Keynote Lectures

1. Object Segmentation Controls Image Reconstruction From Natural Scenes

Peter Neri
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Early visual cortex represents scenes as spatially organized maps of locally defined features, such as edges and lines. As image reconstruction unfolds and features are assembled into larger constructs, cortex attempts to recover semantic content for object recognition; our evolving interpretation of the image is then fed back to the feature extraction stage and may impact its operation. Although we know that feature extraction operates alongside image interpretation, it is not known exactly how these processes affect each other in the sense of a fully specified computational model. I will review work on feature extraction as an isolated process, as well as its operation under instruction of the image interpretation module via semantic content and scene segmentation. Collectively, these results indicate that the human sensory process must be viewed as a multidirectional system where modules at both ends of the spectrum, from higher to lower level representations, interact with and inform each other in a cohesive manner within a highly integrated architecture. The exact manner in which these interactions occur is not easily summarized as a one-size-fits-all operation, but rather as a complex array of different mechanisms operating at different levels of image reconstruction, the extent of which is only partially available at this stage of enquiry.

2. Processing of Feedforward and Feedback Signals in the Lateral Geniculate Nucleus of the Thalamus

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Feedback is a prominent feature in the visual system, but its functional role in visual processing is debated. For example, only 5% to 10% of synaptic inputs to relay cells in the dorsolateral geniculate nucleus (dLGN) of the thalamus arise from retinal ganglion cells, while about 30% are provided by cortical feedback (Sherman & Guillery, 2002, Philosophical Transactions of the Royal Society London B: Biological Sciences, 357, 1695–1708). The functional role of Layer 6 cortico-geniculate feedback and its impact on responses in dLGN remain controversial, as previous investigations have yielded inconsistent results.
Here, we used the mouse model to test how cortico-geniculate feedback shapes dLGN activity.

In awake, head-fixed mice, we performed extracellular recordings with multisite linear silicon probes in dLGN and used optogenetic and pharmacogenetic manipulations to causally interfere with cortico-geniculate feedback.

We first examined spontaneous activity. We found that during transient inactivation of cortico-geniculate feedback activity of dLGN neurons decreased abruptly and transitioned after approximately 150 ms into burst mode firing. This pattern of changes is consistent with removal of excitation normally provided by cortico-geniculate feedback. We next assessed feedback-related changes in spatial integration and found that cortico-geniculate feedback modulates dLGN surround suppression: Transient inactivation of cortico-geniculate feedback led to an expansion of dLGN receptive field center size and a reduction of surround suppression. This decrease in surround suppression often resulted from both a reduction of responses to small stimuli and an increase of responses to stimuli exceeding the optimal size.

Since cortico-geniculate feedback provides on dLGN relay cells both direct excitatory and indirect inhibitory influences via the thalamic reticular nucleus, we developed a novel pharmacogenetic approach to selectively silence the direct excitatory pathway. We will report first results from this pathway-specific silencing and discuss implications of our findings for the role of Layer 6 cortico-geniculate feedback during changes in behavioral state.

3. Converging on a Computational Model of Object Recognition: Psychophysics and Machine Learning

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Avi Ziskind (SRI) and I have implemented a machine-learning model of object recognition, initially to recognize a letter. I will compare its performance to human at several tasks which have been thought to reveal hallmark’s of human performance, including spatial-frequency channels and crowding.

Talks

1. Subconscious Detection of the Orientation Statistics Within Scenes

Szonya Durant
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Istvan Sulykos and Istvan Czigler
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Rapid extraction of the overall statistics of the scene is crucial for perceiving its “gist.” In this work, we examined whether automatic detection of statistical differences between scenes can be measured via visual Mismatch Negativity (vMMN), an early ERP component that has
been suggested to reflect pattern detection over a sequence. We presented a set of Gabor patches of a given (random) mean orientation on each presentation in a sequence and varied the width of the distribution around the mean of the orientations of the patches, so that some sets all had a similar orientation (ordered) or the individual orientations were random (disordered). These two types of sets of Gabor patches formed the standards and deviants in an unattended typical oddball paradigm. We found an asymmetric vMMN effect, where a more disordered set of stimuli elicited a response among ordered stimuli, but not vice versa. This suggested that the visual system was able to learn and build up an expectation about a certain level of order, but not able to pick up on such a pattern for disordered stimuli, tying in with similar findings from symmetry detection. Furthermore, in a general test of ability to discriminate between different levels of order, we found that better discrimination corresponded to a larger vMMN amplitude. We therefore have shown that we are able to subconsciously detect the basic orientation statistics of a scene and this sensitivity is reflected in the vMMN amplitude.

2. TMS Reveals Dual Processing Routes for Biological Motion Perception

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The perception of human movement is a key component of daily social interactions. Sparse dot displays of human movements (biological motion) are commonly used in experimental studies to isolate the underlying processing systems. Although human extrastriate area MT+/V5 is closely associated with simple motion processing, its role in the analysis of biological motion displays is still unclear. We developed two closely matched psychophysical tasks to assess simple coherent motion perception and biological motion perception and measured changes in performance caused by application of TMS over MT+/V5. Performance of the simple motion discrimination task was significantly depressed by TMS stimulation and highly correlated within observers in different TMS conditions. On the other hand, there was no significant decrement in performance of the biological motion task, but low intraobserver correlations across TMS conditions. We conclude that extrastriate area MT+/V5 is an obligatory waypoint in the neural processing of simple coherent motion, but is not obligatory for the processing of biological motion. Results are consistent with a flexible dual neural processing route for biological motion processing.

3. A Possible Human Polymorphism in Motion Adaptation

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Some participants in a Type 1 measurement of the MAE did not show motion adaptation. The task was to adapt to repeated 2 s presentations of a 4 × 4 array of Gabor patches with stationary envelopes and carriers moving vertically, some up and some down.
Adaptation alternated with presentations of a 4 × 4 array of patches, all of which but one moved in the same direction as their retinotopically coincident adapting patch. The task was to report with a mouse which patch was the “odd man out.” Most observers (n = 11) could achieve at least 50% accuracy in the task, but some observers (n = 3) were at chance. These observers were also unusual in not seeing movement of the placeholders as a result of adaptation. To prove this point, a task was designed where adaptation would be a disadvantage. The adapting stimulus was as before, but was now followed by 4 × 4 empty placeholders one of which was moving vertically. The majority of observers found this particularly hard when the movement was in the same direction as the adaptor, but the “nonadaptors” from the first experiment were not affected.

