Fall Vision Meeting 2019
Schedule and Short Abstracts

Thursday, 19 September
15:30 – 16:00  Registration
16:00 – 18:00  Tillyer Award Presentation Lecture and Welcome Reception
Sponsored by the OSA Clinical Vision Science Technical Group
Pablo Artal, Univ. of Murcia, Spain

Friday, 20 September
08:00 – 08:45  Registration and Breakfast
08:45 – 09:00  Welcoming Remarks
09:00 – 11:00  Invited Session I: Understanding Color
Moderator: Hannah Smithson
Speakers:
  Ken Knoblauch, INSERM, France
  Del Lindsey, Ohio State University, USA
  Bevil Conway, NIH, USA
  Maria Olkkonen, Durham University, UK
11:00 – 11:30  Coffee Break
11:30 – 13:00  Contributed Session I: Color and Material
Moderator: Manuel Spitschan
Speakers:
  Taveras Cruz, Yesenia  Using 5-Cone signals to detect the effects of longitudinal chromatic aberration
  Nunez, Valerie  Double-opponent cells in Parvocellular and Koniocellular pathways contribute to the perception of color in color patterns
  Koshizaka, Wakana  The reversal of motion aftereffects on speed perception on color- and luminance-defined motion tested with various temporal frequency
  Morimoto, Takuma  Breaking illuminant metamerism using directional spectral variation in natural environments: dichromats might benefit more than trichromats
  Harvey, Joshua  Modelling metallicity: from low-level visual features to robust material perception
13:00 – 14:30  Lunch
14:30 – 16:00  Poster Session I & Coffee Break
16:00 – 18:00  **Invited Session II: Non-visual Effects of Light in Development and Disease**  
*Moderator:* Geoff Aguirre and Manuel Spitschan  
*Speakers:*  
Shadab A. Rahman, *Brigham and Women’s Hospital, USA*  
Anna Matynia, *University of California, Los Angeles, USA*  
Timothy Gawne, *The University of Alabama at Birmingham, USA*  
Michael Terman, *Columbia University, USA*

**Saturday, 21 September**

08:00 – 08:30  Registration and Breakfast  
08:30 – 10:30  **Invited Session III: Biological Development of the Visual System**  
*Moderator:* Angela Brown  
*Speakers:*  
Robert Johnston, *Johns Hopkins University, USA*  
Jordan Renna, *University of Akron, USA*  
Jesse Gomez, *UC Berkeley, USA*  
Anna Majewska, *University of Rochester, USA*

10:30 – 11:00  Business Meeting  
11:00 – 12:30  **Poster Session II** and Coffee Break  
12:30 – 13:30  Lunch  
13:30 – 15:00  **Contributed Session II: Retina**  
*Moderator:* William Tuten  
*Speakers:*  
Godat, Tyler  
Joseph, Aby  
Warner, Raymond  
McAdams, Harrison  
Sadeghi, Roksana  

15:00 – 15:30  Coffee Break
Fall Vision Meeting 2019
Schedule and Short Abstracts

15:30 – 17:30 Invited Session IV: Perceptual Learning and Video Games – New Ways to Learn

Moderator: Duje Tadin
Speakers:
- Ben Backus, Vivid Vision, Inc., USA
- C. Shawn Green, University of Wisconsin, USA
- Aaron Seitz, University of California Riverside, USA
- Krista Kelly, Retina Foundation of the Southwest, USA

18:45 – 20:00 Banquet at La Tomate Bistro, 1701 Connecticut Avenue, N.W. Washington, DC 20009

Sunday, 22 September

08:00 – 08:30 Registration and Breakfast

08:30 – 10:30 Invited Session V: Aberrations and Vision – The Limits of Visual Performance Studied with Adaptive Optics

Moderator: Jesse Schallek
Speakers:
- Susana Marcos, Instituto de Optica, CSIC, Spain
- Geunyoung Yoon, University of Rochester, USA
- William Tuten, UC Berkeley, USA
- Hannah Smithson, Oxford University, UK

10:30 – 11:00 Coffee Break

11:00 – 12:30 Contributed Session III: Training and Psychophysics

Moderator: Matthew Cavanaugh
Speakers:
- Kwon, Sunwoo: Dissociation between perception and predictive oculomotor behavior in retrained cortically blind fields
- Saionz, Elizabeth: Use it before you lose it: greater efficacy of visual training for recovering contrast sensitivity in subacute cortical blindness
- Billock, Vincent: Audiovisual Enhanced Sensitivity: Both Psychophysical and Neural Data Follow the Same Combination Rule
- Fahrenthold, Berkeley: Effect of Visual Training on Optic Tract Degeneration after V1 Lesions
- Esquenazi, Rebecca: Learning to see again: Perceptual learning for sight restoration technologies

12:30 – 13:00 Young Investigator Award and Closing Remarks
My life in Visual Optics: from the lab to the real world

Pablo Artal, Univ. of Murcia, Spain

In this lecture, I will present some of the problems I wanted to solve during my career in Visual Optics. I was interested in a better understand of the optical properties of the human eye. This is a very simple optical system, but extraordinarily well adapted to the special requirements of our visual system. A better understanding of the optical physics properties of the eye allows to develop new technologies to improve vision in many people. This is related to another of my career's interests: to transfer the research results to practical solutions useful for the patients. In this context, I will revise the main optical properties of the eye and different experiments we developed during the last decades in my laboratory. In particular, some of them based in the use of adaptive optics to manipulate light wavefronts in the eye to correct aberrations and scatter. I will also present several recent results ranging from the nature of the lens movements, the development of new types of intraocular lenses to new opto-electronic instruments for the correction of cataracts and presbyopia.
To test infant chromatic discrimination, researchers have used diverse means, of varying effectiveness to control luminance artifacts that would invalidate such demonstrations. In an elegant analysis of several studies using a range of protocols and methods for stimulus control, Brown and Lindsey (Vis. Neurosci.2013) found that infant responses could be explained solely on the basis of chromatic differences, as if, in effect, they ignored luminance differences. Given infant contrast luminance sensitivity, it seems unlikely that luminance would not influence performance. We examined this issue by testing how infants integrate chroma and lightness differences using Maximum Likelihood Conjoint Measurement (Knoblauch and Maloney, 2012). Twenty-one 6 month olds were tested using a set of stimuli in which chroma and lightness covaried independently, with 3 levels defined along each dimension. All 36 pairings of stimuli were randomly presented, with the the direction of the first eye-movement used as a measure of preference or choice of which stimulus was more salient. About one quarter of the infants completed 2 sets of presentations (72 trials). All infant data were analyzed, however, within a mixed-effects model. Results were compared with adult data in which observers were instructed specifically to judge chroma or lightness and adult data based on first eye movement to most salient stimulus. In brief, infants preferred stimuli of higher chroma but higher lightness reduced preference, indicating a veiling effect qualitatively similar to adult chroma judgments. Thus, infant preferences integrate chroma and lightness similarly to how adults judge chroma differences.
Lexical and non-lexical color categorization and the universality of color understanding

Delwin T. Lindsey, Ohio State University

Color lexicons vary greatly in the numbers of color terms they contain, yet there are striking regularities in how people around the world name colors. This has suggested to many investigators that there is a universal mental representation of color that guides lexical color category formation in every world language. To examine this idea, we have studied the cross-cultural aspects of color naming by comparing responses of English- and Somali-speaking observers in two experiments.

In the first experiment — *color decomposition* — observers named, in their own language, the elemental Hering sensations present in the color appearance of each color sample, but did not rate their proportions. We used those data to look for possible links between an observer’s color lexicon and Hering’s color-opponent representation of color (Kay & McDaniel 1976).

In our second experiment — *sequential n-sort* — observers sorted palettes of color samples into \( n=2, 3, \ldots, N \) “piles” of colors, without requiring that observers name the categories defining their piles. We examined Boster’s (1986) hypothesis that sequential color sorting reveals a universal non-lexical hierarchical representation of color that guides color lexicon evolution.

The color decomposition and color sorting results reveal cross-cultural similarities in the mental representations of color in our two groups of observers, but also striking differences. I will show how these results challenge both the “perceptual landmarks” and the alternative “efficient communication” approaches to understanding color lexicon formation.
The geometry of color space uncovered by magnetoencephalography (MEG)

Isabelle Rosenthal\textsuperscript{1*}, Katherine Hermann\textsuperscript{1,**}, Shridhar Singh\textsuperscript{1}, Dimitrios Pantazis\textsuperscript{2}, Bevil R. Conway\textsuperscript{1,3,#}

1. National Eye Institute
2. Massachusetts Institute of Technology
3. National Institute of Mental Health
*present address: California Institute of Technology
**present address: Stanford University

Arranging samples according to color seems natural—this task is even used as a clinical test of brain function (Farnsworth-Munsell 100 Hue Test). Yet the neural basis that governs color relationships remains elusive. Color is often described by three orthogonal parameters (hue, value, chroma), but this organization is not uniform: the distance between any two colors does not predict the relationship between another pair of colors separated by the same distance. There is no consensus on a space that captures uniform perceptual relationships, and spaces that try to do so empirically, such as Munsell, have an asymmetric organization that is not formally defined in terms of photoreceptor responses. Here we tackle color geometry with a new approach. Using magnetoencephalography (MEG), we measured brain responses to colored spirals defined by the intermediate directions in cone-opponent color space, at two luminance levels (eight colors total). Color could be decoded very accurately from neural activity patterns; hue and luminance could be decoded independently. Using classifiers trained on these patterns, we determined similarity relationships among the colors. We discovered two hue-luminance interactions that reflect nonlinearities in the neural representation of color space: an asymmetry in the representation of the daylight-axis (blue, orange) versus anti-daylight-axis (green, pink); and an asymmetry in the representation of warm (pink, yellow) versus cool (blue, green) colors. Taken together, the results uncover cortical transformations of retinal color signals that give rise to color relationships and show why color cannot be represented in a perceptually uniform (linear) color space.
Learning and memory in color perception

Maria Olkkonen, Durham University, UK

We often have the experience of perceiving the colors and materials of objects in our environment effortlessly. But estimating the surface properties of objects is in fact a computationally hard problem for the visual system, because the light signal that reaches our eyes from surfaces in our environment depends not only on the reflectance of the surface, but also on the illumination impinging on the surface. Statistical regularities about surfaces and illuminants, learned through interacting with our environment and through social communication, may contribute to our ability to compensate for changes in illumination when estimating object color. These statistical regularities may be learned at different timescales from species evolution to individual development to something akin to temporary adaptation. For instance, the typical colors of objects, as well as color categories -- both learned through experience -- may anchor color perception under illumination changes. More short-term learning may also stabilize color perception under more abrupt changes in the environment. In this talk, I will present research on the influence of long-term and short-term color knowledge on color appearance, and link this with color constancy in a probabilistic estimation framework. I will end by discussing ongoing research to push the study of color constancy to more realistic scenes and tasks.
Using S-Cone signals to detect the effects of longitudinal chromatic aberration

Yesenia Taveras Cruz, Jingyi He, Rhea T. Eskew, Jr.

