MEETING REPORTS

Fall Vision Meeting, October 24–27, 2002

The Fall Vision Meeting was held in October, 2002, at the Palace of Fine Arts, San Francisco, California, in cooperation with the Optical Society of America. The Palace was originally built as a temporary home for the Panama-Pacific International Exposition in 1915, but thanks to concerted conservation efforts, it survives today as home to the Exploratorium—a "hands-on" science museum launched by Frank Oppenheimer to promote the public understanding of science. On the evening of October 24th, vision scientists gathered at the SEEING collection to exercise their minds with exhibits on perception and attention. Alongside a set of 40 new exhibits designed by staff neuroscientist Richard Brown and his colleagues, were old favorites like Ames Room and a Land and McCann 2-colour projection display.

Reminded of the mystery and wonder of seeing, conference delegates entered into three days of stimulating scientific discussion. The scope of the meeting was very broad, including symposia on spatial vision, colour vision, virtual reality and clinical work. This report is limited to issues of colour processing, and is divided into three central topics: cone mechanisms; colour and the natural environment; and colour contribution to central visual mechanisms.

CONE MECHANISMS

Conventional wisdom holds that when the eye is focused for mid-spectral light, longitudinal chromatic aberration blurs short-wavelength light so much that it can contribute little to spatial vision. This assumption has been used to explain both the presence of macular pigment, and the sparse mosaic of S-cones in the retina. James McLellan pointed out that such explanations have ignored the effect of monochromatic wave aberrations present in real eyes. He presented data to show that when the effects of all aberrations are taken into account, short wavelengths are not as blurred as previously thought. The potential image quality for S-cones is comparable to that for the M- and L-cones, and macular pigment has no significant function in improving the retinal image.

Keizo Shinomori and John Werner presented data on the temporal impulse response function (IRF) of the S-cone pathway. They found that, in contrast to the luminous IRF which is diphasic and has an excitatory phase of ~40–60 msec, S-cone IRFs have only an excitatory phase with a duration of ~200 msec.

New data on S-OFF ganglion cells[1] reveal anatomical and physiological differences between ON and OFF S-cone pathways. There have been several recent studies suggesting that S-ON and S-OFF pathways may have different contributions from L- and M-cones. This would be an interesting finding. The L and M pigment genes are highly homologous and as yet no one has identified an extracellular label that could be used to achieve L and M cone-specific connections with postreceptoral cells. Two papers presented at the meeting addressed this issue. Rhea Eskew, Quanhong Wang and Franco Giulianini used dynamic L-cone and M-cone noise masks and found asymmetries for S-cone increment and decrement detection; Hannah Smithson and Joel Pokorny used a chromatic adaptation paradigm and did not find asymmetries for rapid-on and rapid-off S-cone ramps. These accounts might be reconciled in future research by considering the way in which ON- and OFF-pathways can be isolated psychophysically, and by disentangling the L and M contribution to dynamic gain control mechanisms.

It is believed that there is a substantial variation in the relative number of L- and M-cones in the retina, even within the colour normal population, and that L:M ratio influences psychophysical measures of spectral sensitivity (i.e. inferred L+M mechanisms). Karen Dobkins and Karen Gunther have also found a significant relationship between L:M ratio and chromatic contrast sensitivity (i.e. inferred L-M mechanisms). Subjects possessing the most symmetrical L:M ratios appear to possess the relatively greatest contrast sensitivity. Dobkins and Gunther account for this relationship by a simple model based on the notion of random L- and M-cone inputs to the center and surround receptive fields of chromatic mechanisms.

Studies of lateral colour effects were well represented in the meeting. Chien-Chung Chen and Christopher Tyler measured interactions between chromatic and luminance stimuli in a lateral masking paradigm and compared their data to previous measurements from a pedestal paradigm. Opposite patterns of interaction in the two paradigms suggest different underlying mechanisms. However the interpretation of their results might be complicated since observers did not make individual settings of subjective luminance. Demonstrations of chromatic assimilation are often treated with suspicion since the effects are qualitatively similar to those expected from physical colour mixing of spread light. Steven Shevell and Dingcai Cao presented compelling evidence from a temporal nulling paradigm that perceptual colour assimilation exists quite apart from the physical spreading of light. Patrick Monnier and Steven Shevell presented measurements of colour appearance as a function of the chromatic modulation of a background of concentric rings surrounding a test ring. They found that S-opponent colour shifts are modulated by L/M-opponent contrast within the background. It seems that the gain of the S-opponent system is regulated by L/M-contrast within a surrounding area.