4. Conjugate Riesz Priors for Visual Motion and Spatial Orientation Estimation

Keith Langley
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Stephen Anderson
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Current innovations of Bayesian models used to account for visual motion perception principally assume that sources of signal uncertainty exist purely in the temporal domain. This assumption easily leads to a Conjugate Prior probability density function (PDF) whose preference exists for low-image speeds. An advantage of a Conjugate Prior is that it leads to tractable estimates for visual motion. When signal uncertainties are considered in both space and time, however, that same low-speed prior that restricts signal uncertainty to the temporal domain is no longer conjugate and the ensuing Posterior PDF intractable. We show that a conjugate Prior PDF for visual motion that assumes signal uncertainties exist in both the spatial and temporal domains can be derived by considering the expectations of spatiotemporal filter responses that includes a stage of motion estimation. This approach also leads to a conjugate Prior PDF for Bayesian models of spatial orientation. We further show that the Prior, Likelihood, and Posterior PDFs for both motion and spatial orientation are simplified by including the Riesz transform as the underlying spatiotemporal signal representation. When examining the conjugate Prior PDF coefficients we find, for example, that estimates of image speed need not depend upon the contrast of the image signal. We also find quite obviously that a Prior PDF that retains a preference for low speed, when combined with a constant model for speed, has difficulty in simultaneously estimating both the mean and variance of a motion (spatial orientation) signal. We conclude that an appropriate Bayesian approach for modeling visual motion and indeed spatial orientation is one derived from the Kalman filter or variants therein, by its virtue in taking into account temporal variation in its parameters of interest.

5. A Neural Network Model for the Dynamics of Orientation Selectivity Neurons in the Bee Visual System

Hadi Maboudi and Lars Chittka
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Bees are unique in their visual learning capacities, which include phenomenon such as visual categorization, numerosity, and attention. One of the main challenges is to determine how perceptually salient features such as bars and complex shapes are represented in the bee brain. We designed a spiking neural network based on a linear generative image model, in which images are represented by using superposition of spatiotemporal basis functions (receptive fields). Since we assume that bees transfer a static visual stimulus into a spatiotemporal signal to their visual system via horizontal scanning movements, the model receives inputs from time-varying images. The activity of neurons is modeled according to the adaptive exponential integrate-and-fire model. The network is further enriched by lateral inhibitory connections to eliminate dependency between neural activities. Where possible, our model is based on empirically determined features of the bee visual system, but where information is lacking, we have made use of information from the fly visual system that has been studied in more detail. Because the sensory neurons in the fly visual system employ the property of the sparseness in time, the objective function for learning the receptive fields is defined based on sparseness of neurons through biologically realistic plasticity rules to find appropriate connectivity values in the network. We finally trained the model on time-varying patches obtained randomly from a set of flowers. The learned spatiotemporal receptive fields as well as lobula’s neurons in the bee visual area respond to bars moving in a direction orthogonal to their long axis. Interestingly, the orientation selective RFs cover a diversity of orientation and spatial frequencies, which are biased toward the speed of input sampling. The obtained excitatory and inhibitory connectivity values through an unsupervised learning suggest that such a coding system may be at work in the bee visual system.

6. Freeze or Flight: Mouse Strategies for Avoiding Capture by Overhead Threats

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In prey species such as mice, avoidance of predators is the key to survival and drives instinctual behaviors, including freeze and flight. When does a threat induce freeze or flight responses? We video-monitored mice freely exploring a 50 × 35 cm arena surmounted by a computer monitor. We studied response to two types of visual stimuli, which were triggered when mice entered the center of the arena. The “sweep” stimulus was a 5° black disc that translated 55° in 4 s. The “loom” stimulus was a black disc that expanded from 2° to 50° in 0.25 s. We defined freezing as reduction of movement speed to less than 2 cm/s, for at least 0.5 s, and flight as run back to nest. In absence of visual stimuli, freezing behavior was observed in 14% of virtual 4 s trials, and flights in 24%. During first encounter with the sweep stimulus, majority of mice showed freezing (11/18; 56%), while some showed flight (5/18; 28%). In subsequent trials, mice usually showed freezing (80%), not flight (6%). Encountering the loom stimulus, most mice instead showed rapid flight (14/18; 78%; 1 animal froze), subsequently increasing to 96% of trials (consistent with Yilmaz & Meister, 2013, Current Biology, 23, 2011–2015). Sweep-induced freezing was preserved when the nest was then removed; loom-induced flight was also preserved, but delayed by approximately 0.15 s. We conclude that mice freeze when the steady sweep of a silhouette emulates a passing predator. Flight instead occurs when animals see that silhouette rapidly expand, consistent with a predatory dive.
7. Melanopsin Contributions to Encoding Spatial Patterns in the Mouse Visual System

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Melanopsin, found in intrinsically photosensitive retinal ganglion cells, is necessary for the accurate encoding of ambient light for subconscious visual responses (e.g., entrainment of the circadian clock; control of pupil size). There is, however, an emerging role of melanopsin in perceptual vision that currently is poorly understood. Particularly lacking is a description of the spatial or temporal information available from melanopsin photoreception and what (if any) functional contribution this makes toward encoding spatial patterns.

To isolate the particular components of the visual world which melanopsin might encode, we modified a commercially available projection system so that each R, G, and B channel was instead a combination of five independently controlled wavelengths. This allowed us to use the principles of receptor silent-substitution to present patterned stimuli in spectra that provided contrast for selected mouse photopigments: melanopsin (51% Michelson contrast); rod & cone opsins (33% Michelson contrast); or melanopsin and rod & cone opsins (51% and 33%, respectively).

With multichannel recording electrodes, we recorded single-unit responses to these stimuli in the dorsolateral geniculate nucleus of anaesthetized mice. A substantial fraction of dorsolateral geniculate nucleus neurons responded to stimuli visible only to melanopsin. Their response was determined by the location of stimuli in space, allowing us to map spatial receptive fields for this input. These were found to be spatially contiguous but temporally distinct from those of rods or cones. Comparisons of the responses evoked by rod or cone stimuli presented with or without concurrent melanopsin contrast revealed a contribution of melanopsin to encoding spatial patterns in radiance over more sustained periods. This signal is robust to superimposed higher frequency signals from rods and cones and is important for the accurate encoding naturalistic patterns or temporal changes in local brightness. Although melanopsin signals are outside the range required for high spatiotemporal acuity vision, they are particularly useful in the encoding of spatial patterns in radiance over longer timescales.

8. What Shape Is France?

Lewis Griffin
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Mentioned in Verne’s illustrated geography of France, the characterization of France as l’Hexagon is a pedagogic standard and national signifier, but it has not always been so. Other French writers have seen it as a pentagon or an octagon, while the Encyclopaedia Britannica prior to 1910 claimed it to be “roughly square-shaped” (E. Weber, My France, 1986).