Longitudinal chromatic aberration (LCA) introduces blur into the retinal image, especially at short wavelengths. LCA is nearly identical in different individuals (Atchison & Smith, 2000). However, psychophysical sensitivity to the effects of LCA may vary across people, since this sensitivity is likely to depend upon multiple factors (e.g., sampling by the retinal mosaic). This study explores a possible psychophysical method to measure sensitivity to the effects of LCA in different individuals. Contrast sensitivity functions (CSFs) were measured in three conditions: (a) achromatic (luminance) detection, (b) S-cone detection (S-cone mediated contrast sensitivity), and (c) S-cone hue judgment (S-cone mediated color perception). Stimuli were flickering Gabor patches, either white/black in task (a), or S-cone isolating purple/yellow-green, in (b) and (c). CSFs from (b) can be analyzed into two components. At low spatial frequencies (SFs), patches appeared colorful and the CSF shape matched the shape of the hue CSF (task c). At higher SFs, patches no longer appeared colorful and the shape was similar to the achromatic detection CSF (a), likely representing a response to a luminance artifact caused by LCA. Using probability summation to combine the estimated sensitivities of the S-cone hue judgment and achromatic detection produced curves that matched the measured S-cone detection sensitivities. The relationship between S-cone contrast detection, S-cone color perception, and achromatic contrast detection may represent a way to measure and model signatures of the effects of LCA.

Double-opponent cells in Parvocellular and Koniocellular pathways contribute to the perception of color in color patterns

Valerie Nunez, James Gordon, Chloe Brittenham, Ryan McNeil, Vera Pertsovskaya, Yanli Yin & Robert Shapley

Previous experiments indicated that edge-dependent, double-opponent neurons are involved in the color perception of patterns (Nunez et al., 2017). These earlier experiments measured perceptual scaling of color saturation by human observers, for equiluminant red squares on a gray background and also red-gray checkerboards of the same size and space-averaged cone contrast. While the red patterns evoked responses primarily from the Parvocellular system, we wanted to determine whether or not double-opponent neurons driven by signals from the parallel Koniocellular pathway are also involved in color-pattern perception. Therefore, we modified our ratings experiments, (pattern-onset, square-wave modulated checkerboards [0.5s on, off until a rating is recorded]), with color contrasts varying along the L-M and S-cone-isolating directions in color space for N=7 observers. Perceived color saturation increased with cone contrast for both stimulus patterns and for both color directions. For both color directions, checkerboard stimuli consistently produced larger color saturation than color squares of the same space-averaged cone contrast. Because V1 is a bottleneck for color perception, we must consider the only two classes of color-responsive neurons in V1: single- and double-opponent neurons. The spatially integrative responses of single-opponent neurons would have produced the same saturation for checkerboards and color squares matched for space-averaged cone contrast. The larger saturation of checkerboards must have been caused by the contribution from a neural mechanism that responded to the checks themselves, namely, double-opponent cells. Therefore, we conclude that double-opponent neurons are involved in the perception of color in color patterns for both the Parvocellular and Koniocellular systems.


This research was supported by grant PAC-1555773 from the National Science Foundation.
Interactions between color-defined motion (CM) and luminance-defined motion (LM) has been investigated in several psychophysical studies. In an fMRI study, we found a peculiar motion aftereffect (MAE) when adapted to long (12s) CM and tested with LM; response to motion in same direction as adaptation exhibited higher amplitude of response. In contrast, ordinary MAE was found when the adapting duration was 3s. To further investigate this phenomenon, we conducted a psychophysical experiment with a similar stimulus set up. After adapting to a rotational motion at 4 Hz for 10s, a pair of sectors of radial motion was presented as test stimulus on left and right side of the fixation point. Both test stimuli moved in the same direction (upward or downward), and the subjects reported which test stimulus appeared faster. The temporal frequency (TF) of the test stimulus was 2 Hz, 4 Hz, or 6 Hz. While 2 Hz test exhibited ordinary MAE (i.e., adapted-direction test appeared slower) subjects reported the opposite for 4 or 6 Hz test, for both CM and LM stimuli. Such reversal of MAE may reflect the property of motion mechanisms for CM and LM, sensitive to lower (<2 Hz) and higher (<4 or 6 Hz) TF, respectively. The MAE in fMRI with short (3 s) and long (12 s) adaptation may reflect the characteristics of LM and CM adaptation, respectively. Therefore, the reversal of MAE in fMRI may be reflecting the interactions of LM and CM mechanisms at high TF.


This study was supported by JSPS KAKENHI No.JP 18H04995 to IK.
Breaking illuminant metamerism using directional spectral variation in natural environments: dichromats might benefit more than trichromats

Takuma Morimoto\(^1\), João M.M. Linhares\(^2\), Sérgio M.C. Nascimento\(^2\), Hannah E. Smithson\(^1\)

\(^1\) Department of Experimental Psychology, University of Oxford, UK
\(^2\) Center of Physics, University of Minho, Campus de Gualtar, Portugal

Illuminant metamerism, where two surfaces appear the same under one illuminant but different under another, has been thought to limit object identification by colour, especially for dichromats, who possess only two classes of cones. The frequency of metamerism has typically been evaluated using surfaces placed under single-spectrum illumination. However, we recently showed that there is a striking directional variation of illuminant spectra in natural lighting environments\(^1\), meaning that a surface will sample different spectra depending on its angle within the environment. Therefore, observers might be able to disambiguate some metamer pairs simply by tilting the surface. We simulated a tiltable matte planar surface using computer-graphics rendering techniques and analyzed the frequency of metamer pairs drawn from a standard object colour spectra database of 53,486 reflectances (SOCS). The results suggest that trichromats can break 33.4% (average across 12 scenes) of metamers simply by tilting the surface. Dichromats can break a similar proportion (deutan: 34.4%, protan: 36.0%, tritan: 30.4%). After removing very similar spectra from the sample (correlation coefficient \(\geq 0.99\)), trichromats can break 50.6% of metamer pairs. Tritans can break a similar proportion (55.3%) while protans and deutans can break significantly more (56.5% and 58.1%, respectively). Several studies have reported that illuminant metamerism is relatively rare. Here, using newly available measures of the spectral variation in natural lighting environments, we suggest that roughly half these metamers can be disambiguated. In addition, under these conditions, protan and deutan object identification by colour is relatively less impaired compared to the trichromatic case.


This study was supported by a Study Visit grant from the Experimental Psychology Society, UK, awarded to TM and by the Portuguese Foundation for Science and Technology (FCT) in the framework of the Strategic Funding UID/FIS/04650/2019 awarded to SN.
Modelling metallicity: from low-level visual features to robust material perception

Joshua S. Harvey, Hannah E. Smithson

The human visual system did not evolve in an ecosystem of metallic stimuli, nonetheless, we are highly accurate in our assessment of metal objects from vision alone. To evaluate the predictive power of local image statistics for observer metallicity judgement, we used computer-generated natural images—natural in the sense that they were rendered using physically-based models of plausible materials and environmental illumination. Low-level image statistics were manipulated indirectly by varying the rendering parameters of metal roughness, which blurs the reflected environment image, and the irregularity of a transparent coating, which effectively introduces a local disarray vector field. In a conjoint measurement task, both metal roughness and coating bumpiness were found to determine observer estimates of metallicity, combining in either additive or multiplicative ways for individuals. Fourier and steerable pyramid analyses show that both physical parameters of the stimulus space have predictable effects on image statistics across different object viewing angles, most notably on local statistics not represented in the Fourier power spectrum. Decision-making models using the activations of oriented filters at two levels of the steerable pyramid (with just two free parameters) replicated observer data for suprathreshold scaling of metal roughness and coating bumpiness, and could also accommodate individual differences in estimations of metallicity. We conclude that low-level, local image statistics, as represented in steerable pyramid analysis, can be used to achieve robust material perception, with individual differences accounted for by differently weighted combinations.
Nonvisual effects of light in development and disease

Shadab A. Rahman¹,², Ph.D., M.P.H.¹,²Division of Sleep and Circadian Disorders, Departments of Medicine and Neurology, Brigham and Women’s Hospital, Boston, MA.¹,²Division of Sleep Medicine, Harvard Medical School, Boston, MA

Electromagnetic radiation in the visible spectrum induces a broad range of physiologic responses beyond image formation. With the advent of electrical lighting, the distinction between night and day is less dependent on the daily solar cycle, and this has introduced the problem of eliciting physiological responses by light exposure at biologically adverse times. For example, light exposure in the evening suppresses the hormone melatonin and can disrupt sleep. Such light-exposure induced physiologic responses in turn can have adverse health consequences ranging from depression to diabetes. Ongoing studies over the past three decades have identified novel receptors and neural pathways that mediate non-image forming (NIF) responses to light exposure, which are unique from those that mediate image forming responses. While various studies confirm that these responses all start at the retina and typically share a monotonic relationship, a common theme emerging from ongoing research is that there is considerable divergence at the level of the stimulus-response mechanisms, signal transduction pathways, and response characteristics. Moreover, each of these components are differentially modulated based on the characteristics of the photic stimulus including intensity, duration, pattern, and spectrum. While metrics and models that quantify and predict these responses, respectively, are warranted both for research and application purposes, the marked divergence between these responses raises the challenge of using surrogate measures that may be less resource intensive to collect. The session will briefly review the divergence in NIF responses to light exposure, current research and application challenges and future directions.
A Union of Light and Pain Pathways in Photophobia, in Sickness and in Health

Anna Matynia, Associate Researcher Ophthalmologist, Director of Basic Research, Laboratory of Ocular Molecular and Cellular Biology and Genetics, Jules Stein Eye Institute, UCLA, DSERC Rm 3-128, 310-825-7519, matynia@jsei.ucla.edu

Background: Photoallodynia, a painful response to light, is a common symptom of migraine and corneal damage or inflammation. Melanopsin, best-known as the photopigment expressed in intrinsically photosensitive retinal ganglion cells (ipRGCs) at the heart of non-image forming vision, also plays an important role in light aversion, a surrogate for photoallodynia. These studies investigate the interaction between light and pain pathways using light aversion in mouse models of disease or injury.