COLOUR AND THE NATURAL ENVIRONMENT

The number of possible visual stimuli is vast, yet some of these possible stimuli are more probable, and some are more interesting, than others. It is likely that the visual brain has evolved to analyze only relevant regions of stimulus space, but can we quantify this functional specialization? Donald MacLeod asked whether our ability to discriminate regions in colour space was constrained by the functional requirement to optimize discrimination among colours in the natural environment. Psychophysical contrast sensitivity proves to be close to optimal, but comparison to physiological data shows less satisfactory agreement. Magnocellular (MC) cells have a much stronger than expected saturating nonlinearity, which supports the view that the function of MC cells is mainly to detect boundaries rather than to specify contrast or lightness. Parvocellular (PC) cells on the other hand are too linear for optimal representation of colour. It is an empirical finding that, for natural surfaces under natural illuminants, a change in illumination will scale the cone excitations by approximately the same factor for all surfaces in an image. It is possible therefore to discount the illuminant by independent multiplicative scaling of each of the three cone signals. However, while this manipulation achieves colour constancy in the sense that it transforms to an illumination-independent representation, it fails to preserve information about the overall chromatic cast of a scene. MacLeod points out that second-order statistics of the distribution of an image's elements in cone excitation space can in principle resolve the ambiguity inherent in the mean alone. He finishes with experimental evidence that human performance in a colour constancy task matches that of a Bayesian observer. Our visual systems can exploit second-order scene statistics, and give them statistically justifiable weight. Barry Lee adopted an information processing approach to quantifying the functional roles of retinal ganglion cell classes. He recorded the temporal and chromatic variation encountered on a tour of two different natural environments and then recorded ganglion cell responses to these stimuli. By comparing coherence rate measured in bits per second (either obtained from a measure of the variability of cell response across repeated stimulus presentations, or by comparison to cell models) Lee has been able to determine how information in luminance and spectral aspects of the stimuli is distributed amongst the different classes of ganglion cells. Serguei Endrikhovski presented a model of colour categorization based on the assumption that colour categories originate from the statistical structure of the perceived colour environment. Clustering analysis of statistics of natural images in the CIELUV colour space produces predictions of the location, rank, and number of colour categories that are consistent with data from psycholinguistic studies (for example, that discussed by Paul Kay later in the meeting).

The phenomenological purity of red, green, yellow and blue remains one of the unexplained mysteries of human colour vision: subjects find it easy to judge these unique hues, but the reason for their special status is not apparent in psychophysical or electrophysiological data. Yoko Mizokami, John Werner, Michael Crognale, and Michael Webster asked to what extent are the unique hues tied to properties of the environment versus properties of observers. They measured individual differences in unique hues as a function of spectral bandwidth to test whether they can be accounted for by normalization to a common stimulus in the environment or by a common weighting of the cone signals[2]. The changes with bandwidth did not support either model, suggesting that the interobserver differences cannot be explained by differences in visual sensitivity (early in the visual system) alone. On the other hand, for individual observers, the differences in unique green between foveal and peripheral viewing are qualitatively consistent with normalization to a common broadband stimulus. Peter Delahunt, Michael Webster, Lei Ma, and John Werner measured achromatic settings before and after cataract surgery. The increase of light at lower visible wavelengths reaching the retina results in a shift in colour appearance, but over a period of several months the visual system adapts to compensate for this change and achromatic settings return to the original value. The observation of a long-term chromatic adaptation mechanism lends weight to the argument that our colour vision mechanisms are constrained by the global properties of the world in which they find themselves.

HOW DOES COLOUR PROCESSING INTERACT WITH OTHER VISUAL FUNCTIONS?

Before an object can be recognized we must decide which parts of the visual array belong together. Ione Fine, Donald MacLeod, and Geoffrey Boynton have developed a Bayesian model that uses colour and luminance statistics to decide whether or not two points within an image fall on the same surface. Their model assumes that the distribution of the luminance and colour of pixels drawn from the same surface has a small variance, whereas the distribution of pixels drawn for different surfaces has a large variance. For a set of images of natural scenes, and a set of novel images of natural and man-made environments, the performance of their model matched the segmentations made by observers. The generalization of the results to novel scenes is consistent with the notion that observers may use a fixed set of priors as a basis for image segmentation across different environments. This work echoes the importance of considering the way in which the properties of the world have shaped our visual processing. Michael D'Zmura discussed a segmentation problem with another layer of complexity. How do we perceive the colours of both transparent filters and the surfaces behind them? D'Zmura summarized evidence to suggest that a region will appear transparent whenever colours of surfaces in that region converge in colour space. He argued that segmentation mechanisms must integrate local colour changes from different spatial locations and that the perception of colour results in a filling-in process that coordinates between layers. He highlighted the late processing of colour scission and the possible role of attention. Allen Nagy has looked explicitly at whether attentional mechansims used in visual search can combine information from cardinal colour mechanisms. His results suggest that even if signals within a cardinal mechanism cannot be used to discriminate the target from possible distractors, they can be used to select a subset of possible target stimuli for attention.

John Krauskopf and Jason Forte have investigated whether there are independent mechanisms that mediate stereo judgments for stimuli modulated in chromaticity and for stimuli modulated in luminance. Krauskopf presented data from a mixture experiment. Thresholds were higher when chromatic stereo information was added to luminance stimuli, a result that contradicts the independent mechanism hypothesis. Karl Gegenfurtner presented data from a series of experiments designed to investigate how well colour signals can be used to control eye and hand movements. Overall, the only difference he finds between colour and luminance in motor control is a 10 msec latency difference that seems to be due to an early stage of sensory processing.

The Fall Vision Meeting was organized by Christopher Tyler, with support from Smith-Kettlewell Eye Research Institute and the School of Optometry, University of California, Berkeley.

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Published online in Wiley InterScience (www.interscience.wiley.com). DOI 10.1002/col.10188