To settle this one would like to appeal to a theory of approximate symmetry, but despite the widespread use of this notion and the scientific potency of its better half—exact symmetry—no satisfactory theory exists. Best is Zabrodsky’s measure of approximate
symmetry (1995, *IEEE Transactions on PAMI, 17*(12), 1154–1166), which is equivalent to the magnitude of the symmetrical component of the shape—larger values indicating better approximate symmetries. Although flawless at identifying the best symmetry of a type, it fails when comparing symmetries of different type, as it always rates subsymmetries as better than larger symmetries. So, for example, France has better triangular than hexagonal symmetry, which fails decisively to agree with intuition or precedent.

We propose a modified measure: The magnitude of the component of the shape which is symmetrical but not more symmetrical. With this measure, subsymmetries are not necessarily better approximations than larger symmetries. As a first attempt at gauging the agreement with perception, the author graded 90 symmetries, 15 types for each of six countries of diverse shape, into 14 ranks. After a power law transformation, the correlation of the measure with the ranks was .81, compared with .73 for Zabrodsky’s measure.

9. Cross-Modal Attention and Sensory Discrimination Thresholds in Autism

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Previous research has suggested that autism is associated with abnormalities in sensory and attentional processing. Here, we assessed these processes independently in the visual and auditory domains using a visual contrast-discrimination task and an auditory modulation-depth discrimination task. To evaluate changes in sensory function by attention, we measured behavioral performance (discrimination accuracy) when subjects were cued to attend and respond to the same stimulus (frequent valid cue) or cued to attend to one stimulus and respond to the noncued stimulus (infrequent invalid cue). The stimuli were presented at threshold to ensure equal difficulty across participants and groups. Results from 15 high-functioning adult individuals with autism and 15 matched controls revealed no significant differences in visual or auditory discrimination thresholds across groups. Furthermore, attention robustly modulated performance accuracy (performance was better for valid than invalid cues) in both sensory modalities and to an equivalent extent in both groups. In conclusion, when using this well-controlled method, we found no evidence of atypical sensory function or attentional modulation in a group of high-functioning individuals with clear autism symptomatology.
10. Perceived Direction of Tilt Determined by Adaptation to Unoriented or Untilted Binocular Stimuli: Surprising Predictions of Efficient Coding Theory

Keith May and Li Zhaoping
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Li and Atick (1994, Network: Computation in Neural Systems, 5, 157–174) presented a theory of efficient binocular integration in which the two eyes’ signals are combined using separately adaptable binocular summation and differencing channels. We designed a dichoptic test stimulus for which the summation channel sees a grating tilted in one direction (clockwise or anticlockwise of vertical or horizontal), and the differencing channel sees a grating tilted in the opposite direction. The observer’s perceived direction of tilt (summation or difference direction) should depend on the relative sensitivities of the two channels. We manipulated channel sensitivity using adaptation. In correlated adaptation, each eye received the same adaptation image, which selectively adapted the summation channel; in anticorrelated adaptation, the adaptor contrast was reversed between the eyes, selectively adapting the differencing channel. In Experiment 1, the adaptation stimuli were unoriented noise; in Experiment 2, the adaptation stimuli were oriented but untilted noise. Despite being unoriented or untilted, the adaptors influenced perceived tilt: The test stimulus usually appeared tilted in the difference direction after correlated adaptation, and tilted in the summation direction after anticorrelated adaptation. We found similar effects when the noise pattern was added to the test stimulus instead of preceding it; this may be caused by very fast adaptation. Our counterintuitive finding of a tilt aftereffect from unoriented or untilted adaptors is formally equivalent to our previous finding of a motion aftereffect from static adaptors (May, Zhaoping, & Hibbard, 2012, Current Biology, 22, 28–32). These results strongly support Li and Atick’s theory.

11. Generalized Visual Quantity Processing: Topographic Representations of Object Size and Relationships With Numerosity in Human Parietal Cortex

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Humans and many animals analyze visual input to estimate quantities that guide behavior and decisions. These quantities include numerosity (object number) and object size. We recently demonstrated topographic maps of numerosity (Harvey et al., 2013, Science,
1123–1126). Here, we ask whether the brain also contains maps of object size, and how these visual quantity representations are related.

Using ultra high-field (7T) functional MRI and population receptive field modeling, we describe tuned responses to visual object size in bilateral human posterior parietal cortex. Tuning follows linear Gaussian functions, shows surround suppression, and tuning width narrows with increasing preferred object size. Object size-tuned responses are organized in bilateral topographic maps, with similar cortical extents responding to large and small objects. These properties of object size tuning and map organization all differ from the numerosity representation, suggesting object size and numerosity tuning result from distinct mechanisms. However, their maps largely overlap, and object size preferences correlate with numerosity preferences, suggesting associated representations of these two quantities. Object size preferences here show no discernable relation to visual position preferences found in visuospatial receptive fields.

As such, object size maps (like numerosity maps) do not reflect sensory organ structure, but instead emerge within the brain. We speculate that, as in sensory processing, optimization of visual cognitive processing using topographic maps may be a common organizing principle in association cortex. Interactions between object size and numerosity maps may associate cognitive representations of these related features, potentially allowing consideration of both quantities together when making decisions.

12. The Nature of Perceptual Illusions

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Illusions are an accepted part of the armory of perceptual analysis techniques, revealing quirks in the machinery of perceptual processing that give clues as to its underlying mechanisms. Rogers (2010) has recently brought this approach into question with the view that illusions represent the operation of a sensory code for which there is no meaningful ground truth against which to compare the illusory percepts and, therefore, that there are no visual illusions. This view supports the Bayesian theory that the percepts labeled “illusions” fall into a continuum of core strategies of adapting perceptual processing to the natural world, again implying that illusions are simply information processing characteristics. This is particularly true in the cases of physically defined rather than perceptually defined quantities, such as light wavelength, which are inherently discrepant from the perceptual experience.