Methods: We used mouse models of corneal injury and migraine to evaluate light aversion behavior. Genetic mouse strains, surgical lesions and pharmacological conditions were employed to dissect relative contributions of image based vision (rod and cone photoreceptors) and non-image based light perception (melanopsin-containing neurons), and investigate melanopsin expression in the trigeminal system. Von frey fibers were used to assess corneal sensitivity.

Results: Light aversion in pathophysiological states can be dissociated from optic nerve light transmission (encompassing rods, cones and ipRGCs) after optic nerve crush or transection, indicating the existence of non-ocular light detecting pathways. We have demonstrated the expression of melanopsin outside of the retina, in small and medium-sized trigeminal ganglion neurons (mTGs), and have shown that these cells are capable of light-regulated excitation. Loss of all melanopsin-expressing neurons (ipRGCs and mTGs) reduces both innate and corneal surface damage-induced light aversion but migraine-related light aversion persists through rod and cone pathways. Loss of mTGs also reduces corneal touch sensitivity, indicating a direct role for mTGs in the cornea.

Conclusions: The neural pathways contributing to light aversion are dependent on disease and its etiology. In healthy conditions, the retina and optic nerve are the predominant mediators of light aversion. By contrast, multiple pathways for light aversion are recruited in pathological states. The same trigeminal ganglion neurons that mediate pain responses to chemical and mechanical stimuli may also respond to light in order to “turn up the gain” for light-induced behaviors. These sensitized pathways may help limit exposure to potentially damaging light, or direct an animal to hide from predators during recovery from sickness or injury.
The Spectral Drive Hypothesis of Emmetropization

Timothy J. Gawne
Associate Professor, University of Alabama at Birmingham (UAB) Dept. Optometry and Vision Sciences, 1716 University Blvd. HPB 528, Birmingham AL. 35294. tgawne@uab.edu, tgawne@gmail.com. 205-934-5495 (phone)

It is now well established that the post-natal developing eye uses optical cues to regulate its axial growth to achieve good focus, a process termed emmetropization. However, the visual cues that the eye uses have remained unclear. Here we present evidence that the primary visual cue is the sensing of different image statistics by the short-wavelength sensitive (SWS) and long-wavelength sensitive (LWS) cone photoreceptors, caused by longitudinal chromatic aberration. We use as a model system the tree shrew Tupaia glis belangeria, small diurnal dichromatic mammals closely related to primates. We develop an optical model for how the SWS and LWS photoreceptors represent an image at different levels of defocus and under different spectral lighting conditions. The model produces two values: a target, a point at which the image statistics of the SWS and LWS photoreceptors are in balance, and a drive, an imbalance in SWS and LWS image statistics which serves to direct eye growth towards the target in a sign-dependent manner. The model makes specific predictions for emmetropization under different spectral lighting conditions, which have been tested in juvenile tree shrews. Critically, while the purpose of emmetropization is to achieve good focus, it is not actually guided by focus, and it can ignore defocus cues if the spectral drive is artificially manipulated. The results may have implications for developing optical treatments to help reduce the growing world-wide burden of human myopia.

Supported by NEI R21 EY025254 and NEI RO1 028578, and P30EY003909 (Core). The author acknowledges useful discussions with Dr. Thomas Norton, Dr. Rafael Grytz, and Dr. Tamara Oechslin, and the technical assistance of Russell Veale, Johanna Henry, and Eric Worthington.
Psychiatric Treatment by Light to the Eyes

Michael Terman, Ph.D., Dept. of Psychiatry, Columbia University and Center for Environmental Therapeutics, New York, New York USA

Light treatment stands as the first active clinical intervention for major depression, with an underpinning in basic lab research on the circadian timing system and seasonal physiological changes in animals. By contrast, pharmaceutical treatments were discovered as side effects of drugs targeted at other medical disorders. The first randomized, controlled clinical trial showed that winter depression (seasonal affective disorder) could remit by truncating long winter nights with bright artificial light in late evening and early morning. Morning light proved most effective, which implicated a change in circadian timing. Seasonality, however, is not essential for the light effect: The much larger cohort of patients with non-seasonal depression also responds to morning light. Bipolar depression can remit as quickly as after a single night awake, but with high risk of relapse after sleep the next night. By adding daily morning light treatment after the night awake, the remission is sustained. Circadian rhythm sleep disorders, especially with sleep onset insomnia, can be normalized by timed light treatment, avoiding recourse to hypnotic drugs. New applications of light treatment with promising initial data include attention deficit hyperactivity disorder, fibromyalgia and other pain disorders, and symptoms of Parkinson’s disease and dementia.
Thyroid hormone signaling specifies cone subtypes in human retinal organoids

Robert J. Johnston, Department of Biology
Johns Hopkins University, Baltimore, MD

The mechanisms underlying specification of neuronal subtypes within the human nervous system are largely unknown. The blue (S), green (M), and red (L) cones of the retina enable high-acuity daytime and color vision. To determine the mechanism that controls S versus L/M fates, we studied the differentiation of human retinal organoids. Organoids and retinas have similar distributions, expression profiles, and morphologies of cone subtypes. S cones are specified first, followed by L/M cones, and thyroid hormone signaling controls this temporal switch. Dynamic expression of thyroid hormone-degrading and -activating proteins within the retina ensures low signaling early to specify S cones and high signaling late to produce L/M cones. This work establishes organoids as a model for determining mechanisms of human development with promising utility for therapeutics and vision repair.

Science. 2018 Oct 12;362(6411).
Melanopsin ganglion cells, critical players in visual system development

Jordan M. Renna, University of Akron

A small population of retinal ganglion cells express the photopigment melanopsin and have dendrites that stratify in the inner plexiform layer of the retina. These melanopsin ganglion cells are critical for visual system development as recent studies have demonstrated they are key players in the propagation of retinal wave activity and the development of the image-forming visual system. Early in development some of these melanopsin ganglion cells defy conventional lamination patterns and extend dendrites from the inner retina into the outer retina, and are closely apposed to s-opsin expressing cone photoreceptor pedicles. These outer retinal dendrites may contribute to setting the laminar stratification pattern of s-opsin cones as dark-rearing studies reduce the number of melanopsin ganglion cell outer retinal dendrites while increasing the number of displaced s-opsin cones. Though they are developmentally regulated, many outer retinal dendrites remain in the adult retina and there is anatomical evidence for synaptic transmission between cone photoreceptor terminals and outer retinal dendrites. This is some of the first evidence in a mammalian retina of a photoreceptor directly coupled to a ganglion cell and a potential novel mechanism for melanopsin ganglion cells to shape the development of the visual system.
Human visual cortex as a window into the developing brain

Jesse Gomez, Michael Barnett, Zonglei Zhen, Kalanit Grill-Spector, Kevin Weiner

The development of the human brain is the most protracted of any species, making childhood experience an integral factor in sculpting the neural hardware that will support behavior in adulthood. Despite its importance, the period of time separating birth from adolescence remains understudied in human neuroscience. I will discuss a series of multimodal experiments focused on human visual cortex as a testbed for understanding how the brain develops. Mapping receptive fields in children for the first time, I will demonstrate that the brain's "window" to the visual world grows from childhood to adulthood, and that the way we look at the world in our childhood impacts how information is pooled within cortex. In another experiment using participants with unique visual experience beginning in childhood -- lifelong players of Pokemon -- we'll also find that the typical retinal image occupied by this new stimulus category is the strongest predictor of emergent cortical specialization, suggesting that the way stimuli are viewed may even determine the organization of visual cortex itself. The potential genetic origins of these phenomena and their implications for maldevelopment will be discussed.

Gomez et al., 2018, Nature Communications
Gomez et al., 2019, Nature Human Behavior
Gomez et al., 2019, PLoS Biology

Acknowledgements: Ruth L. Kirschstein National Research Service Award grant no. F31EY027201, NIH grant nos. 1ROI1EY02231801A1 and 2RO1EY022318-06, and a seed grant awarded by the Stanford University Center for Cognitive and Neurobiological Imaging
Invited Session III: Biological Development of the Visual System
Saturday, 21 September, 08:30 – 10:30

Microglial mechanisms of experience-dependent plasticity in the mouse visual cortex

Ania K. Majewska, University of Rochester

The ability to tune synapses, and thus alter neural networks, is critical to both the normal development of brain circuitry and brain function throughout life, underlying processes such as learning and memory. Microglia are immune cells that infiltrate the brain early in development before the formation of the blood brain barrier. They have critical roles during brain injury, infection or disease. However, new data has thrust these non-neural cells into the spotlight as regulators of synapses. In the absence of pathology, microglia display dynamic interactions with synapses, and contribute to experience-dependent plasticity in the visual cortex in vivo. Manipulations of visual experience elicit a remarkably rapid behavioral response in microglia which is distinct from their inflammatory response, and includes an increase in phagocytosis that corresponds to the early phase of plasticity when synapses are lost in this model and when microglia increase their synaptic interactions. Our recent work has focused on identifying the molecular mechanisms through which microglia respond to changes in neuronal activity and communicate with synapses. We show that push-pull mechanisms allow microglial dynamics to be regulated by behavioral state through microglial receptors that sense purine and norepinephrine release. These opposing pathways impact microglial interactions with neurons and change the remodeling of neuronal networks with experience. Our findings suggest that microglia play an important role in synaptic plasticity, and use a subset of their pathological molecular repertoire to implement plastic changes in the non-pathological brain.
In vivo classification of macaque foveal ganglion cells through optical recording of responses to chromatic and luminance flicker

Tyler Godat, Juliette E. McGregor, Keith Parkins, William H. Merigan, David R. Williams

Despite the significance of the fovea for primate vision, its physiology is much less understood than the peripheral retina. We functionally classified foveal cells in the ganglion cell layer (GCL) of a female macaque that express a genetically encoded calcium indicator (GCaMP6s), allowing optical recording of the responses to chromatic and luminance flicker. Adaptive optics scanning light ophthalmoscopy (AOSLO) was used to image GCaMP6 fluorescence (488 nm excitation, 500-540 nm emission) from a ring of displaced GCL cells driven by cones in the central fovea. We recorded responses to sinusoidal flicker (0.2 Hz, LED 420 nm, 530 nm, 660 nm) modulated in one of three orthogonal directions in color space: white luminance modulation, a modulation calculated to maximize the counterphase excitation of M and L cones while silencing S cones, and a modulation to drive S cones while silencing M and L cones. We calculated the amplitude and phase from the fluorescence responses of 205 cells.

