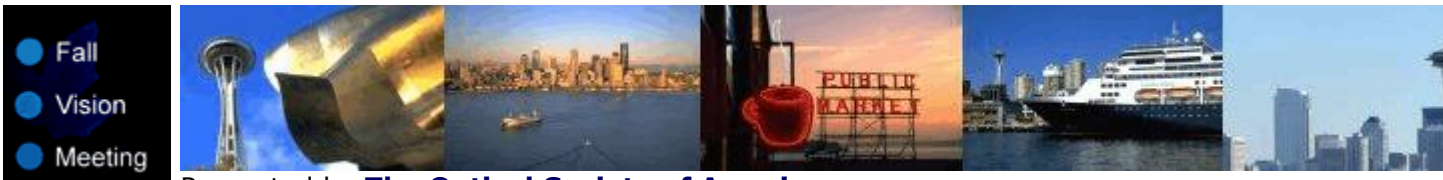

Presented by **The Optical Society of America**

OSAVM 2011

Held at The University of Washington, Seattle
Departments of Psychology and Ophthalmology

September 16 - 18, 2011

The OSA Fall Vision Meeting is a small, low-cost, high-quality annual scientific conference covering all aspects of vision research.

This conference has been generously sponsored by University of Washington, The Optical Society of America and .

Overview of the Conference

The Fall Vision Meeting is a single-track meeting meaning that attendees can see all presentations. Topics are arranged broadly around the four OSA Vision and Color technical groups: Vision, Color, Applications and Clinical. We accept submissions on all aspects of vision science.

Sessions for the 2011 Meeting are:

Classics of Vision Science
Moderator: Steve Buck
Speakers: Gerald Westheimer, John Robson, Tom Cornsweet, and Anita Hendrickson

Connectivity Maps in the Brain
The emerging field of connectomics has the potential to revolutionize our understanding of anatomical and functional neural networks. This session will delve into the current investigations of the connectivity of networks from retina to cortex.
Moderator: Alyssa Brewer
Speakers: Robert Marc, EJ Chichilnisky, David VanEssen, Bob Dougherty

Rehabilitation and Adaptation to Visual Impairment
Understanding the visual consequences of injury and disease, as well as the plasticity of the brain itself, provides new insight for the development of rehabilitation approaches that encourage and

improve adaptation and daily function. The work presented in this session explores adaptations to low vision, blindness and traumatic brain injury, the last of which has seen a marked increase due to the improvised explosive devices in modern warfare.
Moderator: Susana Chung
Speakers: Gordon Legge, Krystel Huxlin, Suzanne Wickum, Eli Peli

"What the Brain Doesn't See"
William James described the visual world of a baby "as one great blooming, buzzing confusion" and suggested that the role of a mature visual system is to filter out distracting, irrelevant stimuli. We are largely unaware of the degree to which this occurs all the time. In a few cases, however, there are percepts which are suppressed intermittently, allowing us to gain some insight into the underlying processes. In this session we examine four different examples of phenomena in which the brain actively suppresses suprathreshold stimuli.
Moderator: Jeff Mulligan
Speakers: Dov Sagi, Randolph Blake, George Sperling, Stephen Macknik

The Aging Visual System
As life expectancy continues to rise, there is an increasing desire to better understand age-related changes in the visual system. This session will explore current understandings of aging in topics ranging from spatial and color vision, to cortical organization, to neural mechanisms of memory and attention.
Moderator: Marilyn Schneck
Speakers: Sarah Elliott, Hugh Wilson, Allison Sekuler, Tony Morland

Cortical Pathways of Color Vision
The first stages of primate color vision, the transduction of light by three classes of cones and the subsequent recombination of these signals into cone opponent processes, are now understood in broad principle. The challenge ahead is to develop a better understanding of the way color is processed in the cortex. This symposium will highlight recent work that investigates cortical color processing, with talks that feature different physiological approaches and analyses across multiple cortical areas.
Moderator: Karl Gengenfurtner
Speakers: Greg Horwitz, Ann Roe, Soumya Chatterjee, Colin Clifford

Conference Organizers and Key Partners

Sponsoring Organization
The Optical Society of America

Director(s)
Joe Carroll
Chair, OSA Vision and Color

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Chair, OSA Vision and Color

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Funding and In-Kind Contributors

University of Washington
http://www.washington.edu

The Optical Society of America
http://www.osa.org

OSA Vision Meeting 2011

September 16 –18
University of Washington
Seattle, WA

Program Schedule

9/15
Thursday evening

6 – 9 pm **Welcome Reception**
Vista Café
William H. Foege building
(Genomic sciences and Bioengineering)

Many thanks to:
Betty Johanna
Phil Berger
Sheri Mizumori

With the generous support of:
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9/16
Friday morning

Talks in Kane Hall 220. Posters in Walker-Ames room, Kane 225.
Please set posters up 11 am – 12 pm Friday, remove by 2:00 pm Sunday.

8 – 8.45 am **Registration**
220 Kane Hall

8.45 -9 am **Welcoming Remarks**
220 Kane Hall

What the Brain Doesn't See
Moderator: Bruce Bridgeman, UC Santa Cruz

9-9.20 am **Perceptual properties of consciously unavailable stimuli [T1]**
Dov Sagi, The Weizmann Institute of Science
Yoram Bonneh, The Weizmann Institute of Science

9.20-9.40 am **The role of feedback circuits in visibility, attention, and awareness [T2]**
Stephen L. Macknik, Barrow Neurological Institute
Susana Martinez-Conde, Barrow Neurological Institute

9.40-10 am **Binocular rivalry [T3]**
Randolph Blake, Vanderbilt University & Seoul National University

10-10:20 am **Measuring the perceptual strengths of visible and invisible stimuli in binocular combination and in binocular rivalry [T4]**
George Sperling, UC Irvine

10:20-11 am **Discussion**

11 -11.30 am **COFFEE BREAK**

11.30 – 12pm **SPECTRUM RECOVERY AWARD**
220 Kane Hall

1 – 2.30 pm **LUNCH BREAK**
Please see the back of the program for suggestions on where to lunch

9/16
Friday afternoon & evening

Cortical Pathways of Color Vision

Moderator: Karl Gegenfurtner, Giessen University

1.30-1.50 pm **Functional Connectivity of Color and Form in V1 and V2 [T5]**
Anna Roe, Vanderbilt University

1.50-2.10 pm **Adaptive measurements of color tuning in macaque V1 [T6]**
Greg Horwitz, University of Washington

2.10-2.30 pm **Micromaps and blobs: fine structure of color representation in primary visual cortex [T7]**
Soumya Chatterjee, Harvard Medical School

2.30-2.50 pm **Representation of color in human visual cortex [T8]**
Colin W.G. Clifford, University of Sydney

2:50-3.30 pm **Discussion**

3.30 – 5 pm **POSTER SESSION**
Walker Ames Room, Kane 225
With refreshments

5 – 6 pm **ROBERT M. BOYNTON LECTURE**
Neural origins of color and spatial coding in the primate retina
Dennis Dacey
University of Washington

6.30 – 9 pm **BANQUET**
University of Washington Club

9/17
Saturday morning

The aging visual system

Moderator: **Marilyn E. Schneck**, Smith Kettlewell Eye Research Institute

8.30-8.50 am **Optical and neural factors contributing to age-related losses in spatial vision [T9]**
Sarah Elliott, University of Chicago

8.50-9.10 am **The effects of aging on vision: Plasticity and tradeoffs [T10]**
Allison B. Sekuler, McMaster University

9.10-9.30 am **Visual Deficits During Healthy Aging of the Ventral Pathway [T11]**
Hugh Wilson, York University Centre for Vision Research
Frances Wilkinson, York University Centre for Vision Research

9.30-9.50 am **Organization of primary visual maps in patients with retinal lesions [T12]**
Antony Morland, University of York

9:50-10.30 am **Discussion**

10.30 – 12 pm **POSTER SESSION**
Walker Ames Room, Kane 225
With refreshments

12 – 2 pm **LUNCH BREAK**
Please see back of program for suggestions on where to lunch

9/17
Saturday afternoon & evening

Contributed Talks, Session 1

Moderator: Alex Wade, University of York

2-2.15 pm **FMRI of the Rod Scotoma: Cortical Projections, Filling-In and Insights into Plasticity [T13]**
Brian Barton & Alyssa Brewer, UC Irvine

2.15-2.30 pm **Apparent retinotopic reorganization in human visual cortex with central pathology [T14]**
Danielle Reitsma, Mary Jo Maciejewski, Viktor Szeder, Douglas Ward, John Ulmer, Wade Mueller, Bernd Remler, Edgar DeYoe, The Medical College of Wisconsin, Radiology

2.30-2.45 pm **Measurement of Motion Detection Thresholds under Natural and Manipulated Retinal Image Motion Conditions [T15]**
Nicole M. Putnam[1] , Pavan Tiruveedhula[1], Qiang Yang[2], David W. Arathorn[2], Scott B. Stevenson[3], Austin Roorda[1]
UC Berkeley (1), 2. Montana State University(2), University of Houston (3)

2.45-3 pm **Adaptation and the perception of structure in radiological images [T16]**
Elysse Kompaniez[1], Craig K. Abbey [2,3], John M. Boone[3], Michael A. Webster[1]
University of Nevada, Reno (1), UC Santa Barbara (2), UC Davis (3)

3-3.15 pm **Efficient integration of local perceived blur in discrimination and matching [T17]**
Christopher Taylor & Peter Bex, Harvard Medical School

3.15-3.30 pm **Dynamics and neural computations underlying visual masking [T18]**
Jeffrey Tsai[1], Alexander Wade[1], Anthony Norcia[2]
Smith-Kettlewell Eye Research Institute (1), Stanford University (2)

3.30 – 4 pm **COFFEE**

Classics of Vision Science

Moderator: **Steven L. Buck**, University of Washington

4-4.20 pm **The Disappearance of Steadily Fixated Visual Test Objects [T19]**
Tom N. Cornsweet, UC Irvine