Instead, I propose that “illusions” are clear cases definable as percepts that are discrepant from a ground truth that can be directly verified by the observer in the situation (as opposed to the authority of other scientific methodologies). For example, a line that appears curved may be verified as straight by sighting along it from a close angle to the paper or a Roman floor that looks fenestrated in depth may be verified as flat by stepping on it. Reference to direct verifiability not only provides an operational definition of “illusion,” but it also makes their analysis more interesting and informative. A range of illusions that illustrate the differences between the philosophical viewpoints will be presented for discussion.
Posters

1. Focussing and Reaching in Depth: Evidence-Linking Monocular Stereopsis and Depth Scaling

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Pictorial images viewed monocularly through a reduction aperture generate an impression of depth much more vivid than binocular viewing and qualitatively similar to binocular stereopsis. The conventional explanation for this effect is based on the removal of conflicting binocular cues and an attendant increase in the perceived magnitude of pictorial depth. An alternative explanation, based on the conjecture that stereopsis is linked to the derivation of egocentrically scaled depth (Vishwanath, 2011), suggests that the effect derives from the scaling of pictorial depth via the reattribution of residual distance information. Previously, we showed that the induction of monocular stereopsis was not linked to a reduction in cue conflict or the perception of a greater magnitude of depth. Here, we provide two sources of evidence in support of the conjecture-linking monocular stereopsis and scaled depth. First, we show that an impression of stereopsis can be induced simply by altering focus (accommodative) distance when viewing a pictorial image with one eye. This supports the idea that monocular stereopsis is associated with a reattribution of distance information (via accommodation and the equidistance tendency). Second, we show that observers can reliably discriminate locations in depth in a pictorial image through manual reaching responses under monocular-aperture but not binocular viewing. In the latter, reaching responses could only discriminate between the actual (randomly assigned) positions of the display surface. This is consistent with the idea that, under monocular-aperture viewing, the visual system appears to scale pictorial depth intervals in a way that permits motoric discrimination.

2. The Processing of Compound Radial Frequency Patterns

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Gunter Loffler
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Radial frequency (RF) patterns are quasi-circular contours that are frequently used to investigate intermediate stages of shape processing. Combinations of RF patterns can be used to construct complex shapes such as head contours or animal torsos. Previous studies have suggested that such complex shapes may be encoded by multiple, narrowly tuned RF shape channels. The aim of this study was to test the hypothesis that complex shapes processing may be based on multiple, independent RF channels.
Thresholds were determined for detection (circle vs. RF compound) and discrimination (RF compound vs. RF compound) of various weighted combinations (symmetrical and asymmetrical) of two RF components (RF3&RF5; RF3&RF8; and RF4&RF7). If both RF components were processed by a common broadband channel, one would expect a substantial increase in sensitivity as the information from both components would be summed within the same channel (additive summation). If the two components were processed independently by separate channels, one would expect only a slight increase in sensitivity for the compound compared with the components (probability summation). The data were analyzed by a model for probability and additive summation under Signal Detection Theory (Kingdom, Baldwin, & Schmidtmann, *Journal of Vision*, 15(5), 1). Results show that summation of information from different RF components is consistent with additive summation. This suggests that the shapes tested here are processed by a broadly tuned mechanism.

3. Does “Crispening” Affect the Perceived Contrast of Artificial and Natural Textures?

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We investigate the role of lightness perception in determining the perceived contrast of textures. Under some conditions, the relationship between onscreen luminance and perceived lightness may be modeled by a simple power law. However, Whittle (1992, *Vision Research*, 32, 1493–1507) observed a local effect, whereby subjects are more sensitive to lightness variations around the background luminance level (the “crispening” effect). We investigate lightness perception by asking subjects to manipulate the luminance of uniform patches presented on a uniform background until they appear to vary, from black to white, in a perceptually linear manner. In a second experiment, we estimate the contrast required to match two white noise patches with a mean luminance of 25% and 75%. Both experiments are conducted using five background luminance conditions (from 0% to 100% luminance). We find that subjects’ contrast judgments can only be modeled by passing the stimulus through the empirically estimated lightness functions before computing contrast. Importantly, the contrast data cannot be explained via a power-law model of lightness, which cannot capture the “crispening” effect. Like Whittle (1992), we find that the addition of a contrast annulus abolishes the “crispening” effect in the lightness experiment and, in turn, the contrast experiments. Finally, we rerun the contrast experiment using a random selection of natural images. Natural textures exhibit a strong “crispening” effect, but edge- and bar-like stimuli do not. We speculate that “crispening” is an adaptation that enhances the contrast of textures.

4. Nonlinear Interactions Between Steady-State Responses to Visual Stimuli

**Daniel Baker, Natasha Gutmanis, Samantha Harris, Rebecca Kitching, Hollie Melton, Rose Anna Norman, Christina Scott, Anika Smith, Kirstie Wailes-Newson and Greta Vilidaitė**  
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Flickering visual stimuli produce entrained neural activity that is easily measured using electroencephalography, termed the steady-state visually evoked potential (SSVEP). For a
single flicker frequency, the brain generates SSVEPs at the fundamental frequency and its higher harmonics, and for multiple frequencies intermodulation responses also occur at the sums and differences of the individual frequencies. We measured SSVEPs from 100 individuals for 11 s trials viewing one or two component stimuli (0.5 c/deg, 7 and 5 Hz on or off flicker, EEG sample rate 1 kHz). The unprecedented signal fidelity that emerges from our large sample size permits several novel observations. The first harmonic responses (1F) decrease rapidly during the first second following stimulus onset, whereas the second harmonic responses (2F) increase during the first 2 s. We attribute this to responses from cells that code changes in the mean contrast level of a stimulus (e.g., complex cells) initially responding to differences from mean luminance (at 1F) and then signaling both increases and decreases of contrast (at 2F). With two frequencies, we observe many responses at nonintermodulation integer frequencies, including 3, 4, 9, and 16–19 Hz, particularly when data are averaged coherently across participants. Many of these are predicted by a two-input contrast gain control model (Busse, Wade, & Carandini, 2009, Neuron, 64, 931–942) fitted to the entire Fourier spectrum from 1 to 20 Hz at a range of contrasts. However, the model underestimates the 2F amplitude and overestimates the amount of suppression between frequencies. We suggest a multi-stage model with several nonlinearities may be needed to explain all our results.

5. Time Course and Interocular Transfer of Size and Contrast Adaptation Aftereffects

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We performed psychophysical experiments to evaluate adaptation to size and contrast, and the dependence of these processes on stimulus texture. Stimuli were discs or rectangles presented against a mid-gray background, consisting of sine-wave or plaid patterns or areas of uniform luminance. In the adaptation phase for size adaptation experiments, a number of large disks (with diameter twice as that taken for a “standard”) jittered in position (based on Baker & Meese, 2012, Perception, 41(S), 33) in the left side of the visual field for up to 20 s. Target stimuli were then displayed, consisting of a fixed diameter standard in the adapted hemifield, and a comparison stimulus of variable size in the unadapted hemifield. Participants indicated which of the target stimuli appeared larger in size. By varying the adaptation period, we obtained exponential time courses for size adaptation with a time constant of $\tau_{\text{size}} = 7.1$ s ($\text{SE}=\pm 0.6$ s). Additional control experiments found no effect of the relative orientation of adaptor and target textures. Adapting to textured stimuli in the center of the visual field produced a strong orientation-specific contrast sensitivity aftereffect with a time constant that was shorter than that measured for size adaptation ($\tau_{\text{contr}} = 3.9$ s, $\text{SE}=\pm 0.2$ s). Similar values of time constant were observed during recovery from adaptation. For contrast sensitivity, we also measured interocular transfer of adaptation by adapting and testing in the same eye or in different eyes. The latter case revealed a 75% reduction of the total adaptation depth, suggesting a strong monocular contribution to contrast adaptation.
6. Reverse Correlation Reveals Averaging Strategies