Response to luminance flicker demonstrated ON and OFF dominant types of cells, while response to the chromatic stimuli reveal cone inputs. 62% of cells were responsive to the M-L cone flicker, and 14% were responsive to the S cone flicker. 3% of cells were responsive to luminance flicker, but unresponsive to either chromatic stimulus. 24% of cells were unresponsive to all three stimuli. By expanding the stimulus space further, this method has the potential to provide a complete characterization of the retinal ganglion cell classes in the primate fovea.

Research reported in this publication was supported by the National Eye Institute of the National Institutes of Health under Awards No. P30 EY001319, T32 EY007125, U01 EY025497 and the Arnold and Mabel Beckman Foundation.
Label-free tracking of single blood cells in the retinal immune response

Aby Joseph, Colin Chu, Kosha Dholakia, Guanping Feng, Andres Guevara-Torres, Jesse Schallek

Leukocytes within the circulation are recruited to the central nervous system (CNS) in response to injury. However, imaging the immune response in the CNS is challenging due to a dearth of approaches that provide label-free study of leukocyte recruitment, surveillance and motility at the cellular level. Recently, adaptive optics scanning light ophthalmoscopy has enabled detailed study of single cell blood flow\(^1\), as well as imaged immune cell motility in the healthy retina. Here we deploy adaptive optics to study long- and short-term dynamics of the immune response. Healthy C57BL/6J mice were imaged in baseline state and were subsequently given an intravitreal injection of lipopolysaccharide, to induce an acute inflammation\(^2\). We tracked single red and white blood cells using phase contrast using 796 nm light to visualize blood cell dynamics label-free. Imaging the same mice over minutes to weeks revealed remarkable vascular and immune cell changes happening over 10-5 to 101 mm/s.

Venules and arterioles showed heterogenous changes in diameter and blood cell velocity at 6-24 hours in response to insult. Over hours, venules dilated by as much as 25.6%. While, arterioles did not appreciably dilate, blood cell velocity increased by as much as 103.1%. Total blood flow increased arterial and venular branches showing commensurate conservation of flow that increased by as much as 98.4%. Within 3-10 days, leukocyte recruitment and blood flow returned to near baseline activity as inflammation subsided\(^2\). Label-free adaptive optics ophthalmoscopy provides a new window to study the interplay of the vascular and immune systems in vivo.


Funding from NIH NEI EY028293, P30 EY001319, Research to Prevent Blindness: Career Development Award, Unrestricted Grant to the Univ. of Rochester Dept. of Ophthalmology, and Stein Innovation Award. Dana Foundation Mahoney Award and Hoffman-La Roche Inc.
Flicker evoked changes in small retinal vessels

Raymond L. Warner, Alberto de Castro, Lucie Sawides, Kaitlyn Sapoznik, Ting Luo, Stephen Burns

Purpose

To use the dual-beam Adaptive Optics Scanning Laser Ophthalmoscope (AOSLO) to measure blood flow changes in arterioles, venules, and capillaries in the human retina in response to full-field and local flicker stimulation.

Methods

The retina of nine healthy subjects ages 25 to 32 were imaged with the dual-beam AOSLO. Vessels targeted for imaging were interconnected arterioles, venules, and capillaries in the superior parafoveal retina. In experiment 1, parafoveal vessel locations were randomized and were imaged in three sets of three 2-minute sessions: (1) No-flicker, (2) Full-Field Flicker (10 Hz), (3) No flicker again. In experiment 2, 10 images in the temporal superior retina in one subject were collected at 7 locations with a local flicker stimulus at the center.

Results

RBC velocities, diameters, and flow were measurable in all subjects with individual vessels from each subject varying in velocity and pulsatility. Flicker stimulation increased the average flow of RBC's for arteriole, venule, and capillary vessels in all subjects. Average flow increased 29% in arterioles, 25% for venules, and 23% for the capillaries. Local flicker stimuli induced variable increases in velocity relative to the position of the local flicker stimulus.

Conclusions

With the use of the dual channel AOSLO, we can measure changes in blood in parafoveal vessels in the human retina. Understanding how flicker stimuli induce changes in the retinal vasculature is important for understanding both how blood flow is regulated in the healthy eye, and ultimately to better understand how disease disrupts neurovascular regulation.

This study was supported by NIH/NEI R01 EY024315
Migraine is associated with greater sensitivity to melanopsin and cone stimulation

Harrison McAdams, Eric Kaiser, Aleksandra Igdalova, David H. Brainard, Geoffrey K. Aguirre

Light sensitivity between headache attacks is a common symptom of migraine, but its photoreceptor basis is unknown. We measured discomfort and physiologic responses in migraines to cone- and melanopsin-directed stimulation (Pre-registration: https://osf.io/qjxdf/).

We are studying 40 people with migraine and inter-ictal light sensitivity (20 with aura, 20 without aura), and 20 headache-free controls (17/14/20 studied to date). Subjects view multiple, 4-second, achromatic spectral pulses that target melanopsin, the cones, or both (light flux) with varying contrast (100-400%). During and following stimulation, we measure orbicularis oculi squint (via EMG) and pupillary response, and subjects provide discomfort ratings.

People with migraine report all stimulation (cone, melanopsin, or light flux), at all contrast levels, as roughly twice as uncomfortable as do controls (for 400% contrast stimuli, on a 0-10 scale, median discomfort scores for migraines vs. controls were 5 vs 3 for cones, 5 vs. 2 for melanopsin, and 6 vs. 3 for light flux). Migraineurs also have increased squint in response to these stimuli (median RMS of EMG activity for migraines vs. controls: 1.72 vs 1.44 for cones, 1.71 vs. 1.32 for melanopsin, and 1.78 vs. 1.40 for light flux). We are currently masked as to group assignment for the pupillometry data. When pooled across groups, we find that the pupil response to melanopsin-directed stimulation is characteristically prolonged.

Migraineurs have increased sensitivity to melanopsin and cone stimulation. We expect to present at the meeting the result of our pre-registered test for group differences in the melanopsin-evoked pupil response.
Thermal and Distance image filtering improve independent mobility in Argus II retinal implant

Sadeghi, Roksana; Kartha, Arathy; Barry, Michael P.; Gibson, Paul; Caspi, Avi; Roy, Arup; Dagnelie, Gislin

Purpose: To simplify the imagery presented to Argus II retinal implant wearers by filtering out information from background objects using head-mounted a thermal camera (T) and a stereoscopic distance filter camera (D). The functionality of these two systems was compared with normal Argus II camera (N) imagery in mobility and obstacle avoidance tasks.

Method: The data were acquired from Argus II users in a mobility test with T/N and obstacle avoidance test with D/N. In both experiments, the accuracy and response time were recorded and were used to calculate the cumulative probability of success over time. Performance using the T/D versus N cameras was compared using the Kolmogorov-Smirnov (K-S) test.

Results: Four Argus II users aged 62-87 completed the mobility task and three of them performed the obstacle avoidance task. Despite interindividual differences, K-S testing of the cumulative probability of success in both experiments showed that significantly less time was spent to respond with T/D compared to N, yet with higher accuracy (p<0.005).

Conclusion: Subjects detected obstacles and people more accurately with T/D than using N. Even though N would have allowed subjects to use cues such as target size to make the discrimination, performance with this camera was much slower and close to chance, presumably due to an interference by (non-target) phosphenes. Addition of T/D camera to N camera in the Argus II system may have significant real-life implications for personal safety and social interactions, thereby improving quality of life.
Uses of virtual reality gaming for visual system training in patients with binocular dysfunction

Benjamin T. Backus, Vivid Vision Inc., San Francisco, CA

Common binocular dysfunctions include vergence disorders, amblyopia, strabismus, and stereo deficiency. Unlike a laboratory study of perceptual learning, which usually focuses on a single skill or mechanism, treating these dysfunctions requires addressing multiple subsystems. Indeed, these four conditions often co-occur. Traditionally these conditions are treated with monocular occlusion (patching), extraocular eye-muscle surgery, and vision therapy (VT) activities. VT shares characteristics perceptual learning, insofar as it combines manipulation of visual input with a cognitive or behavioral task. Various VT activities are based on principles that a cognitive scientist or vision scientist would recognize as being intended to effect perceptual learning in a subsystem of the visual system. But VT can potentially be improved in two ways: making the activities more effective per unit time, and increasing the amount of time that patients spend doing the activities. Whatever their strengths and shortcomings, traditional VT activities are limited by the amount of time that patients spend doing them. By contrast, video games can be made compelling to play, and virtual reality, in particular, is well suited for making games in which visual stimuli are manipulated to facilitate perceptual learning in (cause task performance to be limited by) a selected subsystem. Examples of activities in the Vivid Vision binocular vision treatment product, and changes over time in patient performance, illustrate the approach. Disclosure statement: Prof. Backus is employed by Vivid Vision, Inc., a company that makes virtual reality video games to treat dysfunction of binocular vision.
The Impact of Commercial Video Game Play on Perceptual Abilities

C. Shawn Green

A growing body of literature has investigated the effects of playing commercial video games on perceptual and cognitive abilities. One key takeaway from this literature has been that not all entertainment video games are created equal with respect to their impact on human abilities. The majority of the research to-date has contrasted the perceptual and cognitive effects of playing first- or third-person shooter games (together dubbed "action video games") against the effects of playing other game types [2]. Here I will discuss two evolving shifts in this research domain. The first is the suggestion that the enhanced performance on perceptual tasks seen to arise as a function of action video game experience may have its roots in enhancements in certain more cognitive abilities (e.g., attention). The second relates to dramatic changes in the video game industry [3]. Specifically, when the research on the impact of commercial video games began in the late 1990s, action video games placed load upon the perceptual, attentional, and cognitive systems in a manner not seen in other video games. Today though, first- and third-person shooters are no longer unique in the extent to which they load upon perceptual and cognitive abilities. Instead, a host of other game types have emerged that appear to place similar degrees of load upon these systems. This thus provides an opportunity to further examine the link between sustained load on perceptual/cognitive functions and changes in those functions.