4.20-4.40 pm **Unraveling the primate fovea during development [T20]**
Anita E. Hendrickson, University of Washington

4.40-5 pm **Gratings: the early years [T21]**
John G. Robson, University of Houston

5-5.20 pm **Visual hyperacuity and optical super-resolution [T22]**
Gerald Westheimer, UC Berkeley

5.20-6 pm **Discussion**

6 – 8 pm **POSTER SESSION**
Walker Ames Room, Kane 225
With refreshments

9/18
Sunday morning

Rehabilitation and Aging

Moderator: Susana Chung, UC Berkeley

8.30-8.50 am **Challenging the Dogma of Visual Rehabilitation for Cortical Blindness - Perceptual Re-Learning in V1-Damaged Humans [T23]**
Krystel R. Huxlin, University of Rochester

8.50-9.10 am **Low Vision and Brain Plasticity [T24]**
Gordon E Legge, University of Minnesota

9.10-9.30 am **Driving with Hemianopia [T25]**
Eli Peli & Alex Bowers, Harvard Medical School

9.30-9.50 am **Visual Deficits & Rehabilitation After Acquired Brain Injury [T26]**
Suzanne Wickum, University of Houston

9.50-10.30 am **Discussion**

10.30 – 11 am **COFFEE**

Contributed Talks, Session 2

Moderator: **David Brainard,** University of Pennsylvania

11-11.15 am **Cone-Selective Connectivity in P-Pathway Cells of the Macaque Monkey [T27]**
Barry Lee[1], Robert Shapley[1], Michael Hawken[2], Hao Sun[1] , The State University of New York (1), New York University (2)

11.15-11.30 am **S-Cone Induced Cortical activity Despite an ON-Pathway Defect; a BOLD fMRI-Based Case Study [T28]**
Andrew Salzwedel[1], Matthew Mauck[1], Jay Neitz[2], Edgar DeYoe[1], Medical College of Wisconsin (1), University of Washington (2)

11.30-11.45 am **When Red Plus Red Makes White [T29]**
Jenny Bosten and Donald MacLeod, UC San Diego

11.45-12 pm **A paradox of color discrimination [T30]**
John Mollon[1] and Marina Danilova[2], Cambridge University (1), Russian Academy of Sciences (2)

12-12.15 pm **Speed of Material vs. Object Recognition Depends upon Viewing Condition[T31]**
Bei Xiao[1], Lavanya Sharan[2], Ruth Rosenholtz[1], Edward Adelson[1], Massachusetts Institute of Technology, (1), Disney Research (2)

12.15-12.30 pm **Decoding chromatically-tuned suppressive fields in early visual cortex [T32]**
Alex Wade[1] & Jess Rowland[2], University of York, (1) New York University (2)

12.30 – 2 pm **LUNCH BREAK & POSTER REMOVAL**

9/18
Sunday afternoon

2– 2.30 pm **BUSINESS MEETING**
YOUNG INVESTIGATOR AWARD

Connectivity Maps in the Brain

Moderator: Alyssa Brewer, UC Irvine

2.30-2.50 pm **Network Discovery in the Retinal Connectome [T33]**
Robert E. Marc, University of Utah

2.50-3.10 pm **Functional connectivity in the retina at the elementary resolution of photoreceptors [T34]**
E.J. Chichilnisky, Salk Institute

3.10-3.30 pm **Connections in the brain [T35]**
Robert F. Dougherty, Stanford University

3.30-3.50 pm **The Human Connectome Project [T36]**
David C. Van Essen, Washington University

3.50-4.30 pm **Discussion**

4.30 – 4.45 pm **Final Remarks**

Poster Presentations

P1: Validation of Image Filters for Studies of Visual Accessibility
Paul Beckmann*, Gordon Legge, Christopher Kallie, William Thompson
* University of Minnesota

P2: Chromatic and Luminance Contrast Sensitivity in Preterm and Fullterm Infants: Possible "Sleeper" Effect of Early Postnatal Visual Experience
Rain Bosworth*, Karen Dobkins
* University of California, San Diego

P3: Static and Dynamic Measures of Visual Performance in Athletes
Emily R. Bovier*, Kevin J. O'Brien, Stephanie Ross, Lisa M. Renzi
* University of Georgia

P4: Aging and Dementia in Human Visual Cortex: Visual Field Map Organization and Population Receptive Fields
Alyssa Brewer*, Brian Barton
* University of California, Irvine

P5: Optical Illusions on the Slopes of Hill
Bruce Bridgeman, University of California, Santa Cruz

P6: Rod Hue Biases Produced on CRT Display
Steven L. Buck*, Ryan Juve, David Wisner, Aldebert Concepcion
* University of Washington

P7: Orientation Bandwidth Requirement for Face Identification in Foveal and Peripheral Vision
Andrea Chai*, Deyue Yu, Susana Chung
*University of California

P8: Ability of the Visually Impaired to Perceive Distance from Auditory Cues
Silvia Cirstea*, Andrew Kolarik, Komal Ramlagun, Shahina Pardhan
* Anglia Ruskin University

P9: Individual differences in cone ratio: Measurements by counterphase modulation photometry and by spatial acuity
Marina Danilova*, Chloe Chan, John Mollon
* I.P. Pavlov Institute of Physiology

P10: A New Genetic Assay for Color Vision Deficiency Outperforms Behavioral Tests
Candice Davidoff*, Jay Neitz, Maureen Neitz
* University of Washington

P11: Measuring the Temporal Contrast Sensitivity Function and Macular Pigment Optical Density in Older Adults with and Without Cognitive Impairment
Melissa Dengler*, Anna Thorne, Antonio Puente, Ashley Watts, Billy Hammond, Lloyd Miller, Lisa Renzi

* University of Georgia

P12: Color Appearance of Monochromatic Test Stimuli: An Analysis of Unique Hue Loci in the Vertical and Horizontal Meridians
Nathaniel Douda*, Katherine Mussell, Vicki Volbrecht , Janice Nerger
* Colorado State University

P13: Pediatric Retinal Imaging with SD-OCT
Adam M Dubis*, Sean O Hansen, Deborah M Costakos, William J Wirostko
* Medical College of Wisconsin

P14: Influences of Macular Pigment on Visibility
Laura Fletcher*, Billy Hammond
* University of Georgia

P15: The Luminance Balance and Color Appearance Mode of Surrounding Colors Affect Color Constancy
Kazuho Fukuda*, Keiji Uchikawa, Donald I. A. MacLeod
* Tokyo Institute of Technology

P16: Range Normalization in the Luminance-to-Lightness Mapping
Alan Gilchrist*, Steve Ivory,
* Rutgers University

P17: S-opsin Knockout Mouse Models Cone Dysfunction Associated with a Toxic L/M-opsin Interchange Variant
Scott Greenwald*, James Kuchenbecker, Dan Roberson, Maureen Neitz, Jay Neitz
* University of Washington

P18: Objective Measurement of Transverse Chromatic Aberration with the Adaptive Optics Scanning Laser Ophthalmoscope
Wolf Harmening*, Austin Roorda
*University of California, Berkeley

P19: Physiological Correlates of Apparent Modulation Frequency
Chris Jones*, Chad Duncan, Shane McGuire, Shannon McGuire, Hannah Shoenhard, Arthur Shapiro, Michael Crognale,
* University of Nevada, Reno

P20: Intraretinal Aaxon Collaterals of Melanopsin Cells in Primate and Mouse Suggest a Novel Synaptic Pathway for Feedback of Irradiance Information to the Retina
Hannah R. Joo*, S.K. Chen, Beth B. Peterson, Dennis M. Dacey, Samer Hattar
* Johns Hopkins University

P21: Cortical Visual Function in Infants with Polymicrogyria (PMG) Compared to Controls
John Kelly*, Avery Weiss
* Seattle Children's Hospital

P22: Effects of Luminance and Color Conditions on Color Spreading in Flank Transparency Displays
Eiji Kimura*
Chiba University, Psychology

P23: Can Subjects Tailor Their Detection Strategy to Match Expected Stimulus Size at Absolute Cone Threshold?
Darren Koenig*, Heidi Hofer
* University of Houston

P24: The Neural Locus Where Cone Signals Are Combined for Hue Perception
James Kuchenbecker*, Maureen Neitz, Jay Neitz
* University of Washington

P25: The Source of Overlay Masking in the Human Visual System
Damien Mannion*, Jeff Tsai, Alex Wade
* Smith-Kettlewell Eye Research Institute & University of California, San Francisco

P26: Effects of Lightness on Chromaticity Regions to Yield Gold, Silver and Bronze Colors
Tomohisa Matsumoto*, Kazuho Fukuda, Keiji Uchikawa
* Tokyo Institute of Technology

P27: Optical Design of Hyperspectral Two-dimensional Display and its Application
Toshifumi Mihashi*, Naoki Nakamura, Keisuke Yoshida, Tatsuo Yamaguchi, Yasuki Yamauchi, Katsuaki Sakata, Kazuho Fukuda, Keiji Uchikawae
* Topcon Corp.