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It is known that individuals can encode summary statistics about groups of elements, such as their mean orientation (e.g., Dakin, 2001). A common account of this averaging process is that people only use a subsample of elements from an array. Here, we used a reverse correlation method to examine the sampling strategy for participants who judged the average (a) head rotation of a group of faces, (b) gaze deviation of a group of faces, and (c) orientation of a group of Gabor patches. Participants \( n = 6 \) categorized (leftwards or rightwards) the average (a) head rotation, (b) gaze deviation, and (c) orientation (clockwise or anticlockwise of vertical) of Gabor patches. For all stimuli, the head rotation (gaze deviation or Gabor orientation) of each face (Gabor) was drawn from a normal distribution with a mean of zero. A minimum of 1,200 trials were collected from each participant. Reverse correlation maps were generated by correlating, on a trial-by-trial basis, the location and value of each face (Gabor) with the participants’ responses. Results for head rotation and gaze deviation show a clear sampling area in the center of the array that was significantly larger for judgments of average head rotation than gaze deviation. Variations between participants could not be attributed to differences in their sampling efficiency. Maps from the orientation task reveal smaller apparent sampling areas and lower peak correlations. These data suggest that observers do not average across all elements, but rather display clear biases for centrally localized elements. Individual differences in sampling efficiency (within a category) likely reflect differences in strategies.

7. Adaptation to Tilted Scenes

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When adaptation distorts the apparent feature content of subsequently viewed images, it suggests that our visual system has neural mechanisms selective for those features. We examined whether our visual system has a putatively high-level mechanism selective for the spatial orientation of scenes that is distinct from its low-level mechanisms encoding the orientations of gratings. The logic of our experiment was the same as that used by Ware and Mitchell (1974). They reported significant reductions (between 50% and 80%) in the tilt aftereffect when the spatial frequencies of adapting and test gratings differed by two octaves. This suggests that mechanisms encoding the orientations of gratings are selective for spatial frequency. To address our hypothesis about scenes, perceived uprightness was measured...
following adaptation to an image of a house tilted 15° anticlockwise or clockwise of upright. We had three conditions where the adaptor and the tests were circularly windowed images of (a) the same house, (b) different houses, and (c) the same house filtered to contain a 1.5-octave band of spatial frequencies around one of two central frequencies (10 cpd and 1.5 cpd). Prolonged viewing of a scene tilted anticlockwise produced an apparent clockwise tilt in subsequently viewed untilted test scenes, irrespective of whether the adaptor and tests were the same house (mean = 1.01°) or not (mean = 1.18°). The aftereffects we obtained with spatial frequencies-filtered houses were similar in magnitude (mean = 1.49°) to the unfiltered condition. The mechanism responsible for these aftereffects is not selective for spatial frequency. We therefore conclude it is distinct from the low-level mechanisms that encode the orientations of gratings.

8. Effect of Stimulus Placement and Presentation on Duration Discrimination

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Isabelle Mareschal
Queen Mary University of London, England

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The way in which stimuli are presented during psychophysical studies can affect perception and subsequent judgments, known as the “order effect” (Nachmias, 2006, Vision Research, 46, 2456–2464). Previous studies have suggested this effect may have both a temporal and a spatial component (Ayhan et al., 2009, Journal of Vision, 9, 2). Here, we examined how perception of duration can be influenced by the spatial position of stimuli. Two circular sinusoidal gratings (one reference and the other test) were shown sequentially and participants judged which of the two was presented for a longer duration. Stimulus order was randomized between trials. The reference lasted 600 ms, and the test had one of seven possible values (between 300 and 900 ms). In addition, the second stimulus could appear in the same retinotopic, spatiotopic, or “full” (both retinotopic and spatiotopic) region of space on the screen. While there were no observed effects of visuospatial memory type, participants were more susceptible to stimulus order effects in conditions in which they made a saccade, compared with in those that they did not. In these conditions, the test duration was overestimated by a significantly larger amount when the reference stimulus was presented second. Participants were also significantly less sensitive to differences in duration when the reference stimulus was second. These findings suggest that how stimuli are presented can influence the degree to which time-order errors bias duration perception.

9. Integration of Multiple Visual Inputs in the Blowfly

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The stabilization of gaze may involve multiple sensory systems. In blowflies, two visual pathways provide input to the gaze stabilization system: the high-resolution compound eyes and the simple dorsal ocelli.

Individually, the corresponding pathways involved cover different dynamic input ranges, incur different processing delays, and suffer from different levels of sensor and processing noise. Information from multiple sensory pathways must be integrated in order to effect appropriate movements of the head to stabilize gaze; however, it is not entirely clear how this happens.

Using high-speed videography, we investigated the combination of information from the two visual pathways at the behavioral output. We measured compensatory rotations of the head in response to a simulated roll rotation of a false-horizon around the fly, oscillating at up to 10 Hz. We found that the ocellar input reduces the response delay by an average of 5 ms but does not significantly affect the response gain or bandwidth. Our result suggests a nonlinear integration of compound eye and ocellar information.

We are now performing intracellular recordings from elements along the visuomotor pathway likely to be involved in the integration of motion vision and ocellar signals, in response to the same visual stimulus used to evoke head movements in our behavioral experiments. This will allow us to study how signals affected by different processing delays along the two visual pathways are combined to ultimately reduce the delay of the behavioral output.

10. A Mystery Regarding the Visual Gamma Response to Luminance Defined Square-Wave Gratings

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Neuronal oscillations in the gamma (30–100 Hz) frequency range are readily induced by visual stimulation, but their functional role remains uncertain. Square-wave gratings have been widely used to induce visual gamma in humans. We were interested to explore why these gratings are effective at generating gamma oscillations: Is gamma driven purely by the contrast energy of the stimuli or is the presence of sharp, high-contrast edges critically important?

Varying the duty cycle of square-wave gratings alters their energy while preserving the number and contrast of their edges, so as an initial test of this question, we presented 10 participants with gratings at five different duty cycles while measuring their gamma response using magnetoencephalography. We found a significant modulation of gamma amplitude with duty cycle, consistent with gamma being related to the contrast energy of the stimulus, but we also found a striking and unexpected asymmetry of the tuning curve: Gamma amplitude to values of duty cycle <50% was significantly greater than for corresponding values >50%.