Acknowledgements: Office of Naval Research Grant N00014-17-1-2049 to C.S.G.
The Promise of Brain Training Games; Applying Perceptual Learning to produce broad-based benefits to vision

Aaron Seitz

Imagine if you could see better, hear better, have improved memory, and even become more intelligent through simple training done on your own computer, smartphone, or tablet. Just as physical fitness underwent a revolution in the 20th century, brain fitness is being transformed through innovations in psychology, neuroscience and computer science. This talk discusses recent research that begins to unlock this potential in the context of training vision. Research in the field of perceptual learning has demonstrated that vision can be improved in both normally seeing and visually impaired individuals, however, a limitation of most perceptual learning approaches is their emphasis on simplicity. In the present research, we adopted an integrative approach where the goal is not to achieve highly specific learning but instead to achieve general improvements to vision. We combined multiple perceptual learning approaches that have individually contributed to increasing the speed, magnitude and generality of learning into a perceptual-learning based video-game. Our results demonstrate broad-based benefits of vision and real world on-field benefits in baseball players. I discuss both the exciting potential of the approach and limitations associated with the young stage of the field.

Acknowledgements: National Institute of Health 1R01EY023582
Binocular Treatment for Childhood Amblyopia

Krista R Kelly

Amblyopia ('lazy eye') is the leading cause of monocular visual impairment in children. In addition to abnormal visual acuity, amblyopia can result in functional impairments in reading and fine motor abilities, and low self-esteem. The most common treatment is to patch the stronger eye to force use of the amblyopic eye, but normal visual acuity is not always achieved and normal binocular vision is rarely recovered. Patching can also be uncomfortable and an emotional burden for the child, resulting in low adherence. Recent advances in the treatment of childhood amblyopia have focused on binocular therapies consisting of games and movies that may reduce interocular suppression so the child can experience binocular vision. Laboratory and clinical trial data have shown improvements in visual acuity and binocular outcomes with as little as 2 to 4 weeks of binocular treatment in amblyopic children and adults. However, a few clinical trials have poor results with binocular treatment, possibly due to low adherence, small tropias, or a high prevalence of intractable amblyopia in older, previously treated participants. Although binocular treatments show promise, particularly in younger children, more research must be conducted to determine the most effective way to implement binocular treatment for maximum visual improvement, and to tease apart the mechanisms by which visual improvement occurs. Advanced binocular treatments have the potential to be added to the repertoire of standard-of-care treatment for childhood amblyopia, but questions remain to be answered before they can be used nationally and internationally in clinical settings.

Research funded by NIH grants (EY022313 and K99EY028224)
Visual Simulators: from understanding of vision mechanisms to applications in clinic

Susana Marcos, Sara Aissati, Clara Benedi, Carlos Dorronsoro Enrique Gambra, Aiswaryah Radhakrishnan, Maria Viñas, Michael Webster, Lucie Sawides
Instituto de Optica, CSIC; 2EyesVision, SL

Adaptive Optics visual simulators, composed of wavefront sensing, and active elements (deformable mirror or SLM), allow manipulating the ocular optics to either correct or induce optical aberrations, and therefore allowing to probe spatial limits to spatial vision and mechanisms of neural adaptation. Visual function improves upon correction of aberrations (i.e. VA and CSF). However, the same blurred image is judged as perceptually different by different subjects, with high correlation between subject’s best perceived focus and native optical blur level. Furthermore, from series of images degraded by similar blur levels but different blur orientation, the images blurred with blur orientation matching the native aberrations were perceived as sharpest. These data indicate that eyes are naturally adapted to their own aberrations. Adaptive Optics has also been used to understand optical and perceptual interactions between chromatic and monochromatic aberrations, and reveals adaptation to blurred images in blue. Interestingly, subjects can adapt to scaled aberrations. Adaptation to orientation bias also occurs, as the best perceived focus shifts away from isotropia after adaptation to oriented blur. The way patients adapt to oriented blur is clinically relevant, for example in the management of astigmatism correction, as habitually non-corrected astigms shift their best perceived focus to isotropia shortly after correction of their astigmatism, and equally perceived best focus shifts after short exposure to simultaneous vision. Visual simulators need to be made compact to be clinically useful. A temporal multiplexing technique (SimVis) has allowed binocular simulations of clinical multifocal corrections, allowing patients to experience vision prior to surgery.
Perceptual evidence of neural adaptation to the eye’s habitual aberrations

Geunyoung Yoon, PhD
Flaum Eye Institute, The Institute of Optics, Center for Visual Science, Biomedical Engineering, University of Rochester

Visual perception depends on the quality of the eye’s optics forming images on the retina and on subsequent neural processes. In eyes with prolonged visual deprivation induced by the abnormally large ocular aberrations, the actual visual performance after precise correction of the aberrations is significantly poorer than that predicted from optical theory and that measured in normal eyes. This unexplained vision loss suggests an interesting long-term interaction between the quality of retinal images and neural processing. The overarching goal of the study is to investigate optical and neural mechanisms underlying long-term adaptation to the habitual optical quality. We use a binocular adaptive optics (AO) vision simulator to fully correct the aberrations in a unique patient group, keratoconus (KC) – a progressive corneal disease causing a normally-developed visual system to suffer severe optical degradation in adulthood. Our studies found that long-term adaptation alters neural processing of both contrast and phase of retinal images. Under AO correction, KC subjects showed abnormal contrast sensitivity, with impaired sensitivity at high spatial frequencies (SF) and enhanced sensitivity at low SFs. It was found that neural adaptation compensates for phase congruency disrupted by eye’s aberrations, which attenuates the perceived blur over time. These neural mechanisms also have significant impact on binocular vision such as contrast summation and stereopsis. Our findings suggest that the cortex adapts to imperfect ocular optics, presumably to maximize the efficiency of visual processing and to allow for more veridical perception under natural viewing conditions.
Spatial summation in the human fovea measured with adaptive optics

William Tuten, School of Optometry, UC Berkeley

The human fovea is equipped with neural mechanisms whose spatial grain is finer than the spatial and temporal blur introduced into the retinal image by optical aberrations and fixational eye motion, respectively. As a consequence, pre-retinal factors have the potential to play a significant role in shaping visual performance in the central retina. In this presentation, I will discuss experiments in which the spatial summation of light increments delivered to the human fovea was examined using a custom adaptive optics scanning laser ophthalmoscope that provided precise control over high-order ocular aberrations and stimulus motion on the retina. We found that these pre-retinal factors had relatively little impact on behavioral measurements of foveal summation. When pre-retinal factors were minimized, the area over which incident photons were pooled completely (i.e., Ricco’s area) had an average diameter of 2.43 arcmin, encompassing between two and three dozen foveal cones. When the measurements were repeated in the presence of habitual aberrations and natural stimulus motions on the retina, Ricco’s area did not increase significantly. Our results obtained across conditions were in good agreement with predictions generated by a computational observer that included a physiologically-realistic model of the front-end of the visual system coupled with a post-receptoral summing filter.
Are fixational eye movements adaptive? Two tests of the interaction between photoreceptor sampling, eye movements and psychophysical performance

Hannah E. Smithson
Laura K. Young
Anna-Katharina Hauperich
Allie C. Hexley
Sarah E. Regan

1. Department of Experimental Psychology, University of Oxford, Anna Watts Building, Radcliffe Observatory Quarter, Woodstock Road, Oxford, OX2 6GG, UK.

Under conditions in which visual performance is limited by sampling, small eye movements that influence the way the optic array is sampled have the potential to change visual behaviours. We use high-resolution, adaptive-optics-enabled (AO) in vivo retinal imaging to measure fixational eye movements during psychophysical tasks, and we analyse responses in relation to the way the retinal stimulus is sampled by the photoreceptor mosaic.

In the first experiment, fixation stability is measured as a function of edge blur. Under instruction to maintain fixation on an anisotropic target, participants make fewer eye movements in the direction that maximises temporal flux in retinal stimulation. However, edge blur has little effect on stability, suggesting that the error signal for eye position is based on the centre of gravity of a stimulus, rather than local flux at a boundary.

In the second experiment, eye movements are tracked whilst assessing psychophysical thresholds on a sampling-limited spatio-chromatic task. Amongst observers who pass standard colour vision tests, the average ratio of L:M cones is 2:1; however, it can vary substantially between individuals. The data are analysed to test whether eye movements enhance spatial thresholds for L- and M-isolating Landolt Cs and whether this advantage follows sampling-based predictions as a function of L:M ratio.

AO retinal imaging enables the study of spatio-temporal sampling of visual stimuli in a way that has not previously been possible. We discuss the effect of fixational eye movements on visual performance and the intriguing possibility that fixational eye movements are adaptive to one’s specific retinal cone mosaic.
Invited Session V: Aberrations and Vision – The Limits of Visual Performance Studied with Adaptive Optics
Sunday, 22 September, 08:30 – 10:30

This work was funded by the following grants to HES: Fight For Sight (1467/8); University of Oxford Wellcome Trust Institutional Strategic Support Fund (105605/Z/14/Z); the University of Oxford Medical Research Fund (MRF/LSV2015/2161); the EPA Cephalosporin Fund (CF 277); the John Fell Oxford University Press (OUP) Research Fund (103/786 and 151/139). AKH and SER are funded by the BBSRC Interdisciplinary Bioscience DTP. ACH is funded by an EU Marie Skłodowska-Curie Innovative Training Network (H2020-MSCA-ITN-2017, 765911).
Dissociation between perception and predictive oculomotor behavior in retrained cortically blind fields

Sunwoo Kwon, Jude Mitchell, Krystel Huxlin

When saccading to a moving peripheral target, smooth pursuit can track the target immediately upon saccade landing, reflecting pre-saccadic motion integration (Gardner and Lisberger, 2001). Similarly, saccades to peripheral, static apertures containing global motion stimuli drive predictive smooth eye movements, called “post-saccadic following responses” (PFR), along the target motion direction immediately following saccade landing (Kwon et al., 2019). PFR persists even when motion disappears in-saccade-flight, indicating that pre-saccadic motion selection initiated the subsequent following response. Here, we asked if this automatic processing persists in 7 cortically blind (CB) patients who sustained V1 damage in adulthood. Patients exhibited normal PFR gain in intact portions of their visual field (0.15±0.08), and the magnitude of PFR gain was negatively correlated with direction integration thresholds (r=-0.54, p=0.01). However, at blind field locations where patients failed to discriminate global motion direction, they exhibited no significant PFR (gain=0.004±0.019). We then asked whether visual training that recovers global motion perception in CB fields (Huxlin et al., 2009), can restore this automatic pre-saccadic processing. The resulting PFR gain was only 0.03±0.09 (t-test: p=0.6104 relative to untrained locations), well below normal (t-test: p=0.03). In summary, peripheral visual discrimination training, which recovers global motion perception in the blind field, does not restore a normal PFR. Such poor automatic pre-processing of motion in retrained CB fields suggests that after V1 damage, neural circuits engaged in the PFR may differ from those mediating conscious motion perception at the same visual field locations.