P28: An Eye-Movement-Defined Hierarchy of Visual Stimuli
Jeffrey Mulligan*, Scott Stevenson
* NASA Ames Research Center

P29: The Effect of Dot Speed and Density on the Maturation of Global Motion Perception
Sathyasri Narasimhan* , Deborah Giaschi
* University of British Columbia

P30: Influence of Luminance vs. Chromaticity Distribution of Surrounding Surfaces on Luminosity Threshold of a Surface Color
Ai Numata*, Tec Kazuho Fukuda, Keiji Uchikawa
* Tokyo Institute of Technology

P31: Determining Heterochromatic Flicker Photometry Frequency for Macular Pigment Optical Densitometry by Critical Flicker Fusion Frequency
Kevin O'Brien*, Bill Smollon, Bill Wooten, Billy Hammond
* University of Georgia

P32: Mid-level Pattern Masking: Contrast or Response Gain Control?
Lynn A. Olzak*, Jordan R. Wagge, Robin D. Thomas
* Miami University of Ohio

P33: Comparison of Macular Pigment Optical Density Spatial Profiles Measured Using Two-Wavelength Autofluorescence with Foveal Pit Morphology
Ginger Pocock*, Max Snodderly, Maka Malania, William Bosking,
* University of Texas at Austin

P34: Adaptation to Alterations of Three-Dimensional Space Perception in Stereoscopic Displays
Anne-Emmanuelle Priot*, Olivier Sillan, Corinne Roumes, Claude Prablanc
* Institut de recherche biomédicale des armées

P35: Numerosity Estimation Is Not Derived Only from Density and Size Judgments
Sabine Raphael*, Barbara Dillenburger, Michael Morgan
* Max-Planck Institute for Neurological Research

P36: The McCollough Aftereffect Strength Varies with Test Chromaticity: Local Distortions in Color Space
Alan Robinson*, Donald MacLeod
* University of California, San Diego

P37: Measuring Volume Scotoma in Bitemporal, Binasal and Central Field Loss
PremNandhini Satgunam*, Eli Peli
* Harvard Medical School

P38: Image Correlates of Peripheral Contour Discrimination in Natural Scenes
Thomas Wallis*, Peter Bex
* Schepens Eye Research Institute & Harvard Medical School

P39: Abnormalities in Distribution and Transformation of Visual Inputs in Children with CVI
Avery Weiss*, John Kelly, James Phillips
* Seattle Children's Hospital

P40: Evaluation of Relationship between Fusional Range and Visual Fatigue
Shoji Yamamoto*,Kyosuke Takahashi, Toshiya Nakaguchi, Norimichi Tsumura
* Tokyo Metropolitan College of Industrial Technology

P41: Visual Perception of Surfaces with Transparent Layers
Kazuki Yoshida*, Isamu Motoyoshi, Kazuho Fukuda, Keiji Uchikawa
* Tokyo Institute of Technology

Welcome to the University of Washington!

OSA Vision and Color Division Leadership

Joseph Carroll, Medical College of Wisconsin (Division Chair)
Jennifer Hunter, University of Rochester (FiO Subcommittee Chair)

Clinical Vision Sciences Technical Group

Jason Porter, University of Houston (Chair)
Rowan Candy, Indiana University (Vice-Chair)

Applications of Visual Science Technical Group

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Laura Walker-Renninger, SKERI (Vice-Chair)

Vision Technical Group

Alyssa Brewer, University of California, Irvine (Chair)
Jeff Mulligan, NASA (Vice-Chair)

Color Technical Group

Kathy Mullen, McGill University (Chair)
David Brainard, University of Pennsylvania (Vice-Chair)

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Steve Buck, University of Washington
Ione Fine, University of Washington
Jay Neitz, University of Washington

Web Site

Alex Wade, York University

Joseph Carroll
Chair, OSA Vision and Color Division
Medical College of Wisconsin

Steven Buck, Jay Neitz & Ione Fine
Chairs, Local Organizing Committee

General Information

- The Deca, University Inn and Watertown hotels, Vista café (Thurs reception) and UW Faculty Club (Banquet) are within a 10 min walk from Kane Hall. Please speak to one of the local organizers if you have special transport needs.

- Meal tickets for the banquet are in your registration packet if requested on your registration form. For any last minute banquet questions please talk to Steve Buck.

- The Young Investigator Award is an OSA tradition and will be awarded to the student or postdoc who gives the best presentation at the meeting. Poster and paper presentations will be considered equally and invited speakers are not eligible.

- There will be a public wireless network at Kane Hall. For access, please contact a local organizer.

- Please remember to turn off all cell phones, PDAs, and pagers during the talks.

Poster Instructions

- Your poster should be put up between 11:00 am and 12:00 pm Friday, September 16. The poster session will be held in the Walker-Ames room Kane 225, which is close to the meeting room. You are asked to stay with your poster from 3:30-5pm Friday (even-numbered posters) or 10.30-12am Saturday (odd-numbered posters). Please remove your poster 1:00 - 2:00 pm Sunday since the poster boards will be removed after that.

- The posters should be prepared to fit on an approximately 4 ft (tall) x 8 ft poster board.

- All boards will be numbered. Attach your poster to the board that corresponds to your number on the "Poster Presentations" list that follows this page in the program booklet.

- Bring pushpins for attaching your poster. Do not use tape. We will have a limited supply of pushpins available at the registration desk should you be unable to bring your own.

- Do not try to mount heavy materials, as they will have difficulty staying attached to the foam core poster board.

- There will be staff available if you have any difficulties putting up your poster.

Robert M. Boynton Lecture

The 2011 Robert M. Boynton Lecture, "Neural origins of color and spatial coding in the primate retina" will be given by Dennis Dacey. Dennis received his PhD in 1983 from the University of Chicago working with Phil Ulinski on the evolution and neural organization of the reptilian brain and then traveled to Sydney, Australia where he completed a postdoctoral fellowship with Jonathan Stone studying the physiology and morphology of cat retinal ganglion cells. Dennis moved to Seattle in 1986 where he began work on the primate retina with Bob Rodieck in the Department of Ophthalmology. He subsequently made Seattle his home joining the Department of Biological Structure in 1989 and the Neuroscience Core Staff in the National Primate Research Center at the UW in 1998.

Dacey is a neurobiologist who, for the last 25 years, has focused his work on the organization of the primate retina. He pioneered the development of a physiologically viable in vitro retinal preparation opening the door to a greater understanding of the full complexity of the neural retina and how a plurality of cell types and circuits contributes to the creation of parallel visual pathways. With long-time collaborators Vivianne Smith, Joel Pokorny and Barry Lee, Dacey applied intracellular recording and staining methods to explore the neural origins of cone-opponency in primate retinal ganglion cells, a question of fundamental interest to Bob Boynton in an earlier era. Dacey received the Paul Kayser International Award of Merit in Retinal Research in 2002 from the International Society for Eye Research and the Retinal Research Foundation and was the 2004 recipient of the Rank Foundation Prize in Optoelectronics together with Smith, Pokorny and Lee.

His lecture will address the fundamental synaptic mechanisms that determine how signals from the cone photoreceptors are combined in the retinal circuit to initiate parallel color-opponent and achromatic pathways. All modern accounts of early visual processing distinguish an initial trichromatic sampling of the retinal image by the long (L), middle (M) and short (S) wavelength sensitive cones followed by a postreceptoral stage in which cone signals are combined to form an achromatic or luminance channel (L+M) and two chromatic or cone-opponent channels (L-M and S-(L+M). A longstanding question that will be one focus in today's lecture is the relationship of these 'cardinal' postreceptoral mechanisms defined psychophysically and the parallel pathways from retina to primary visual cortex defined physiologically. A second outstanding question that will be considered is the degree to which highly selective, cone-type specific wiring is employed by retinal circuitry and the implications for the evolution and functional roles of the unique 'midget' circuit in the primate retina.

Robert M. Boynton Lecture - Selected References

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McMahon MJ, Packer OS, Dacey DM (2004) The classical receptive field surround of primate parasol ganglion cells is mediated primarily by a non-GABAergic pathway. *Journal of Neuroscience, 24*(15):3736-3745.

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VISION SCIENCE AT THE UNIVERSITY OF WASHINGTON

Department of Psychology

Geoffrey Boynton uses fMRI and behavioral measurements to study the relationship between neuronal responses in the visual cortex of the brain and conscious experience.

Steven L. Buck examines the effects of rod-cone interactions on human visual perception, especially color vision.

Ione Fine examines the effects of long term visual deprivation on human visual, tactile and auditory processing.

Scott O. Murray uses fMRI and behavioral measurements to examine attention, the neural mechanisms of object recognition, and other high level visual processes.

Jaime F. Olavarria studies the organization, function and development of neuronal pathways in the mammalian central visual system.

John Palmer focuses on the psychophysical measurement of attentional effects on behavior.

Department of Ophthalmology

John Kelly specializes in the research, diagnosis and treatment of blinding disorders in children and adults.

Jay Neitz examines the interplay of visual experience and genetics both in normal vision and in vision disorders using a combination of molecular genetic, biochemical, imaging, electrophysiological and behavioral approaches.

Maureen Neitz studies cone-based vision using a multidisciplinary approach ranging from genetics to behavior.

Tueng Shen uses a bioengineering approach to development of artificial corneas, drug eluting intraocular lenses, and embedded sensors in ocular devices.

Mike Mustari studies the neurophysiology of eye movements and eye movement disorders in primate models

Jennifer Chao utilizes stem cell technologies to study the physiology of retinal degeneration, using patient-derived induced pluripotent progenitor cell techniques.

Murray Johnstone uses ultrastructural imaging to understand the structure and function of the trabecular meshwork in the primate and human eye

Avery H. Weiss specializes in the assessment of visual function and development, including the ability to quantify vision in preverbal infants or nonverbal children using behavioral and visual-evoked potential techniques and the development of normal and abnormal eye movements.

Russell Van Gelder studies non-visual photoreception and the development of techniques to confer photosensitivity to non-photoreceptive cells in the retina.

Department of Physiology & Biophysics

Adrienne Fairhall is interested in the computational principles underlying information representation and processing in the nervous system, particularly the mechanisms and dynamics of adaptation.

Albert F. Fuchs examines how a sensory stimulus elicits an appropriate eye movement response using a variety of neurobiological approaches.

Greg Horwitz uses electrophysiology, psychophysics and computational modeling to examine color perception.

Fred Rieke combines quantitative physiological experiments and theory to understand how the biophysical mechanisms involved in phototransduction, synaptic transmission, and neural coding contribute to adaptation.

Michael Rudd combines psychophysical methods with computational modeling of perceptual and neural data to investigate the physiological basis of lightness and brightness perception.