As varying the duty cycle also causes mean luminance to vary (and thus creates a potential confound), we tested 10 further participants with stimuli in which mean luminance was matched across the five conditions by systematically varying the Michelson contrast of stimuli. To our surprise, rather than eliminating the asymmetry this manipulation reversed it! Given that the contrast energy of square-wave gratings decreases symmetrically as duty cycle increases or decreases away from 50%, these asymmetries are a mystery for which we have no explanation.
11. On the Origin and Modulation of Narrow-Band Gamma Oscillations in Mouse Primary Visual Cortex

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Broadband gamma oscillations (30–50 Hz) of neural activity in higher mammals have been widely implicated in cognitive functions such as visual attention and feature binding. These oscillations are also present in mouse primary visual cortex (V1). Interestingly, these broadband gamma oscillations co-occur along with a narrow band close to 60 Hz (Niell & Stryker, 2010, Neuron, 65(4), 472–479). While broad band gamma has been well-studied, here we investigate the origin and modulation of narrow-band gamma (NBG) oscillations. Based on recordings of local field potentials in awake mice, we found that the NBG required light and was absent in the dark. However, the peak-frequency of NBG was independent of the frequency of light stimulation. The synaptic basis of these oscillations was revealed in excitatory currents recorded using in-vivo whole-cell voltage clamp. The laminar profile of the NBG showed response modulation to be highest in Layer 4 of V1, the predominant recipient of lateral geniculate nucleus (LGN) inputs. Indeed, we found many neurons in the LGN that fired action potentials at the NBG frequency. NBG shows characteristics that are unlike those of broad-band gamma. While broad-band gamma increases with contrast of visual stimuli ($p = .04$, $n = 7$), NBG power decreased with contrast ($p < .01$). NBG was also correlated with the behavioral state of the animal: It was stronger during running or when the pupil was dilated. We conclude that NBG is a phenomenon in mouse V1 that is inherited from LGN inputs and reflects both the visual environment and behavioral state of the animal.

12. Dynamic Encoding of Motion and Form in Population Response of Primate Area Middle-Temporal

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Neurons in the middle-temporal area (MT) of primate cortex are important in the analysis of visual motion. It is generally thought that these neurons transform the signals of localized motion detectors into a representation of motion that is invariant to other image attributes, including contrast and contour orientation. Motion perception is, however, rarely invariant to these attributes. Here, we used electrode arrays to monitor the spiking activity of neural populations in area MT of anesthetized marmoset monkeys ($n = 5$), while presenting
sinusoidal gratings of varying orientation and spatial and temporal frequency. Applying new methods of multivariate classification analysis, we were able to estimate how well population activity encoded the direction, orientation, and spatiotemporal frequency of the drifting grating. We found profound dynamics in the population response, which systematically ordered the representation of image attributes. Early, within the first 100 ms, population response encodes contour orientation and spatiotemporal frequency. Attribute-invariant direction sensitivity emerges later. These dynamics appear to reflect presence of a largely transient, orientation-selective response that is most prominent at high-spatial frequency and low-temporal frequency. We conclude that invariant motion representations in area MT take time to develop and that population response in area MT can provide a representation of image attributes other than motion. We speculate that these dynamics reflect convergence of two visual pathways: an early, orientation selective pathway and a later, motion selective pathway.

13. Assessing Whether Contrast Sensitivity Remains Enhanced 1 Month After 40 h of Visual Training
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Historically, video game play has shown to have a significant improvement in the contrast sensitivity (CS) of individuals (Green & Bavelier, 2012, *Current Biology*, 22(6), 197–206). Yet, there have been no studies to date which indicate whether CS remains enhanced post training.

This study investigates whether CS remains enhanced 1 month after 40 h of turn-based strategy (TBS) and action video game play (AVGP).

A total of 11 participants played an action or TBS game for 40 h over 1 month. Visual function was assessed before and after training using a series of psychophysical experiments. These include spatial CS, temporal and peripheral CS for 20 Hz and 24 Hz. All tests used spatial frequencies of 0.5, 2, 10, and 20 cycles/deg. Seven participant controls did not undergo any visual training.

Game training indicated a significant improvement in CS after training in AVGPs and CVGPs in peripheral and temporal contrast sensitivity at 20 Hz and 24 Hz ($p = < .05$). Additionally, CS remained enhanced after training for only the AVGPs, 1 month after training. CS remained stable in the seven controls throughout the study.

The CS remained enhanced 1 month after training as action games contain a constant high velocity of object movement, high motor, perceptual and cognitive load, and high attentional capacity which are not generally present in daily tasks or in TBS games (Green & Bavelier, 2003, *Nature*, 423, 534–537).

14. Steady-State Responses to Uncomfortable Visual Stimuli
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Visual discomfort can consist of a variety of symptoms, for example, headache, eyestrain, and illusory motion such as shimmering are reported. Shimmering illusions are reported on
viewing op-art based stimuli, possibly due to the role of microsaccades (e.g., Troncoso et al., 2008, *PNAS*, 105(41); Zanker et al., 2010, *Journal of Vision*, 10(2), 1–14). However, eye movements are not the sole cause of visual discomfort from such periodic stimuli: Juricevic et al. (2010, *Perception*, 37(7), 1098–1013) argued that excessive neural responses might be another source of discomfort. There is some support for this assertion, as stimuli with lowest visually evoked potential (VEP) response magnitude were also those with lowest discomfort ratings (O’Hare et al., 2015, *PLoS ONE*, 10(9)). However, this support is incomplete as discomfort ratings did not map clearly onto VEP amplitude for stimuli of lower spatial frequencies tested. Therefore, the current study used steady-state VEP responses to quantify EEG response magnitude, as this method has some advantages over transient VEP waveforms (Norcia et al., 2015, *Journal of Vision*, 15(4); Vialette et al., 2010, *Progress in Neurobiology*, 90, 418–438). Results indicate that both eye movements and early cortical responses contribute to the subjective discomfort of these stimuli, the extent to which depends on flicker frequency.