Use it before you lose it: greater efficacy of visual training for recovering contrast sensitivity in subacute cortical blindness

Elizabeth L. Saionz\textsuperscript{1,2,4}, Michael D. Melnick\textsuperscript{3,4}, Duje Tadin\textsuperscript{3,4,5}, Krystel R. Huxlin\textsuperscript{3,4,5}

\textsuperscript{1}Translational Biomedical Science Program, \textsuperscript{2}Medical Scientist Training Program, \textsuperscript{3}Dept. Brain and Cognitive Sciences, \textsuperscript{4}Flaum Eye Institute, \textsuperscript{5}Center for Visual Science; University of Rochester

A hallmark of chronic (>6 months) V1 stroke in humans is loss of luminance contrast sensitivity (CS) and visual discrimination abilities in the cortically blind (CB) field. Training chronic CBs on high-contrast random dot stimuli in their blind field may restore motion discriminations, but CS remains impaired.\textsuperscript{1} Recently, we showed that some subacute CBs (<3 months) retain blind field CS at a range of spatial frequencies (SFs), particularly for drifting stimuli.\textsuperscript{2} Here, we asked whether training could further improve blind field CS, and compared its efficacy in subacute (n=5) and chronic (n=5) CBs. All subjects trained at 2 non-overlapping blind field locations on static orientation and direction discrimination tasks; Gabor (1 cpd) contrast varied within session on a 3:1 staircase. After daily home training for 3-6 months, we measured changes in static (orientation discrimination) and motion (direction discrimination) CS (0.1-10 cpd) using the qCSF. Training with drifting Gabors improved motion CS across multiple SFs in both chronic and subacute CBs, but did not recover static CS. Training with static Gabors improved both static and motion qCSFs in subacutes, but failed to elicit any improvements in chronic CBs. Our results suggest greater capacity for recovery of visual discriminations in the subacute over the chronic post-stroke period, particularly regarding static stimuli. Given the potential for trans-synaptic retrograde degeneration of parvocellular units in the dorsal lateral geniculate nucleus and retina, we propose that early training may take advantage of networks that are preserved immediately after V1 lesion but deteriorate absent deliberate training.

Audiovisual Enhanced Sensitivity: Both Psychophysical and Neural Data Follow the Same Combination Rule

Vincent A. Billock, Naval Aerospace Medical Research Laboratory, NAMRU-D
Micah Kinney, Naval Aerospace Medical Research Laboratory, NAMRU-D
M. Alex Meredith, Department of Anatomy & Neurobiology, Virginia Commonwealth University

A dim light looks brighter when accompanied by a spatiotemporally coincident sound. The apparent brightness enhancement is a power law of the unenhanced signal. There is a class of neurons - modulated unisensory neurons - in visual cortex that follow the same enhancement power law with a similar exponent, suggesting that cortical modulated unisensory neurons could be a neural correlate of suprathreshold audiovisual brightness enhancement (Billock & Havig, 2018). However, audiovisual detection thresholds follow a different rule, a modified Pythagorean sum called the Minkowski equation, with an exponent of about 1.82 (Schnupp et al., 2005). We analyzed 41 neurons in cat extrastriate visual cortex (area PLLS) that respond to both visual and auditory stimuli (bimodal neurons) and have enhanced responses to audiovisual combinations (Meredith et al., 2012).

We find that this class of cortical neurons combine audiovisual stimuli in the same way as Schnupp's psychophysical data, obeying the Minkowski sum with a very similar exponent of about 1.75. This suggests that cortical bimodal neurons could be a neural correlate of audiovisual threshold sensitivity.

The result is especially interesting because some within-vision cue combinations inherent in binocular vision and color vision also obey the Minkowski equation, suggesting that sensory combination mechanisms could be neurally generic and broadly applicable.

Meredith et al.(2012) Are bimodal cells the same throughout the brain? In the Neural Bases of Multisensory Processes (pp. 51-64).

Partly supported by NSF #1456650 to V. Billock
Effect of Visual Training on Optic Tract Degeneration after V1 Lesions

Berkeley K. Fahrenthold¹, Matthew R. Cavanaugh¹, Allison Murphy², Sara Ajina³, Arash Sahraie⁴, Holly Bridge³, Krystel R. Huxlin⁵

¹Flaum Eye Institute, University of Rochester Medical Center, ²Department of Neuroscience, University of Rochester Medical Center, ³Nuffield Department of Clinical Neurosciences, University of Oxford, ⁴School of Psychology, University of Aberdeen, ⁵Flaum Eye Institute, Center for Visual Science, University of Rochester Medical Center

Damage to the primary visual cortex causes a contralateral visual field defect known as cortical blindness (CB). While some vision can recover spontaneously in the first few months post-insult¹, without intervention, a slow, progressive loss of vision characterizes the ensuing months and years²,³. Trans-synaptic retrograde degeneration⁴–⁷ may explain this progressive loss, which in humans, manifests by reduced optic tract (OT) size ipsilateral to the lesion⁸. Given that visual training can reduce the size of visual deficits months to years after occipital stroke⁹, we asked here if visual training slows or stops this degeneration. As such, we measured optic tract volume in 31 chronic (>6 months post-stroke) cortically blind patients, 17 of whom underwent visual training. About half of the subjects (17/31) exhibited significant OT shrinkage on the side of the lesion, resulting in a positive laterality index (LI), while the remaining 14/31 exhibited similar left and right OT volumes (LI=0). Training-induced visual recovery did not decrease LI, or prevent LI from getting worse in those who had LI=0 pre-training. However, there was a negative correlation between pre-training LI and visual field shrinkage post-training (R²=0.5, p = 0.019). Our results suggest significant heterogeneity in OT shrinkage after V1 stroke, which progresses irrespective of visual training in the chronic period. However, importantly it appears that pre-training LI predicts the magnitude of visual field recovery achievable with visual training in chronic CB, with patients whose LI was 0 before training exhibiting the greatest amount of visual field recovery.

Contributed Session III: Training and Psychophysics
Sunday, 22 September, 11:00 – 12:30

Learning to see again: Perceptual learning for sight restoration technologies

Rebecca Esquenazi, Kimberly Meier, Michael Beyeler, Geoffrey Boynton, Ione Fine

Electronic retinal prostheses, the only sight restoration technology currently approved for implantation in patients, cause simultaneous, rather than complementary firing within on- and off-center retinal cells. Here, using 'virtual patients' - sighted individuals viewing distorted input - we examine whether plasticity might compensate for the resulting neuronal population coding distortions. Four participants were trained in a perceptual learning task using dichoptic presentation of original and contrast-reversed images as a proxy for inappropriate on and off-cell stimulation. Each greyscale image (I) and its contrast-reverse (I') was filtered using a radial checkerboard in Fourier space (F) and its inverse (F'). \[ I \ast F \] + \[ I' \ast F \] was presented to one eye, \[ I \ast F \] + \[ I' \ast F \] to the other, such that regions producing on-responses in one eye produce off-responses in the other eye.

Participants viewed these distorted scenes which had a 50% chance of containing an embedded object in a random size, location, and orientation. Participants indicated whether a cued object was present or absent, and repeated the task once daily for up to 20 one-hour sessions. All participants initially showed poor performance, but continuously improved across each session, as measured by d' scores. Future studies will examine transfer of learning (e.g. 1/f noise in each image pair, monocular presentation, and switching the Fourier filters across eyes) to examine whether participants have learned to suppress or 'flip the perceptual sign' of neural populations associated with the contrast reversed image, or have learned how to more efficiently extract visual information from distorted images.

Acknowledgements:
1. Vision Training Grant (EY07031) from the NEI
2. Effects of Blindness on Human Early Visual Pathways R01 EY014645-08
Spatial exogenous attention impacts recovery in cortically blind fields

Matthew Cavanaugh\textsuperscript{a}, Marisa Carrasco\textsuperscript{b}, Krystel Huxlin\textsuperscript{a}

\textsuperscript{a}Flaum Eye Institute, and Center for Visual Science, University of Rochester, Rochester, NY 14642, USA
\textsuperscript{b}Department of Psychology and Center for Neural Science, New York University, New York, NY 10003, USA

Cortical blindness (CB), vision loss resulting from damage to the primary visual cortex or its immediate afferents, can be partially alleviated through visual perceptual training\textsuperscript{1}. However, learning does not transfer deeper within the blind field\textsuperscript{2,3}. Given that exogenous spatial attention (ESA) enables perceptual learning\textsuperscript{4} and facilitates transfer\textsuperscript{5}, here, we sought to reduce the spatial specificity of training by manipulating ESA. Chronic CB subjects trained on left-right, global direction integration just inside the blind field. In Flash training (n=3), a pre-cue (5-deg disc, 15Hz flicker, 200ms duration) appeared 7-deg deeper in the blind field. In Exposure training (n=3), an identical stimulus appeared simultaneously, 7-deg deeper in the blind field. Pre-cues (1-deg discs, 15Hz flicker, 200ms duration) appeared above both stimuli. For all conditions, blind-field pre-training performance approximated chance. Both ESA training conditions improved performance at trained locations, but Normalized Direction Range (NDR) thresholds following Flash training (57±16%) were poorer than after both Exposure training (35±5%), and single stimulus training without pre-cues (27±9%); the last two groups did not differ (p>.1). None of the three groups exhibited learning at the deeper locations. Thus, the Flash pre-cue reduced training efficacy in the blind field, possibly by withdrawing attentional resources from the training location into a location where no stimulus was presented. Our findings show that directing ESA deep in the blind field attracts attention automatically and hinders performance if no relevant task information is presented at that location, revealing that exogenous attention exerts its effects even in the blind field.

The Roles of S, M, and L Cones in Constructing Trichromatic Color Space

Bruce Drum

Conventional trichromatic color vision models\(^1\) postulate that long- (L), middle- (M), and short-wavelength (S) cone signals reorganize into two color-opponent channels where L+S (red) and M (green) cone signals cancel each other, and L+M (yellow) and S (blue) cone signals cancel each other.