Michael N. Shadlen examines how visual information is transformed from evidence in a sensory map to a perceptual judgment that motivates behavior by combining electrophysiological, psychophysical and computational techniques.

Peter Detwiler is studying how a prototypic signal transduction pathway works by examining the molecular mechanisms by which retinal rod photoreceptor cells detect and respond to light.

Sharona Gordon examines the molecular mechanisms by which an ion channel can integrate disparate sensory signals using a combination of molecular biology, biochemistry, and electrophysiology.

William Zagotta examines how cyclic nucleotide-activated channels mediate the generation of an electrical response to light in rods and cones of the vertebrate retina using a combination of molecular biology and patch-clamp techniques.

Department of Biological Structure

John Clark uses recombinant expression of proteins, site directed mutagenesis and transgenic animals in the investigation of the molecular and cellular basis for lens cell transparency in normal aging and in association with neurodegenerative diseases.

Dennis M. Dacey studies the functional organization of the macaque retina as a model for understanding the early stages of the human visual processing.

Orin Packer uses anatomical and physiological techniques to study how the photoreceptors of the primate retina sample the retinal image and how retinal microcircuitry codes chromatic and spatial information.

Anitha Pasupathy focuses on the neural basis of visual shape perception and recognition using a combination of single cell neurophysiological studies in awake monkeys, behavioral manipulations, computational modeling and reversible inactivation techniques.

Tom Reh studies the mechanisms which control neuronal proliferation and differentiation during neurogenesis of the vertebrate central nervous system by examining both developing and regenerating retina using in vivo and in vitro experimental approaches.

Ric Robinson uses eye movements in trained monkeys to study the role of the cerebellum in voluntary movements using a combination of cell recording, anatomical tracing, and temporary cerebellar deactivation.

Helen Sherk examines how animals use visual cues during locomotion by recording and modeling neuronal population responses to naturalistic movies within cat visual cortex.

Rachel Wong assesses structural and functional changes in developing retinas with normal or perturbed cell-cell communication using live-cell imaging approaches, and electrophysiological techniques.

Department of Biochemistry

James B. Hurley is identifying the molecules and mechanisms responsible for photoexcitation, recovery and adaptation and survival of photoreceptors in the retina.

Susan Brockerhoff studies the biology of the zebra fish cone photoreceptor with the goal of dissecting the molecular basis of human retinal disease.

Department of Bioengineering

Ricky Wang is developing next-generation optical coherence tomography techniques for the analysis of anatomic abnormalities and blood flow alterations in a variety of retinal diseases

Talk Session Abstracts

What the Brain Doesn't See

Moderator: Bruce Bridgeman, University of California, Santa Cruz

William James described the visual world of a baby "as one great blooming, buzzing confusion" and suggested that the role of a mature visual system is to filter out distracting, irrelevant stimuli. We are largely unaware of the degree to which this occurs all the time. In a few cases, however, there are percepts which are suppressed intermittently, allowing us to gain some insight into the underlying processes. In this session we examine four different examples of phenomena in which the brain actively suppresses suprathreshold stimuli.

T1 Perceptual properties of consciously unavailable stimuli

Dov Sagi, The Weizmann Institute of Science, Neurobiology
Yoram Bonneh, The Weizmann Institute of Science, Neurobiology

Motion-induced-blindness (MIB) is used to examine accessible properties of high-contrast visual objects which are not consciously available. Visual stimuli consist of a static Gabor target embedded in a rotating grid. Under such conditions, the target perceptually disappears within a few seconds. Following Observers' report of disappearance, a high-contrast Gabor cue is presented. The cue effect on the reappearance of the target within the limited trial time is examined. Surprisingly, results show very low reappearance rates when cues are remote from the target or when orthogonal to it, even when proximal. High reappearance rates are observed with cues proximal and similar to the target. Plaid targets reappear with components cues and plaid cues, however plaid cues are not very effective with component targets. It seems that subconscious objects preserve their location and components-orientation, demonstrating that visual processes sensitive to proximity and feature-similarity operate across the boundary of consciousness. By controlling the duration of target presentation we find that ”reactivating” the target may take 200-400 msecs, depending on the depth of suppression.

T2 The role of feedback circuits in visibility, attention, and awareness

Stephen L. Macknik, Barrow Neurological Institute, Laboratory of Behavioral Neurophysiology
Susana Martinez-Conde, Barrow Neurological Institute, Laboratory of Visual Neuroscience

The mammalian visual system includes numerous brain areas that are profusely interconnected. With few exceptions, these connections are reciprocal. Feedback connections usually outnumber feedforward connections by about an order of magnitude, leading to widespread speculation that feedback connections play a critical role in visual awareness. However, evidence from physiological experiments that use illusions of invisibility as well as cognitive manipulation of the attentional spotlight suggest that feedback plays a modulatory role, rather than a driving role. In the primary visual cortex, attentional feedback has an exquisitely precise mechanistic pathway of action involving specific neuronal populations that reveal attention to be a form of surround-suppression. That is, focal attentional enhancement occurs as a function of suppressed neuronal activity in the surround, and therefore increased signal: noise is achieved in the focus because input from the surround otherwise serves as noise. Here we discuss theoretical constraints on the significance of feedback's anatomical numerical advantage and specificity, and we describe theoretical limits on feedback's potential physiological impact. These restrictions confine the potential role of feedback in visual awareness and rule out some extant models of visual awareness that require a fundamental role of feedback. These ideas further predict a mechanism for visual misdirection in magic tricks, based on the magician's successful manipulation of the spectator's focus of attention.

T3 Binocular rivalry

Randolph Blake, Vanderbilt University & Seoul National University

Binocular rivalry is often touted as an effective tool for studying the neural concomitants of consciousness, a justifiable claim given that rivalry entails complete perceptual erasure of an ordinarily visible stimulus for seconds at a time. My talk summarizes emerging insights about rivalry's underlying processes and documents how those insights have shaped the evolution of models of rivalry over the past two decades, a period of time during which interest in rivalry has exploded. Two themes run throughout the talk. The first centers around the extent to which a stimulus suppressed from perceptual awareness during rivalry remains effective as assessed using psychophysical and brain imaging techniques. Evidence bearing on that question implies that some aspects of a stimulus are less susceptible to interocular suppression than are others. Interocular suppression thus operates like the chemical process of fractional distillation, separating qualia comprising visual awareness of objects and events. A second theme focuses on the influence of visual cognition and non-visual "top-down" factors, including motor control, on the dynamics of binocular rivalry. Time permitting, I will speculate about emerging questions that could shape work on rivalry during the next several years, including the bases of the large individual differences in rivalry dynamics.

T4 Measuring the perceptual strengths of visible and invisible stimuli in binocular combination and in binocular rivalry

George Sperling, University of California, Irvine, Cognitive Sciences

Two types of experiments are reviewed that measure the separate (unconscious) perceptual strengths of images processed by each eye while the observer perceives only a combined, single cyclopean image. The first experiment deals with an enigma: when the two eyes view identical high-contrast stimuli and then one eye closes, perceptually, nothing seems to change. Does this mean that only one eye's stimulus was used for the cyclopean perception? In fact, when the two eyes receive similar stimuli but possibly of different contrasts, both stimuli contribute to the cyclopean image approximately in proportion to a power, typically about 2, of their overall contrast (Ding and Sperling, PNAS, 2006). The authors demonstrate a neural competition mechanism that accounts for both the power law and the enigma. The second group of experiments (Bartels and Logothetis, JOV, 2010) explores the time course of binocular rivalry in which very different images are presented to the two eyes and only one is perceived. A re-analysis of their data enables measurement of the relative strengths of the two components of perceptual image strength, one related to the eye receiving the image and the other to the nature of the image itself. Both components decline in strength linearly and in parallel as a function of time since stimulus onset.

Cortical Pathways of Color Vision

Moderator: Karl Gegenfurtner , Giessen University, Psychology

The first stages of primate color vision, the transduction of light by three classes of cones and the subsequent recombination of these signals into cone opponent processes, are now understood in broad principle. The challenge ahead is to develop a better understanding of the way color is processed in the cortex. This symposium will highlight recent work that investigates cortical color processing, with talks that feature different physiological approaches and analyses across multiple cortical areas.

T5 Functional Connectivity of Color and Form in V1 and V2

Anna Roe, Vanderbilt University, Psychology

The encoding of visual object perception is achieved at early visual processing stages by distinct circuitry for object surface (e.g. color) and object shape (e.g. contour) features. In Macaque monkeys, within primary visual cortex (V1), blobs and interblobs are associated with color and form processing, respectively; in the second visual area (V2), color and form are associated with distinct functional stripes. However, little is known about the functional circuitry between such structures. We have examined functional interactions within and between color and form pathways in V1 and V2 by conducting cross correlation studies of pairs of V1-V2 neurons. We find evidence for two distinct functional networks between V1 and V2. The network for color tends to be color-matched and is characterized by a broad divergent network capable of linking distant locations in the visual field. We find V1-V2 form networks are of two types: a more tightly synchronized, orientation-preserving network and a less synchronized orientation-diverse network. In contrast to the divergence of color networks, the form network is more spatially focused, exhibiting only local spatial interactions. Our examination of interactions between surface and form suggests the presence of a border-to-surface direction of information flow. We suggest that such diversity of V1-V2 interactions underlies the spatial and functional integration required for computation of higher order surface and form perception.