15. Relationship Between Heterophoria and Accommodative Lag at Distances Closer Than 40 cm

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There is a bilateral cross link interaction between accommodation and vergence systems that cause changes in vergence when accommodation demand is altered and vice versa (Hung et al., 1980, *IEEE Transactions Biomedical Engineering*, 27, 439–447). Heterophoria varies depending on distance and it has been well documented (Chen et al., 2003, *Malaysian Journal of Medical Sciences*, 10, 90–94), though relationship between heterophoria and accommodation lag has been reported to a lesser extent (Momeni-Moghaddam et al., 2014, *Clinical and Experimental Optometry*, 97), mainly in children (Sreenivasan et al., 2012, *Vision Research*, 57, 9–17) or predicting theoretical models (Schor, 1999, *Ophthalmic and Physiological Optics*, 9, 134–150). The present study aims to look at interaction between heterophoria and accommodation lag across different near task distances (40 cm, 30 cm, and 24 cm) in young, binocularly normal, asymptomatic emmetrope adult subjects. Accommodation was measured by an open field infrared autorefractometer Shin Nippon SRW-5000. Comparing heterophoria at 40 cm and 24 cm, our results show that heterophoria changes in exo direction with closer distance. Mean phoria change was 1.18 ± 0.77 Δ (Wilcoxson p < .05) suggesting that average change in heterophoria for emmetrope group is around 0.7 Δ more exophoric per dioptry. Our results support coupled nature of accommodation and vergence system in following way: In order to maintain bifoveal fixation for larger near exophoria, there is an additional amount of convergence that is compensating the exophoria. At the same time, convergence is stimulating increase in accommodation that explains decrease in accommodation lag at binocular condition compared with monocular.
16. The Relationship Between Motion Processing and Position Updating

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To what extent is motion processing involved in position perception? There is some evidence to suggest that the visual system may employ motion information to extrapolate position representations of moving objects to compensate for neural delays. We used a continuous position monitoring paradigm to explore this. In Experiments 1 and 2, participants monitored a variable number of targets as they moved semirandomly among distractors. Immediately after the motion phase, observers reported the final position of one of the targets. Information about directions of object motion in the form of superimposed arrows (with either veridical information, no information, or biased information) had no effect on performance. In Experiments 3 and 4, observers monitored a variable number of targets in the absence of intermingled distractors and with variably veridical motion information provided by superimposed arrows. In addition to the position report single task, we also investigated performance under the dual task requirement of reporting the final direction of motion as well as final position of one of the targets. We replicate findings that increase in set size and cause a graded decline in precision for position reports and motion direction reports. The additional demands of monitoring motion directions did not disrupt position report accuracy. In fact, motion direction monitoring appears to facilitate precision of position reports for small set sizes ($N < 2$) especially when explicit motion direction information is absent. Since dual tasks are traditionally associated with performance costs rather than benefits, the results appear to indicate the involvement of motion processing in position updating.

17. The Perception of Biological Motion in Central Visual Field and Near Periphery

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Biological motion perception characterizes our sensitivity to the actions and intentions of other humans. The importance of recognizing these signals reflects in our ability to perceive a living human even if the object is represented by only 10 moving dots (Johansson, 1973). Current study examines the ability to detect biological motion in the central and peripheral visual field.

The perception of biological motion was compared in central and peripheral visual field. We used a similar experimental setting to the work by Ikeda et al. (2005) and Gurnsey et al. (2008; stimuli size and eccentricities) but slightly different stimulus structure (reduced amount of dots representing the object). Our results demonstrate that all participants reached the same threshold levels in both in $4^\circ$ eccentricity and in central visual field. In the case of further eccentricities ($8^\circ$ and $15^\circ$), the performance slightly deteriorated and only 62% of the
participants reached the same threshold level as in central visual field. Furthermore, the threshold sufficient for perceiving biological motion in central visual field ranged from three to four dots whereas in near periphery was three to six dots.

Most of the experiments analyzing the perception of biological motion use a walking human. However, everyday perception of other living beings includes variety of actions of different perceptual dynamics that might or might not be perceived equally fast. According to our preliminary results we argue that some actions (e.g., jumping) tend to be perceived faster than the others (e.g., mowing).

**Funding**

This study is supported by project no. 2013/0021/1DP/1.1.1.2.0/APIA/VIAA/001.

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**18. Color-Motion Binding and the Directional Limitations of Motion Transparency**

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The perception of two or more distinct moving surfaces at the same retinal location (motion transparency) represents a significant computational challenge for the brain. We explored the limitations of motion transparency using two superimposed random-dot fields that were defined by different directions of motion and color (red or green of equal luminance). In Experiment 1, we varied in fixed intervals the proportion of dots of one color that travelled in a single direction (the “color-motion coherence”) and measured ($n=4$) the threshold direction difference for discriminating between the two surface directions. In Experiment 2, we varied in fixed intervals the angular direction difference between the surfaces and measured ($n=4$) the threshold color-motion coherence needed to discriminate between them. When color-motion coherence was high (e.g., 90% of red dots moving in the same direction), we found a smaller direction difference was needed to correctly bind color with direction than at lower coherences. Color-motion coherence thresholds also tended to be lower with increasing direction differences, though they stabilized at differences of around $45^\circ$. Thresholds were also considerably higher at shorter (150 ms) compared with longer (1,000 ms) stimulus durations. The results suggest that while color is an effective cue in surface segregation, this may be underpinned by feature-based attention rather than by an early integration of color and motion information per se.

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**19. Discrimination of the Order of Point Patterns Depends on Presentation Parameters**

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Subjective assessments of order in the positional arrangement of points in point patterns are common in the analysis of evolving systems (e.g., developmental biology) and humans are particularly consistent even when diverse stimuli are considered (Protonotarios et al., 2014, *Journal of Royal Society Interface*, 11(99), 20140342). For jittered square lattices of dots, humans can distinguish up to 16.5 jnd levels of order between total disorder (Poisson) and perfect order (no jitter; Protonotarios et al., 2015, *Perception*, 44(4), 465–465). The number of jnds between the two extremes is a measure of the average discrimination performance for pattern pairs of similar order values. In this work, for the same class of patterns, we examine the effect of presentation parameters (dot size, dot number, and pattern area) on discrimination. Eight observers were presented twice in random order with pairs of 31 dot patterns and had to “select the one that appeared more ordered to them.” Ten experiments based on the same 2AFC task were conducted in total, each with different choice of presentation parameter values. Dot diameter ranged between 0.6 cm and 1.2 cm, dot number between 80 and 245, and the radius of the circular area of the pattern between 3.8 cm and 8.4 cm. We found that discrimination performance ranges between 12.9 jnd and 17.7 jnd, and we identified the aspect ratio (“dot diameter or average dot spacing”), as the primary parameter that controls it. An increase of 0.01 in aspect ratio results in 0.75 jnds increase in discrimination performance. Our finding has a practical application suggesting high aspect ratio for easier order discrimination between displayed dot patterns.