This scheme is inconsistent with the hues that remain when S cone or L+M cone contributions are removed.\(^2\) When S-cone contributions are removed (e.g., by foveal or small field tritanopia, S-cone saturation, genetics, disease, toxicity, or light damage), vision becomes dichromatic, with short wavelengths appearing greenish blue, long wavelengths appearing reddish orange, and wavelengths near 570 nm appearing achromatic. Conversely, when L+M cones are suppressed by white light adaptation, the S-cone hue signal appears more red than blue.

These findings imply that L cones signal reddish orange, M cones signal greenish blue, and S cones signal bluish red. Also, S and M cones modulate color appearance in a complex manner, with S cone red cancelling M cone green to reveal blue near 470 nm and L+M cone yellow cancelling S+M cone blue to reveal green near 500 nm. Also, since removing S cones removes yellow, yellow must be a contrast color that requires an S-cone off signal. Similarly, selectively suppressing L+M yellow signals may weaken S cone blue signals by reducing chromatic contrast.

Some recent single-cone color naming results\(^3,^4\) seem inconsistent both with classical color opponent models and the more complex model above. Ultimately, however, models of opponent-color organization must explain both single-cone and conventional color appearance.


The research upon which this presentation is based was supported in part by National Eye Institute grant EY07327. The author has no commercial relationships related to this work.
Aging differences in reading sentences masked with noise and improvement with text motion

A.E. Elsner\textsuperscript{1}, R.N. Gilbert\textsuperscript{1}, S.E. Hassan\textsuperscript{1}, R.L. Warner\textsuperscript{1}, B.P. Haggerty\textsuperscript{1}, E.J. Kollbaum\textsuperscript{1}, C.A. Clark\textsuperscript{1}, M.S. Muller\textsuperscript{2}

\textsuperscript{1}Indiana University School of Optometry
Bloomington, IN, USA
\textsuperscript{2}Aeon Imaging, LLC
Bloomington, IN, USA

Purpose: We are modelling noise pattern masking as a means to simulate the decrease of S/N in aged or diseased retinas. We previously observed that text oscillation improves reading speed and error rate.

Methods: Subjects (5 females and 5 males) with spherical error 3.5 to -7.5, normal contrast sensitivity (Pelli-Robson), and no macular scotoma were divided into groups younger (31.4 + 5.0 yr) and older (62.8 + 5.8 yr). Using a digital light ophthalmoscope (DLO), we presented sentences via Maxwellian view in a 25 x 18 deg field and determined retinal locus by simultaneously capturing coplanar retinal images at 860 nm. Subjects read IU Read sentences separately, at a 1920 x 1080 pixel resolution and 20/60 Helvetica font. The text contrast (delta I/I) was 50%. The added noise had a center spatial frequency of 5.8 c/deg, and Michelson contrast 0 - 40% with , 10 sentences per condition. Each 10 - 14 word sentence was stationary or oscillating sinusoidally and horizontally, amplitude 0 - 2 deg.

Results: Errors increased with a nonlinear function of noise contrast, and the improvement of reading with text motion depended on noise contrast. With no text motion, younger subjects read faster than older ones (p=.039), but errors did not significantly differ (p=.199). Younger vs. older errors were 52.2 vs. 57.7 and 9.8 vs. 7.3 for no motion vs. motion at noise contrast 0.4.

Conclusions: Slower reading speeds but not more errors in older subjects are consistent a speed-accuracy trade-off, with motion improving reading in most subjects.

NIDILRR 90BISA000-01-00 to Matthew Muller
National Institute on Disability, Independent Living, and Rehabilitation Research
NIH NEI EY024186 to Matthew Muller
NIH NEI EY028499 to AEE
What sets the state of chromatic adaptation?

Mark D. Fairchild
Program of Color Science / Munsell Color Science Laboratory
Rochester Institute of Technology, Rochester, NY USA

For more than a century the process of chromatic adaptation has been modeled using derivatives of the original von Kries hypothesis that the cones adapt largely independently and dependent on their general states of stimulation.\(^1\) Such models have been implemented in physiological experiments and in international standards such as CIECAM02.\(^2\) While it is easy to write down the von Kries hypothesis in equations, setting the parameters of such equations remains a bit of a mystery. Does chromatic adaptation depend on the light source, the scene average, a local average somehow integrated in time and space, cognitive interpretation of the stimuli, or all of the above in some unknown combination? This presentation aims to explore the titular question by reviewing historical experiments on stimulus complexity,\(^3\) temporal adaptation,\(^4\) spatial adaptation,\(^5\) examining recent data on the precision and reversibility of corresponding colors experiments,\(^6,7\) and proposing a new theory/model with hysteresis-based dependencies for the traditional von Kries coefficients. It is hoped this will prompt some discussion on the physiological basis for mechanisms of chromatic adaptation that could be used to guide future colorimetric models.\(^8\)

This work was supported by the Munsell Color Science Laboratory Endowment.
Illuminants estimated by human observers for natural objects under daylights compared with those predicted by the optimal color hypothesis

Kazuho Fukuda 1, Takuma Morimoto 2, Ben Kusano 3, Keiji Uchikawa 4
1. Kogakuin University
2. University of Oxford
3. Kanagawa University
4. Kanagawa Institute of Technology

Color constancy is a visual function to perceive the world to be constant in color under various illuminants. The visual system must estimate an illuminant in a scene to achieve color constancy. It was reported that the optimal color hypothesis (Uchikawa et al., JOSA, 2012) computationally predicted physical illuminants better than other candidate models based on the mean chromaticity or on the mean cone signals, for the distribution of 400 colors in a color space calculated with the spectral surveys of natural objects and daylights (Uchikawa and Fukuda, ICVS 2017). In the present study, we carried out a psychophysical experiment to compare the predictions of the optimal color hypothesis and human illuminant estimations in the same color distributions. In the experiment, stimuli were presented on a CRT, consisting of 217 hexagonal elements: a center test and 216 surrounding elements. Each element subtended 1-deg in diagonal. The colors of the surrounding elements were calculated using spectral reflectances of 215 natural objects and spectral power distributions of five test daylights, which were both measured in natural environments in Japan. Five male observers with normal color vision participated in the experiment. Observers adjusted the chromaticity and luminance of the center test element so that it appeared as a full white paper (paper match) under a test daylight. The results showed that mean illuminant estimations obtained for each daylight condition are fairly close to the predictions of the optimal color hypothesis although individual differences in illuminant estimations were found large.

Uchikawa & Fukuda, Illuminant estimation by the optimal color hypothesis for natural objects and daylights, ICVS 2017, Germany (2017)

This work was supported by JSPS KAKENHI Grant Number JP17H01809 and JP17K04503. TM's Ph.D studentship is funded by the Aso Scholarship, the Sasakawa Fund Scholarship, and awards from the Kikawada Foundation and the Japanese Student Services Organization.
Higher order aberrations during accommodation in children

Rohan P. J. Hughes*, Stephen J. Vincent*, Scott A. Read*, Michael J. Collins*
*Contact Lens and Visual Optics Laboratory, School of Optometry and Vision Science, Queensland University of Technology, Brisbane, Queensland, Australia

Background: In adults, higher order aberrations (HOAs) vary during accommodation [1] which reduces retinal image quality [2]. These changes may provide a mechanism linking near work and myopia development [3], however little is known about HOAs during accommodation in children.

Methodology: HOAs of 90 children (mean age and spherical equivalent refraction: 8.2 ± 1.8 years; +0.63 ± 0.34 D) were measured at four accommodation demands (0, 3, 6 and 9 D) using a Hartmann-Shack aberrometer (COAS-HD). Individual Zernike term coefficients up to and including the 6th-order were analysed over a 4 mm pupil at each accommodation demand. Root mean square (RMS) errors were calculated for total (2nd-6th orders), higher order (3rd-6th orders) (HO), individual radial orders, coma (Z[3,-1], Z[3,1], Z[5,-1] and Z[5,1]), trefoil (Z[3,-3], Z[3,3], Z[5,-3] and Z[5,3]) and spherical aberration (Z[4,0] and Z[6,0]) (SA). Visual Strehl ratios based on the optical transfer function were determined from HOAs (VSOTF).

Results: Total, HO, all individual orders, coma, trefoil, and SA RMS varied significantly with accommodation demand (p < 0.0001), as did several individual Zernike terms and the VSOTF (p < 0.0001). The change in the VSOTF from 0 D was 0.002 ± 0.067 (p = 1.000), -0.024 ± 0.098 (p = 0.451), and -0.147 ± 0.188 (p < 0.0001) at 3, 6 and 9 D, respectively.

Conclusions: HOAs changed significantly during accommodation resulting in a significant reduction in retinal image quality at the 9 D accommodation demand. Longitudinal studies are required to examine the potential influence of these changes on eye growth.


The authors wish to acknowledge Pryntha Rajasingam for her assistance during data collection.
A virtual reality-based test to assess functional vision in people with simulated ultra low vision

Kartha, Arathy¹; Sadeghi, Roksana¹,²; Tran, Chau³; Nardo, Zoe³; Adeyemo, Olukemi¹; Yang, Liancheng¹; Geruschat, Duane¹; Dagnelie, Gislin¹

Purpose: Ultra low vision (ULV) is severe visual impairment with visual acuity less than 20/1600. People with ULV have residual vision that enable them to perceive lights and shadows. The purpose of this study was to develop a standardized test to assess functional vision in people with ULV.

Methods: Twenty volunteers wearing translucent patches to simulate ULV participated in this study. Each participant performed a virtual reality based assessment of functional vision that comprised 19 activities developed from a ULV inventory. Each activity had 2, 3 or 4 alternative forced choices and came in three difficulty levels, with 3 trials for each item/level. Responses were scored as 0 for incorrect and 1 for correct.

Results: Responses were analyzed using d prime (d’) analysis. The results showed a wide spread of d’ scores for item measures where the easier task had more negative d’ values and vice versa (max = 0.08; min = -3.19; range = 3.27) indicating that the tasks were distributed across a wide range of difficulty levels. Person measures calculated using d’ were consistent with the level of simulated visual impairment.

Conclusion: Overall, the current study validated the use of a novel virtual reality based test for assessing functional vision in people with simulated ULV, and its potential use as a robust method to assess functional vision in people with ULV. The portable design allows for easy transport and administration for home based evaluations, which would be an advantage in this population. Further investigation and validation is ongoing in an actual ULV population.