T6 Adaptive measurements of color tuning in macaque V1

Greg Horwitz, University Washington, Physiology & Biophysics & Washington National Primate Research Center

Color processing in the cortex can be understood as a set of mathematical operations on signals originating in the cone photoreceptors. Linear approximations to these operations have been instructive in the retina and LGN but less so in V1. Under a linear model, any set of stimuli that evoke the same response should lie on a plane in color space. This prediction holds irrespective of static output nonlinearities and thus can apply to complex as well as simple cells. We measured isoresponse surfaces for 118 V1 neurons in cone contrast space and found that 40% conformed to this prediction. Data from the remaining 60% were better fit by quadratic surfaces. Some quadratic surfaces were cup-shaped, indicating sensitivity to narrow regions of color space. Others were ellipsoidal, indicating sensitivity to all color directions. The principal axes of quadratic surfaces tended to be aligned with L-M, L+M, and S directions, showing that these directions provide a useful basis for describing the color tuning of V1 neurons. Our results demonstrate that cone signals combine nonlinearly in V1 and represent a step towards a complete description of the operations that characterize color processing in the cortex.

T7 Micromaps and blobs: fine structure of color representation in primary visual cortex

Soumya Chatterjee, Harvard Medical School, Neurobiology

Electrophysiological and optical imaging studies have made a strong case for the existence of a functional architecture related to color selectivity in V1. The known architecture comprises small cortical patches, roughly centered on cytochrome oxidase blobs, that respond preferentially to chromatic visual stimulation. There are hints of richer substructure within these color patches, but the resolution limits of intrinsic optical imaging, as well as the difficulty of inferring functional geometry from single-unit recordings, have precluded a more detailed description.
To bridge the gap, we used two-photon calcium imaging to create maps of color selectivity at single-cell resolution in V1 of the adult macaque. With spatially uniform cone-isolating stimuli, we found that there are unambiguous ensembles of segregated color cells. The ensembles can be further subdivided into small clusters of cells with distinct chromatic preferences, in effect creating micromaps of color within larger color clusters. These micromaps

form functional columns that are in register with blobs.

Further, we compared responses to both spatially uniform and spatially structured cone-isolating stimuli. Uniform stimuli invariably produced tightly segregated color responses centered on blobs, while significantly suppressing activity in interblobs. Spatially structured (drifting bar) stimuli roughly maintained the color patches seen with uniform stimuli, but responses spread far into interblobs as well. We speculate that cortex acts as a 'switch' between two systems based on the spatial frequency content of the visual input. Low spatial frequency (or uniform) color stimuli are represented by only a subset of V1 color cells that tend to lie in blobs, consistent with the lowpass nature of chromatic processing, while structured stimuli seem to engage both blobs and interblobs in a larger representation.

T8 Representation of color in human visual cortex

Colin W.G. Clifford, University of Sydney, Psychology & Australian Centre of Excellence in Vision Science

Mechanisms of color vision in cortex have not been as well characterized as those in sub-cortical areas, particularly in humans. We used fMRI to investigate the initial transformation of sub-cortical inputs by human visual cortex. From V1 onwards we found a stronger response to patterns modulating in color between lime and magenta than between orange and cyan even though the stimuli were matched for cone contrast and the response they would elicit in the postulated L-M and S-(L + M) sub-cortical opponent channels. This result implies that sub-cortical chromatic channels are recombined early in cortical processing to form novel representations of color. The bias for lime-magenta over orange-cyan will be discussed with reference to single-unit data from macaque V1 and human psychophysics to explore the idea that visual cortex efficiently deploys chromatic mechanisms in anticipation of a diet of images characteristic of the natural environment.

The Aging Visual System

Moderator: Marilyn E. Schneck, SKERI

As life expectancy continues to rise, there is an increasing desire to better understand age-related changes in the visual system. This session will explore current understandings of aging in topics ranging from spatial and color vision, to cortical organization, to neural mechanisms of memory and attention.

T9 Optical and neural factors contributing to age-related losses in spatial vision

Sarah Elliott, University of Chicago, Institute for Mind and Biology

Two studies were conducted to quantify neural factors contributing to age-related changes in spatial vision. First, high order aberrations (HOAs) were measured and corrected in the eye with adaptive optics (AO) while observers performed contrast sensitivity and visual acuity tasks. With a large pupil, AO improved spatial vision performance significantly more for older compared to younger observers. Despite this, performance remained lower for older observers. When age-related miosis was controlled, young and old observers experienced similar benefits of AO. Correcting HOAs may increase the relative impact of other optical factors for older observers, such as intraocular scatter, but the importance of neural factors was not ruled out. We then explored age-related changes in contrast gain related to the magnocellular and parvocelluar pathways, a direct neural correlate to spatial vision performance. Younger and older observers participated in discrimination tasks thought to probe the distinct contrast gain

signature of each pathway (Pokorny & Smith, 1997). Model fits to the data revealed an age-related shift in gain slope and elevated thresholds for both pathways, although functional losses were greater for the P pathway under tested conditions. We conclude that age-related decline in spatial vision is the result of both optical and neural factors.

T10 The effects of aging on vision: Plasticity and tradeoffs

Allison B. Sekuler, McMaster University, Psychology, Neuroscience & Behaviour

The "greying population" is the fastest growing group the developed world. Despite the importance of this group, we know relatively little, however, about how aging affects critical functions such as vision and neural processing. Although it was once assumed that aging would lead to only declines in neural function, recent research shows that although while some abilities decline with age, others are spared and may even improve, and neural systems underlying visual processing may change substantially throughout our lifetimes. This lecture will discuss the trade-offs in visual and neural processing that occur with age, with a focus on pattern vision and motion perception.

Financial support provided by the Canadian Institutes of Health Research and the Canada Research Chair Programme.

T11 Visual Deficits During Healthy Aging of the Ventral Pathway

Hugh Wilson, York University Centre for Vision Research
Frances Wilkinson, York University Centre for Vision Research

To diagnose the onset of subtle forms of visual pathology in the elderly, it is critical to develop an understanding of performance during healthy visual aging. In the ventral or form vision pathway, our research and that of others shows that healthy elderly performance remains roughly equivalent to the young in V1 (orientation discrimination) and V4 (curvature processing in radial frequency patterns). However, we have recently documented a significant deficit in face discrimination across view changes in healthy aging. Further work using adaptation shows that this results from broadened bandwidths for representing different face views. Neural modeling can explain this on the assumption of weakened lateral inhibition between adjacent face views along with increased neural noise. Subsequent fMRI studies show differences between young and elderly on face identification tasks consistent with psychophysics. These results are consonant with electrophysiology in higher visual areas of senescent monkeys, where bandwidths for motion direction increase dramatically. Finally, this reduction in inhibition higher in the ventral pathway in aging is consistent with the increase in first, unprovoked epileptic seizures around age 70.

T12 Organization of primary visual maps in patients with retinal lesions

Antony Morland, University of York, Psychology, York Neuroimaging Centre

The primary visual cortex (V1) represents information retinotopically. Age-related changes in the retina can frequently give rise to visual field defects. In age-related macular degeneration (AMD) field defects are, at least at first, restricted to central regions of the visual field. What happens to areas of V1 that originally represented the centre of the visual field? One possibility is that these regions take on responses to more peripheral retina. This effect has been demonstrated in patients with congenital lesions of the central retina. If the effect were to occur in patients with AMD it may ameliorate visual loss. We examined whether peripheral information was remapped to areas of V1 that normally represent the centre of the visual field in 16 MD patients using fMRI retinotopic mapping procedures. We found no evidence of remapping in V1. It appears likely, therefore, that remapping of V1 is limited and perhaps only possible when lesions of the retina occur very early in life. However, it is reassuring that V1 does not undergo widespread remapping as it would have to be undone to maximize the benefits of treatments that aim

to restore retinal sensitivity in MD patients.

Contributed Talks, Session 1

Moderator: Alex Wade, University of York

T13 FMRI of the Rod Scotoma: Cortical Projections, Filling-In and Insights into Plasticity

Brian Barton, University of California, Irvine, Cognitive Sciences
Alyssa Brewer, University of California, Irvine, Cognitive Sciences

Are ectopic responses in lesion projection zones (LPZs) the result of long-term reorganization (plasticity) or short-term filling-in (adaptation)? We used field-standard travelling-wave and cutting-edge population receptive field (pRF) model functional MRI visual field mapping techniques with 4 types of flickering checkerboard stimuli under photopic and scotopic conditions to measure the effects of the rod scotoma in human early visual cortex. Our main findings are: 1) populations of neurons were silenced within the LPZ of the rod scotoma; 2) conscious perception was correlated with neural activity across stimuli in V1, V2, V3, and hV4; pRFs overlapping the LPZ 3) shifted their pRFs more eccentric from the rod scotoma and 4) changed their pRF sizes. Each of these effects differs in degree and range for each of the maps measured, such that maps with larger pRFs (leading to greater overlap with the rod scotoma) show effects further into their representations of the visual periphery. Thus, ectopic responses in LPZs are not unique identifiers of cortical reorganization, but can be a result of short-term filling-in.

T14 Apparent retinotopic reorganization in human visual cortex with central pathology

Danielle Reitsma, The Medical College of Wisconsin, Biophysics
Mary Jo Maciejewski, The Medical College of Wisconsin, Biophysics
Viktor Szeder, The Medical College of Wisconsin, Biophysics
Douglas Ward, The Medical College of Wisconsin, Biophysics
John Ulmer, The Medical College of Wisconsin, Radiology
Wade Mueller, The Medical College of Wisconsin, Neurosurgery
Bernd Remler, The Medical College of Wisconsin, Neurology
Edgar DeYoe, The Medical College of Wisconsin, Radiology

The potential for reorganization of human cortex in response to central pathology remains controversial, particularly for visual cortex. Consequently, we used BOLD fMRI and conventional visual field mapping techniques (checkered rings and wedges) to study cortical organization in healthy subjects and a group of 30 patients with central pathology. To dissociate reorganization from pathology-related deletions, we focused our analysis on increases in representation, specifically, of the ipsilateral visual field in each hemisphere. Patient hemispheres were divided into two distinct groups: (1) Not reorganized (n = 54) - Retinotopic maps within these hemispheres could have pathology-related deletions but the remaining topography was normal. (2) Reorganized (n = 3) - These hemispheres all had increased representation of the ipsilateral field beyond the range of normal subjects, despite pathology-related loss in other portions of the field. Quantitative analysis revealed that the number of fMRI voxels representing the ipsilateral hemifield in reorganized hemispheres averaged over 3X the number in healthy subjects ($p = 0.005$) and 7X the number in patient hemispheres without reorganization ($p < 0.002$). A concern was that patients with scotomata can develop an eccentric preferred retinal locus (PRL) for fixation that might produce artifactual changes in retinotopy. To control for this, we used scanning laser ophthalmoscopy with optical coherence tomography to

measure the average preferred fixation locus relative to the foveal pit in 2 of the 3 patients with reorganization and found offsets of less than 1^{o} in both. We then estimated the worst-case effect of a 1^{o} PRL on cortical retinotopy both empirically using BOLD-fMRI in healthy subjects with intentionally shifted fixation and, theoretically, using a computational model (based on Schira et al., 2009). Neither empirically nor theoretically shifted fixation yielded cortical retinotopy that could account for the reorganization observed in the patients. Thus, we conclude that cortical retinotopy in patients with central visual pathology can undergo apparent reorganization so as to increase the ipsilateral field representation, and that this effect is not accounted for by a PRL.