20. Sensorimotor Adaptation Explains Resistance of Grasping to Visual Illusions

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The most influential model of neural processing of visual information postulates the existence of independent visual systems for action and perception, respectively implemented in the dorsal and ventral visual streams of the human brain. According to this dual-streams theory, vision for action accurately computes the metric properties of objects, whereas vision for perception constructs conscious impressions of space that are subject to the occasionally distorting effects of context. To determine whether visuomotor encodings of object size and shape differ from conscious perceptual encodings of those properties, previous studies have tested whether grasping movements directed at objects embedded in visual illusions are affected to the same extent as perceptual reports of object size. In many studies, grasp control has been found to resist visual illusions, supporting the idea that visual processing for action computes accurate, metric spatial representations. However, other studies have reported comparable illusion effects on action and perception. To reconcile these findings, we show that repeated grasping of objects in a size-distorting illusion gradually produced accurate grip preshaping over 20 trials without reducing the illusion’s effect on conscious perception. In a follow up experiment, we show that when repeatedly grasping a single object within the same illusory context, the effect on grasping was remedied in a single trial. Our findings suggest that (a) the dorsal visuomotor areas may only be dedicated to integrate visual and haptic error signals to maintain appropriate calibration of the visuomotor system, without relying on metrically accurate visual processing and (b) perception and action share the same visual representation of object properties.
21. Detection of Chromatic and Luminance Distortions in Natural Scenes

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A number of previous studies have measured visual thresholds for detecting spatial distortions applied to images of natural scenes, for example, sinusoidal spatial modulations (Bex, 2010, *Journal of Vision, 10*(2), 23.1–23.15). Here, we consider the relative contribution of the chromatic and luminance layers of images of natural scenes for detection of sinusoidal scale distortions. We first report that when the distortion was applied to both luminance and chromatic layers of a scene, sensitivity did not depend on whether the undistorted comparison image, in a 2AFC task, was of the same or different scene. Next, we report the effects of individually distorting the chromatic or luminance layer. When the luminance layer was distorted, performance was the same irrespective of whether the chromatic layer was present, absent, or phase scrambled, revealing that the chromatic layer in whatever form did not affect sensitivity. However, when the chromatic layer was distorted, sensitivity was higher when the luminance layer was intact compared with when absent or phase-scrambled. Moreover, even when the chromatic layer was visibly distorted, it appeared to contribute little to the sense of distortion. We conclude (a) that observers have an in-built sense of how a normal image of a natural scene should appear, and (b) that both the appearance and detection of distortions is mediated predominantly by the luminance as opposed to chromatic layer of the image.

22. Enhancement of Hue Discrimination at Category Boundaries? The Case of Unique Red

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Is the discrimination of color enhanced at the category boundary between different hues, in the way that auditory discrimination is enhanced at the boundary between phonemes? In previous studies, we have given a positive answer for the case of the locus of unique blues and yellows, the boundary that divides color space into reddish and greenish hues. However, we did not find enhancement at the locus of unique green, the boundary between yellowish and bluish hues. In the present study, we examined discrimination near the locus of unique red and we show that the result depends on the direction in which the category boundary is traversed. In interleaved experimental runs, we measured chromatic discrimination using a four-alternative spatial forced choice and we measured the locus of unique red by phenomenological judgments. When the locus of unique red was traversed along −45° lines in a MacLeod-Boynton diagram, the locus of minimal thresholds coincided
approximated with the locus of the equilibrium hue; but this was not the case when the unique red locus was traversed in +45° direction. To account for the varying results found for this and other unique hues, we suppose that the neural channel that determines the discrimination threshold will sometimes coincide with the channel that determines the perceptual hue equilibrium, and sometimes will not. If a given point in chromaticity space is a unique hue, then it should remain a unique hue independently of the direction in which measurements are made; but discrimination thresholds almost certainly will depend on different underlying channels when measurements at made in different directions through the same point in chromaticity space.

23. Do We Need a New Determination of Complementary Wavelengths?

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Two monochromatic lights are “complementary” with respect to a particular white if, when additively mixed, they match that white. Complementary colors are often judged to be especially harmonious. Many handbooks of visual science give a standard table of pairs of wavelengths that are complementary with respect to the standard Illuminant D65. Curiously, however, there do not appear to have been any direct empirical determinations of complementary wavelengths for almost a century. The values tabulated in textbooks are derived by calculation from the CIE (1931) Observer.

The purpose of this presentation is to draw attention to the very different set of complementary wavelengths that are predicted by the physiological fundamentals recently introduced by Technical Committee 1-36 of the CIE. For wavelengths in the range 400 nm to 450 nm, the complementary wavelengths are similar to those predicted by the CIE (1931) Observer (or by the Judd Observer on which the Smith-Pokorny cone fundamentals are based.) But above 450 nm, complementsaries derived from the new Observer increasingly diverge from those derived from the 1931 Observer. For the new Observer, the complementary of 490 nm falls at 634 nm, whereas the value for the 1931 Observer is close to 600 nm. The wavelengths 491 nm to 493 nm have complementsaries for the 1931 Observer but no complementsaries for the new Observer.

A modern empirical determination of complementary wavelengths would be valuable. The largest technical difficulty would lie in the exact simulation of D65 (or other achromatic standard); but this difficulty could be side stepped by a transitivity test that used three sets of predicted complementsaries.

24. Population Receptive Field Mapping of Chromatic Channels

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Traditional population receptive field (pRF) mapping uses 100% contrast black and white checkerboard patterns to produce retinotopic maps and receptive field information from across the visual cortex (Dumoulin & Wandell, 2008, NeuroImage, 39(2), 647–660). These
pRF maps, therefore, reflect the spatial tuning of the neuronal populations responding to high-contrast achromatic stimuli. Chromatic pathways tend to be spatially low-pass compared with luminance pathways (Mullen, 1985, *The Journal of Physiology*, 359, 381–400; Schluppeck & Engel, 2002, *Journal of Vision*, 2, 480–492; Webster, De Valois, & Switkes, 1990, *Journal of the Optical Society of America A*, 7(6), 1034–1049); however, there are currently no reports of fMRI-based pRF techniques being applied to measure these innate resolution differences in human subjects. In this study, we used a modified version of Dumoulin and Wandell’s “drifting bars” stimulus to produce three pRF mapping conditions: L+M+S cone achromatic, L-M cone “red/green,” and S-cone isolating “yellow/blue.” Isoluminance was set by radiometric calibration of the scanner display system, followed by individual minimum motion settings for each subject (N = 6). In Experiment 1, the bars for each condition were 2.5° wide and contained a randomly updated (2 Hz) spatially pink noise (1/f) carrier. In Experiment 2, the bars were reduced to 0.5° and the pink noise was replaced with a white noise carrier. Overall, we found that pRF sizes were smaller for all conditions in Experiment 2. In both experiments, pRF size increased with eccentricity and with ascending hierarchy of visual areas. However, we did not observe any differences for the chromatic conditions in either experiment. We report the pRF properties obtained for each condition and discuss our findings in the context of pRF mapping stimulus design.