Thank you to all the participants who volunteered for the study. We would like to thank Chris Bradley for his assistance with the statistical analysis and Jack Black and Alfred Vinnett for their assistance with recruitment and testing.
Evaluation of the Motion Lagging Effect Induced by the Perceived Change of Velocity in Peripheral Vision

Bin Li, University of California, Berkeley

Human peripheral vision is differently processed in the brain compared to the foveal vision. This study investigates the motion perception in the periphery, specifically if one would detect any lagging or change in the velocity of the motion stimulus presented in the periphery, when an identical stimulus is presented in the foveal region. In this study, the subjects saw three 10 seconds visual stimuli with one video clip situated in the center and the other in one of the three peripheral positions, and were asked to foveate on the center and report if perceive any lag and/or velocity change in the peripheral video. From the experiment, a significant effect of the positions on the subject's perceived lag was found but not for the effect of the positions on the perceived change in velocity. The result suggests that humans perceives a pure lagging effect in their peripheral vision more readily than a velocity slowing effect, which corroborates the result from prior study.

Johnston, A., & Wright, M. J. (1986)
Lichtenstein, M. (1963)

I would like to thank Anjana Iyer and Diana Heath for their generous helps during the process.
Using dynamic contrast estimation to assess interocular summation for non-rivalrous stimuli in typical and atypical binocular vision

Kimberly Meier¹, Kristina Tarczy-Hornoch², Ione Fine¹, Geoffrey M Boynton¹

1: Department of Psychology, University of Washington
2: Department of Ophthalmology, Seattle Children’s Hospital

Interocular summation has been measured using a wide variety of stimuli, measurements, and models. Our goal was to develop an intuitive and robust measure of interocular summation that reflects naturalistic (non-rivalrous) conditions and provides a direct measure of the perceptual experience of the observer. Observers fixated a Gabor (2 cpd; 4 deg radius, orientation rotating at 1 deg/sec to minimize adaptation effects) through a stereoscope. Gabor contrast was slowly modulated at 1/8 Hz in one eye, and 1/6 Hz in the other. Subjects dynamically reported perceived contrast over time by manipulating a Thrustmaster Pro joystick.

With less than an hour of data per subject it was possible to estimate individual contrast response functions for each eye. Data were well fit by a simple model that indicated binocular summation varied across individuals, ranging from approximately quadratic summation to a max rule. The ratio of the best fitting gain parameters for the left and right eye were closely correlated with interocular contrast ratios measured using a previously-established interocular phase-offset technique (Kwon et al. 2014), including in participants with binocular dysfunction. Our dynamic perceived contrast task provides an intuitive, rapid and robust method for characterizing binocular summation in typical and atypical binocular vision such as amblyopia and strabismus, and is suitable for measuring BOLD responses to each eye independently in an fMRI scanner.
Repeatability and Reliability of Manual Cone Identification in Adaptive Optics Images of Choroideremia

Jessica I. W. Morgan,1,2 Yu You Jiang,1 Andrew M. Huang,1 Robert F. Cooper1,3
1 Scheie Eye Institute, Department of Ophthalmology
2 Center for Advanced Retinal and Ocular Therapeutics
3 Department of Psychology
University of Pennsylvania

Though adaptive optics scanning light ophthalmoscopy (AOSLO) has enabled visualization of the human cone photoreceptor mosaic, the reliability of quantifying cone metrics has not been determined, especially in images of retinal disease. Here, we assess intra- and inter-grader agreement of manual cone identifications in Choroideremia, an X-linked inherited retinal degeneration.

Using a custom AOSLO, split-detection images of the photoreceptor mosaic from 17 Choroideremia patients were acquired at locations surrounding the fovea and along all four meridians. Images were registered, montaged, and 204 regions of interest (ROIs) were selected. Three experienced graders manually identified cones in each of the ROIs. In addition, Grader 1 manually identified cones in all ROIs a second time at least six months later. True and false positive rates and Dice's coefficient were calculated for each ROI using Grader 1's first identifications as ground truth.

Intra-grader agreement was slightly higher than inter-grader agreement. Repeated measurements from Grader 1 gave a Dice coefficient of 0.873±0.058 with a true and false positive rate of 0.943±0.050 and 0.181±0.095, respectively. In comparison, inter-grader agreement yielded Dice coefficients of 0.850±0.090 and 0.814±0.079 for Graders 2 and 3, respectively (0.876±0.128 and 0.884±0.168, true positive rates; 0.159±0.087 and 0.226±0.109 false positive rates).

Manual cone identifications from AO images of Choroideremia show good intra- and inter-grader agreement. The measured agreement places limitations on expectations for algorithms that automatically identify cones in images of Choroideremia and will be needed for quantifying disease progression at the cellular level.

Conflicts of interest: JIWM US patent 8226236, AGTC funding. RFC consultant for MCW and Translational Imaging Innovations.
Poster Sessions
Friday, 20 September, 14:30 – 16:00
Saturday, 21 September, 11:00 – 12:30

Funding: NIH R01EY028601, NIH U01EY025477, NIH P30EY001583, Research to Prevent Blindness, Foundation Fighting Blindness, the F. M. Kirby Foundation, and the Paul and Evanina Mackall Foundation Trust.
Evaluation of brightness perception for a multi-planar volumetric display

Tatjana Pladere, Veronika Muravjova, Gunta Krumina

In the volumetric display, multiple planes with light scattering properties can be used to generate three-dimensional images with real volume. This structure of optical element is known to be facilitating depth perception, but at the same time limiting the maximum achievable luminance (Osmanis et al., 2018). Our study has aimed to test whether the structure of optical element affects brightness perception of the maximum luminance stimuli when demonstrated on different depth planes of the volumetric display.

Fifteen young participants with normal vision matched brightness of 6 deg x 6 deg stimuli presented on two displays in accord with the adaptive psychophysical procedure. The participant's task was to compare the brightness of the stimulus on the flat panel display (Samsung Electronics, S24C650) to the one on the volumetric display (LightSpace Technologies, x1405). The uniform background was ensured by covering the rest of monitors with dark coverage. Both displays were characterized using a Photo Research SpectraScan PR-655 spectroradiometer.

RGB to luminance conversion using gamma function approximation was employed to analyse the results of the psychophysical test. Overall, the average threshold appeared to be independent of stimuli demonstration in varying depth of the optical element, however, significant variation was present among participants. Mostly, the obtained results were slightly lower comparing with the actual luminance of stimuli on different planes (no significant difference was reached). Altogether, these findings indicate that users can perceive the maximum luminance visual stimulus on different depth planes of the volumetric display as equally bright.


The research has been funded by the University of Latvia and LightSpace Technologies Inc., the donation of SIA Miktotikls and the Foundation of the University of Latvia (the project No. 2184).
Optical manipulations affecting blur perception in one or both eyes

Eric S. Seemiller, Arthur Bradley, Pete S. Kollbaum

Visual scenes encompass multiple depth planes forcing the visual system to constantly process defocus in the retinal image. Defocus can be useful to drive accommodation or contribute to depth perception, but it is also the most prevalent contributor to poor spatial vision. In addition to accommodation, sensory processes may also seek to reduce the overall perception of blur, especially if defocus is mismatched between the eyes (anisometropia). This experiment aimed to determine blur detection thresholds and supra-threshold perception of blur in simulated anisometropia. It also investigated how higher order aberrations interact with defocus perceptually. Simulated retinal images were presented binocularly to optically-corrected and visually normal observers with a dual-screen mirror haploscope. Image simulations were independently generated for each eye with Fourier optics software (pupil diameter of 5 mm, Stiles-Crawford apodization). Using through-focus peak image quality as a reference image, subjects adjusted the spherical defocus in one or both eyes until the image was "just noticeably blurry". This was repeated 10 times in each condition (left eye defocus, right eye defocus or bilateral defocus). Anisometropic defocus thresholds (mean (+/- SD) = 0.472D ± 0.183D) were more than twice the bilateral defocus thresholds (0.219D ± 0.104D). In the presence of opposite-signed spherical aberration (0.2 microns), subjects tolerated nearly twice as much defocus (mean ratio = 1.87 ± 0.45) though peak image quality was considerably lower. This increase in blur tolerance will be discussed in the context of monocular and binocular neural blur suppression and also the effect it may have in targeted therapeutic anisometropia, such as monovision.
Luminance capture equiluminance in the 3-dimensional motion

Arthur Shapiro, Anthony LoPrete

Virtual Reality (VR) and Augmented Reality (AR) environments depend on binocular cues in order to create the perception of depth. However, the experience of depth can also be influenced by local adaptation, contrast, and other cues. Improvement of VR and AR environments therefore requires new techniques for efficiently measuring and understanding the interaction between color contrast and depth. To this end, we have created a novel display-the Pulfrich Helix--in which two columns of equally spaced dots move horizontally back and forth (see https://bit.ly/2O5cTrr). The dots create two types of motion: 1. when a darkening filter is placed over one eye, the dots become part of a three-dimensional helix spiraling around the central Y axis; 2. a low-frequency motion that tracks the intersection of the two columns of dots that move vertically and horizontally. Observers typically do not see the low-frequency motion; however, when the display is blurred, the helix motion dramatically disappears and the observer sees motion tracking up or down the screen. Here, we report that the vertical motion also overrides the perception of helical motion when all the dots are equiluminant with the background. Furthermore, the helical motion dramatically reappears when just one of the dots differs in luminance from the background. We measure the number and contrast of dots required to produce the perceptual change from 3D helix to vertical streaming. The results indicate that even very small luminance contrast signals capture the equiluminant information and turn two-dimensional equiluminant motion into a three-dimensional percept.
**Probing the role of S cones in human melatonin suppression**

**Manuel Spitschan, Christian Cajochen**

Melatonin suppression by light in humans is largely mediated by the photopigment melanopsin, which is expressed in the intrinsically photosensitive retinal ganglion cells (ipRGCs). Whether the cones and rods also robustly contribute to melatonin suppression is at present not known. In a within-subject 7h in-laboratory protocol individually timed to habitual bedtime, we probed the role of short-wavelength sensitive cones (S cones) in this process. In each of two sessions (order counterbalanced across participants), we exposed participants (n=21 total participated) to light differing in the amount of S cone excitation by more than 1 log unit, with minimal relative change in the L and M cones, melanopsin and rods. Throughout the protocol, at 30 minute intervals, saliva samples (for later melatonin assay) were collected. In addition, participants performed an auditory psychomotor vigilance test (auditory PVT) and provided subjective sleepiness judgments (KSS). During the light exposure phase, pupil size was measured using a head-mounted eye tracker. Salivary melatonin assays were performed using RIA. Forthcoming analyses will allow for inferences of the role of S cones in human melatonin suppression.

Wellcome Trust (204686/Z/16/Z)