T15 Measurement of Motion Detection Thresholds under Natural and Manipulated Retinal Image Motion Conditions

Nicole M. Putnam, University of California, Berkeley, Vision Science
Pavan Tiruveedhula, University of California, Berkeley, Vision Science
Qiang Yang, Montana State University, Computational Biology
David W. Arathorn, Montana State University, Computational Biology
Scott B. Stevenson, University of Houston, Optometry
Austin Roorda, University of California, Berkeley, Vision Science

Despite retinal image motion caused by fixational jitter, the world appears stable. Previous studies from our lab found that targets that slip on the retina in a direction consistent with eye motion - even if they are amplified - are perceived as stationary or moving less than for other directions of motion. We now establish a quantitative measure of how these percepts affect the detection of motion.

Real-time retinal tracking and targeted stimulus delivery using an AO Scanning Laser Ophthalmoscope enables us to present any stimulus motion including natural, stabilized, amplified, and rotated trajectories. Three subjects performed a 2AFC task judging clockwise or counterclockwise motion of a stimulus under stable and amplified motion conditions in directions consistent with and opposite natural eye motion. Stimuli were presented extrafoveally to avoid fixation tracking.

The smallest thresholds occurred under natural eye motion conditions (~0.8 arc min). When the magnitude of retinal motion was equal but opposite natural motion, thresholds were ~3 times larger. When the retinal stimulus slip was doubled, thresholds were only ~2 times larger.

The visual system perceives true motion of objects despite confounding motion of their retinal images, but only when that confounding motion's direction is consistent with fixational eye motion.

T16 Adaptation and the perception of structure in radiological images

Elysse Kompaniez, University of Nevada, Reno, Psychology
Craig K. Abbey, University of California, Santa Barbara, Psychology, University of California, Davis, Biomedical Engineering,
John M. Boone, University of California, Davis, Radiology and Biomedical Engineering
Michael A. Webster, University of Nevada, Reno, Psychology

Radiologists often spend hours interpreting medical images. We are interested in the role that visual adaptation may play in the perception of structure in radiological scans. To focus our study, we concentrated on breast imaging, where a judgment of breast density is a standard component of the report from a screening mammogram. Images were taken from random sections within breast regions of normal mammograms and displayed on a CRT.

Adaptation was measured with a standard asymmetric matching task. In one set of experiments, we asked whether

the “unnatural” statistics of radiological images induce changes in the “natural” adaptation state of the observer. For example, the scans have steeper power spectra, and adapting to them produced shifts in the perceived spectrum of filtered noise consistent with adaptation to blur. In a second set, we asked whether adaptation could selectively alter the appearance of different scans. For example, exposure to an image of tissue classified as “dense” could bias an ambiguous target to appear more “fatty” or vice versa. Our results show that observers can rapidly adapt to the image structure in mammograms, and this could potentially be an important factor in the perception and learning of radiological images. EY-10834

T17 Efficient integration of local perceived blur in discrimination and matching

Christopher Taylor, Harvard Medical School, Ophthalmology
Peter Bex, Harvard Medical School, Ophthalmology

Blur is a fundamental property for image and optical quality assessment. Blur has been studied with single contours, but natural scenes are composed of a range of depth planes giving rise to retinal images with broad distributions of blur. To study blur perception under more natural conditions, we generated locally controllable dead leaves stimuli – 128 mutually occluding ellipses of random luminance, contrast, orientation, size, aspect ratio, and position. Each element was individually Gaussian blurred allowing blur mean and blur variance to be manipulated independently. Four blocked mean blurs (μ = 2, 4, 8, 16 cycles/image) and three blur variance levels (σ = 0, 0.25, and 0.5 μ) were interleaved in a 2IFC blur discrimination task. In a matching task, the perceived blur of a high variance image, with fixed mean blur, was matched to that of a low variance image of adjustable mean blur. Matching results and equivalent noise analysis on the blur discrimination data showed that observers were surprisingly capable of integrating wide distributions of blur with limited bias toward sharp or highly blurred elements. Thus, the distribution of local image blur, rather than the blur of single items, determines perceived optical and image quality.

T18 Dynamics and neural computations underlying visual masking

Jeffrey Tsai, Smith-Kettlewell Eye Research Institute
Alexander Wade, Smith-Kettlewell Eye Research Institute
Anthony Norcia, Stanford University, Psychology

We study visual masking using source-imaged electroencephalography (EEG) and frequency-domain analysis in humans, examining a wide range of relative stimulus strengths and spectral components driven by individual stimuli (self terms) and those due to interaction between stimuli (intermodulation [IM] terms). Consistent with previous reports, in early visual cortex, masking manifests in the self-terms as an effective reduction of input contrast. We identify a novel signature of masking -- the magnitude of the second-order IM term peaks when the input contrasts are equal and reaches a minimum when they are widely different. To account for our data, the standard divisive gain control model, parametric in response dynamics, was fitted to the self- and IM-terms simultaneously. Previous instantiations of similar models with either very short or very long temporal integration in the formulation of the gain pool response performed worse than a model with an integration time of approximately 30 ms. Finally, the magnitude of the spectral components depends only on the ratio of the input contrasts. This “contrast-contrast” invariance suggests that neurons in visual cortex operate on a representation of relative rather than absolute contrast. Together, these results provide a more complete description of masking within the framework of gain control.

Classics of Vision Science

Moderator: Steven L. Buck, University of Washington, Psychology

T19 The Disappearance of Steadily Fixated Visual Test Objects

Tom N. Cornsweet, University of California, Irvine, Cognitive Sciences, Electrical & Computer Engineering, Ophthalmology

In 1951 I was lucky to apply for and be accepted for graduate school in the Psychology Department at Brown, where there were twelve graduate students and six faculty, four of whom were in the National Academy of Sciences. Around the time when I arrived, the characteristics of the small eye movements that occur during attempted steady fixation were well understood, but there was vigorous debate about the reasons for their occurrence and about their effects on vision. It is obvious that rotational eye movements cause the retina to shift under the retinal image. Our group and a group in England published papers within a month of each other showing that, when this movement of the retina with respect to the image of a scene is prevented, the scene disappears within a fraction of a second. The question debated then was whether or not the beginning of such disappearance was the trigger for the movements. My dissertation research showed that disappearance did not trigger movements. Instead, the eyes tend to drift away from the target and microsaccadic movements tend to correct the resulting fixation error.

Classic paper: Riggs, L.A., Ratliff, F., Cornsweet, J.C., & Cornsweet, T.N. (1953). The disappearance of steadily fixated visual test objects. *Journal of the Optical Society of America, 43*(6), 495-500.

T20 Unraveling the primate fovea during development

Anita E. Hendrickson, University of Washington, Biological Structure and Ophthalmology

Shortly after joining the brand new University of Washington Department of Ophthalmology in 1966, I discovered the classic book on human retinal development by Ida Mann. When a friend in the UW Primate Center asked me if I wanted the eyes from 16 timed fetal and infant M. nemestrina, I had my first opportunity to discover for myself the very strange development of the fovea. This talk will review the evidence that I and my collaborators have amassed on foveal development, and will present an integrated model of primate foveal development based on these data.

Classic paper: Yuodelis, C., & Hendrickson, A.E. (1986). A qualitative and quantitative analysis of the human fovea during development. *Vision Research, 26*, 847-855.

T21 Gratings: the early years.

John G. Robson, University of Houston, Optometry

The first wide-ranging attempt to characterize the visual process in terms of the transfer of visual signals defined in the spatial frequency domain was that of Otto Schade (1956). Schade's interest was in being able to incorporate the human visual observer into the complete chain of devices comprising a television system (camera, transmitter, display, observer) in order to predict the overall performance and hence optimize the engineered components. In this context Schade made the first comprehensive measurements of the minimum contrast required to detect the bars of sinusoidal gratings, an extension into the spatial domain of the popular linear systems approach to system

characterization in the temporal domain based on signals modulated sinusoidally in time. Although I had become familiar with linear systems methods in the course of my PhD work analyzing human muscle control mechanisms, it took the publication of nonsense results by DePalma and Lowry in 1962 (they claimed that sinusoidal gratings were more visible than square wave gratings) to convince me to help Fergus Campbell to see if it was possible to understand the relationship of the contrast thresholds for gratings of different waveform in terms of linear systems (Fourier) theory. It was possible. Our early success (though our results were not published until 1968) encouraged me to extend the psychophysical observations to the combined spatial and temporal domains (1966) and to collaborate with Christina Enroth in applying similar techniques to characterizing cat retinal ganglion cells (1966).

Classic paper: Campbell, F. W., & Robson, J.G. (1968). Application of Fourier analysis to visibility of gratings. *Journal of Physiology, London, 197*, 551-566.

