual Search

Talks, (779-784) Tuesday, May 10, 8:30 - 10:00 am

Visual Search

Posters, (947-962) Tuesday, May 10, 2:00 - 7:00 pm

Visual Working Memory

Posters, (610-625) Sunday, May 8, 2:00 - 7:00 pm

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