T22 Visual hyperacuity and optical super-resolution

Gerald Westheimer., University of California, Berkeley, Neurobiology

Once it is realized that thresholds, such as those for vernier alignment, are a small fraction of the classical Rayleigh resolution limit, the optical and information-theoretical consequences have to be faced. Transferring discussion into the spatial-frequency domain, in which the diffraction limit is embodied in the cut-off frequency [1], makes it clear that no physical principles are violated. Often, by a kind of Bayesian process, inferences are drawn about the target from the spectrum inside the cut-off frequency and prior expectation of associations with possible patterns beyond it. All this is in contrast to modern practices of optical super-resolution, which employ sophisticated stratagems to shift actual high-frequency components into the pass-band of the imaging device and hence require, as a consequence, sophisticated procedures for object reconstitution.

Classic paper: Westheimer, G. (1977). Spatial frequency and light-spread descriptions of visual acuity and hyperacuity. *Journal of the Optical Society of America, 67*, 207-212.

Rehabilitation and adaptation to visual impairment

Moderator: Susana Chung, University of California, Berkeley

Understanding the visual consequences of injury and disease, as well as the plasticity of the brain itself, provides new insight for the development of rehabilitation approaches that encourage and improve adaptation and daily function. The work presented in this session explores adaptations to low vision, blindness and traumatic brain injury, the last of which has seen a marked increase due to the improvised explosive devices in modern warfare.

T23 Challenging the Dogma of Visual Rehabilitation for Cortical Blindness - Perceptual Re-Learning in V1-Damaged Humans

Krystel R. Huxlin, University of Rochester, Flaum Eye Institute

Unilateral damage to the adult primary visual cortex causes a loss of conscious vision over contra-lateral parts of the visual field in both eyes. Such partial cortical blindness hinders every aspect of daily life, including reading, navigation, and driving. While visual rehabilitation for this condition has been controversial, the existence of residual visual processing abilities in cortically blind fields (commonly known as 'blindsight') suggests that it might be possible to recover vision though perceptual training. Our laboratory has focused on retraining motion perception, studying the properties of recovered vision psychophysically and using fMRI. To date, we have shown that

discrimination of both simple and complex, moving visual stimuli can be retrained back to normal levels of threshold performance in cortically blind fields. Testing with controlled fixation shows that the recovered abilities are localized to retrained visual field locations, but generalize to discrimination of untrained (including non-motion) stimuli and tasks. Supporting this broad generalizability of re-learning, fMRI data suggest that visual training in cortically blind fields may not just recruit brain circuits mediating blindsight. Instead, altered activity in spared early and higher-level visual areas points to largely canonical routes of visual processing as the substrates of recovered vision.

T24 Low Vision and Brain Plasticity

Gordon E. Legge, University of Minnesota, Psychology

Evidence for the functional reorganization of visual brain areas in blind people provides compelling examples of brain plasticity associated with visual impairment. But what sorts of plasticity are present in cases of low vision? “Low vision” refers to any long-term visual deficit, not correctable by lenses, affecting everyday visual function while preserving some level of useful vision. In cases of low vision, visual cortex still participates in visual processing, but with abnormal input, characterized clinically as reduced acuity, reduced contrast sensitivity, and/or visual-field loss. What sorts of plastic changes in the visual pathway accompany these three types of vision loss? What are the behavioral consequences of these changes? What is the impact of the age of onset of low vision on plasticity? I will discuss these unresolved questions, using examples of psychophysical and fMRI studies from my research. An important example is macular degeneration. This common eye disease often results in central-field loss, requiring the use of peripheral vision for reading and other tasks usually mediated by central vision. I will also address the relevance of research on low-vision plasticity for rehabilitation.
Research supported by NIH grant EY002934.

T25 Driving with Hemianopia

Eli Peli, Harvard Medical School, Schepens Eye Research Institute, MEEI
Alex Bowers, Harvard Medical School, Schepens Eye Research Institute, MEEI

People with hemianopia are permitted to drive (following a road test) in a small but growing number of jurisdictions. We have been studying driving with hemianopia on the road and in a driving simulator, with and without peripheral prisms that provide visual field expansion. In agreement with others, we found that in a road test some hemianopes performed well enough to be deemed safe. However, in our simulator studies, where we challenge the blind side with frequent pedestrian detection events, we find wide individual variability in detection performance (10% – 90%). Furthermore, when approaching intersections, many failures to scan to the blind side were recorded. Importantly, hemianopes who head scanned more to the blind side had better detection performance. In our on-road study, hemianopes responded better to unexpected events (on the blind side) and committed fewer errors requiring tester interventions when using real peripheral prisms than sham prisms; this was true for both current and non-current drivers. Although improved detection with peripheral prisms may not be sufficient to convert all unsafe hemianopes to safe drivers, they may be a useful driving aid. We argue that road tests may not provide sufficient opportunities to evaluate detection of blind-side hazards.

T26 Visual Deficits & Rehabilitation After Acquired Brain Injury

Suzanne Wickum, University of Houston, Optometry

There is growing interest in the pathophysiology, diagnosis, and management of visual and ocular deficits caused by brain injury. According to the Centers for Disease Control and Prevention 795,000 people suffer strokes each year while an estimated 1.7 million people sustain a traumatic brain injury (TBI) annually. Seventy-five percent of TBIs

that occur each year are concussions or other forms of mild TBI. In addition, TBI has been deemed the "signature wound" of Operations Iraqi Freedom and Enduring Freedom. The 2008 Rand report notes that about 30% of troops engaged in combat > 4 months may have suffered mild TBI from blast waves of improvised explosive devices and that 57% of soldiers with probable TBI have not been evaluated by a physician for brain injury. Acquired brain injury can have many deleterious effects including visual acuity loss, peripheral visual field loss, hemispatial neglect, binocular vision anomalies, extraocular motility disorders including nystagmus, accommodative disorders, photophobia, and ocular health disorders. Undiagnosed visual problems may interfere with a patient's overall rehabilitation. This presentation will review the impact of TBI on visual function in soldiers and the implementation of visual rehabilitation strategies specially designed for each patient based on their clinical symptoms.

Contributed Talks, Session 2

Moderator: David Brainard, University of Pennsylvania, Psychology

T27 Cone-Selective Connectivity in P-Pathway Cells of the Macaque Monkey

Barry Lee, The State University of New York, Optometry
Robert Shapley, New York University, Neural Science
Michael Hawken, New York University, Neural Science
Hao Sun, The State University of New York, Optometry

Cells in the P-pathway show L/M-cone opponency. Whether or not cone opponency derives from cone-specific connectivity to the receptive field surround is controversial. To answer this question, spatial frequency (SF) tuning curves were obtained with achromatic, equiluminant red-green, M-cone, and L-cone isolating gratings. A band-pass index (BPI=ratio of low frequency/peak response) was calculated. BPI=1 means the spatial frequency response was low-pass with no trace of a surround. BPI=0 means the center and surround were exactly balanced and opposite in sign. For achromatic gratings, BPI was in the range <0,1> with mean 0.53 (retina) and 0.44 (LGN). However, in about 80% of P and Parvo cells, BPI=1 for the center cone (mean BPI = 0.94). Therefore, in most P-pathway cells, the center cone did not contribute to the antagonistic surround. Another issue concerns the possible existence of P cells with mixed cone input to the center (Crook et al., J. Neurosci., 31, 2011) but with strong cone opponency with large fields. We observed a few cells showing this behavior at eccentricities >=10 deg; this behavior could not be modeled by a random wiring approach. These data suggest considerable cone-specificity in the wiring of the midget, P-pathway.

T28 S-Cone Induced Cortical activity Despite an ON-Pathway Defect; a BOLD fMRI-Based Case Study

Andrew Salzwedel, Medical College of Wisconsin, Biophysics
Matthew Mauck, Medical College of Wisconsin, Cell Biology
Jay Neitz, University of Washington, Ophthalmology
Edgar DeYoe, Medical College of Wisconsin, Radiology

Rods and S-cones synapse with ON-bipolar cells that use the same metabotropic glutamate receptor, mGluR6. Strikingly, in individuals where mGluR6 signaling is interrupted by GRM6 mutations, rod vision is lost, but normal color vision is retained despite the absence of S-ON bipolar input. Here we report the first neuroimaging study of a GRM6-/- patient. BOLD fMRI was used to measure cortical activity in visual areas V1-V3, V4, VO, V3a, and MT in response to diffuse stimuli presented monocularly, that were chromatically modulated to stimulate specifically either S or M+L cones at frequencies of 1-20 Hz. Robust cortical activity was elicited in both conditions and the overall pattern was similar to control subjects. This suggests that the H2 horizontal cell to OFF-bipolar pathway—not

S-cone to ON- bipolar and small-bistratified cells—are responsible for normal blue- yellow hue perception. Moreover, we propose that inner retina crossover inhibition between ON- and OFF-pathways explains the remarkably normal photopic vision in GRM6 patients. Some quantitative differences were evident, most notable was attenuation of both S and M+L signals at high temporal frequencies (> 7 Hz) suggesting that the higher level, ON-OFF pathway interactions shape the temporal properties of both S and M/L pathways in normal observers.

T29 When Red Plus Red Makes White

Jenny Bosten, University of California, San Diego
Donald MacLeod, University of California, San Diego

Retinal signals depend critically on contrast, or on the factor of change applied to a background stimulus; and so does perception at threshold where Weber's Law holds. We extend this principle to suprathreshold color appearance.

When a colored blob fades against a grey background under steady fixation, physically different stimuli appear the same. In our experiments, such a blob is revived by a suprathreshold change of intensity. If the retina reports factors of change rather than absolute color, we make a surprising prediction: the revived blob should retain its achromatic appearance instead of emerging in its true color.

A test Gaussian blob was allowed to fade, and revived by a brief (200 msec) change Subjects adjusted a briefly pulsed comparison blob in DKL space to match the revived test blob. Chromaticities of the matches to test blobs that were doubled or halved in intensity were indeed close to achromatic, though with a small shift towards the physical chromaticity of the test blob when the intensity was doubled. Results conformed to the prediction that a perceptual match is determined by equal factors of change, though with some regression towards the absolute stimulus in some subjects.

T30 A paradox of color discrimination

John Mollon, Cambridge University, Experimental Psychology
Marina Danilova, Russian Academy of Sciences, I. P. Pavlov Institute

At early stages of the visual system, color information has been thought to be carried by two channels: one originating in the midget ganglion cells and representing the ratio of L- and M-cone excitation, the second originating in the small bistratified ganglion cells and representing the ratio of S-cone excitation to the sum of the other two. When color discrimination depends on one of the channels, are thresholds affected by the excitation of the second? Classical studies (e.g. Krauskopf and Gegenfurtner, 1992; Miyahara et al, 1993) suggest that the two channels are largely independent.

In the upper-left quadrant of the MacLeod-Boynton diagram, we identify a region where the S-cone excitation affects discrimination on the L/M axis. The effect is paradoxical, in that discrimination improves when S-cone excitation is increased.

Observers discriminated the two halves of a 2-deg foveal field. The luminance of each half-field was jittered, to eliminate luminance cues. Targets were presented for 150 ms on a background metameric to D65.

One explanation of our results is that observers exploit a neural channel not aligned with either axis of the MacLeod-Boynton, a channel that is most sensitive near the subjective transition from reddish to greenish hues.

T31 Speed of Material vs. Object Recognition Depends upon Viewing Condition

Bei Xiao, Massachusetts Institute of Technology, Brain and Cognitive Sciences

Lavanya Sharan, Disney Research
Ruth Rosenholtz, Massachusetts Institute of Technology, Brain and Cognitive Sciences
Edward Adelson, Massachusetts Institute of Technology, Brain and Cognitive Sciences

Very little is known about rapid categorization of materials in comparison with objects and scenes. In the conditions used by Sharan et al. (VSS 2011), material categorization is fast, but slower than object categorization. Here, we studied the effect of viewing condition on the reaction time (RT) of material and object categorizations using photographs of real-world objects.

Stimuli included photographs of 30 gloves (15 leather; 15 fabric) and 30 handbags (15 leather; 15 fabric). Two viewing conditions were used: a "Full" view showing the whole object and a "Zoomed-in" view showing part of the object. For each viewing condition, two sets of 2AFC task on either material or object categorization were performed by two groups of observers, and their reaction time was measured. A color discrimination task (red versus blue circles) was used as baseline.

For the "Full" images, observers were faster at the object task (Baseline Corrected RT = 73 ms) than the material task (Baseline Corrected RT = 85ms). For the "Zoomed-in" images, observers were faster at the material task (Baseline Corrected RT = 75 ms) than the object task (Baseline Corrected RT = 97ms). The results show that the speed of material and object categorization depends on the viewing condition.

T32 Decoding chromatically-tuned suppressive fields in early visual cortex

Alex Wade, University of York
Jess Rowland, New York University

Visual cortex is known to contain neurons with extended, suppressive, extraclassical receptive fields. The effects of these fields on neural responses are poorly understood at a population level. For example, if these extraclassical receptive fields are chromatically tuned, neuronal populations whose surrounds lie within directly-stimulated regions might contain information about stimulus chromaticity even though their classical receptive fields are not stimulated directly. Here, we tested this hypothesis using an fMRI multivariate pattern classification technique. We showed that fMRI BOLD signals in both peripheral V1 and V2 carry information about foveal stimulus color. These regions, containing neurons whose classical receptive fields do not overlap with the stimulus location, were as informative about stimulus color as regions driven by the stimulus directly. Most voxels in the periphery exhibited a reduction in their BOLD signal in response to the central stimulus and classification was supported by these suppressed voxels alone. The ability to classify chromatic and achromatic stimuli based on these population responses agrees with recent electrophysiological studies showing that many V1 and V2 neurons have large, chromatically-tuned suppressive surrounds.

Connectivity Maps in the Brain

Moderator: Alyssa Brewer, University of California, Irvine, Cognitive Neuroscience

The emerging field of connectomics has the potential to revolutionize our understanding of anatomical and functional neural networks. This session will delve into the current investigations of the connectivity of networks from retina to cortex.

T33 Network Discovery in the Retinal Connectome

Robert E. Marc, University of Utah, Moran Eye Center

Connectomes are characteristic network graphs with complete adjacency matrices. Their mapping remains a grand challenge in neuroscience. We have used deep connectomics mapping (mapping to statistical saturation) via automated transmission electron microscope (ATEM) imaging at 5,000 images/day, automated image volume assembly, comprehensive molecular tagging to classify cells, Viking annotation to trace networks, cell visualization with 3D renderers, and network analysis with database browsers and connectivity viewers.

We have built the first 2 nm-resolution retinal connectome (RC1) and are exploring it with teams of expert annotators. This resolution allows unambiguous identification of synapses and gap junctions. We have discovered many new retinal features, including novel networks for type A(II) amacrine cells, the critical fan-out element in mammalian rod-cone networks. We have also defined the three fundamental signal processing roles for retinal amacrine cells. The over 30 different amacrine cell classes of the mammalian retina engage in three distinct modes of inhibition: (1) nested feedback / feedforward signal processing; (2) ON-OFF channel crossover motifs; and (3) long-range scotopic-photopic control loops. The next stage in connectomics is populating adjacency matrices with synaptic and coupling weights to generate realistic models.

Commercial Relationships: R.E. Marc, Signature Immunologics, CEO.

T34 Functional connectivity in the retina at the elementary resolution of photoreceptors

E.J. Chichilnisky, Salk Institute, Systems Neurobiology Laboratories

To understand a neural circuit requires knowing the pattern of connectivity between its inputs and outputs. For example, the role of the retina in color vision depends on the pattern of connectivity between the lattice of cone photoreceptors and multiple types of retinal ganglion cells via the retinal circuitry. In the vertebrate nervous system, this kind of complete functional circuitry information has generally been out of reach. Here we report the first measurements of functional connectivity between input and output layers of the retina at single-cell resolution, and use the information to probe the neural computations subserving color vision. We employed a unique 512-electrode technology to record simultaneously from complete populations of the ganglion cell types which collectively mediate high-resolution vision in primates (midget, parasol, small bistratified). We then used fine-grained visual stimulation to separately identify the location and spectral type ([L]ong, [M]iddle or [S]hort-wavelength sensitive) of each cone photoreceptor providing input to each ganglion cell. The populations of ON and OFF midget and parasol cells each sampled essentially the complete population of L and M cones, with low redundancy. However, only OFF midget cells strongly sampled from S cones, an unexpected specificity. Statistical analysis revealed a non-random pattern of inputs from L and M cones to the receptive field centers of midget cells, while inputs to the receptive field surround were random. This specificity of cone inputs could not be explained by clumping in the cone mosaic, implying that developmental or adaptive mechanisms enhance opponent-color signals transmitted from retina to brain.

T35 Connections in the brain

Robert F. Dougherty, Stanford University, C Cognitive and Neurobiological Imaging

Magnetic resonance imaging (MRI) can be used to map the pattern of diffusion in tissue. These diffusion MR measurements allow us to infer the complex pattern of long-range anatomical connections in the human brain. Understanding these connections and measuring their properties in individual brains is important because they are crucial to normal brain function, their disruption may underlie many neurological disorders, and their variability across individuals may explain behavioral variability. These connections also mature relatively late in development

and limit neural plasticity in the adult. In the visual system, we can routinely find and measure the connections between the retina and the LGN (the optic nerve and optic tract), the connections from the LGN to V1 (the optic radiation), and many cortical connections important in visual processing. I will discuss diffusion MR measurements that we and others have made in the visual system and describe how these measures advance our understanding of the visual processing circuits. Finally, I will describe our efforts to more precisely measure neural tissue properties by using quantitative tissue models to combine diffusion measures with other quantitative MR measures such as longitudinal relaxation and magnetization transfer.

T36 The Human Connectome Project

David C. Van Essen, Washington University, Neurobiology

The Human Connectome Project (HCP) offers an exciting opportunity to characterize brain circuitry and its variability in healthy adults. A consortium of investigators led by Washington University, University of Minnesota recently began a 5-year project to characterize the human connectome in a large cohort of twins and their non-twin siblings. Structural and functional connectivity will be charted at high resolution in each individual using diffusion MRI and resting-state fMRI, respectively. Task-evoked fMRI, MEG/EEG, and behavioral data will also be acquired. Advanced analysis methods, including novel approaches to brain parcellation, will enable mapping of functionally distinct parcels in individual subjects and in the overall population. Comparisons across subjects will reveal aspects of brain circuitry which are related to particular behavioral capacities and which are heritable or related to specific genetic variants. Data from the HCP will be made freely available to the neuroscience community. A user-friendly informatics platform will enable investigators around the world to carry out many types of data mining on these freely accessible, information-rich datasets. Since vision is the dominant functional modality in the human brain, the HCP will generate an enormous amount of information about circuitry of the human visual system, especially visual cortex.

Poster Session Abstracts

P1 Validation of Image Filters for Studies of Visual Accessibility

Paul Beckmann, University of Minnesota, Psychology
Gordon Legge, University of Minnesota, Psychology
Christopher Kallie, University of Minnesota, Psychology
William Thompson, University of Utah, Computer Science

An environment is visually accessible if a person can rely on vision to travel efficiently and safely through it, to perceive its spatial layout, and to update location and orientation within the environment. We are studying how architectural and interior design decisions and viewing conditions interact with vision deficits of people with low vision to determine the visibility of obstacles and other important features. Deficits in acuity and contrast reduce visibility of key features and increase confusability between features in a space, e.g., rendering a step invisible or confusable with a shadow boundary. Here, we describe an image-filtering method intended to reveal the featural information available in an arbitrary scene for an observer with a specified level of reduced acuity. Images were filtered using thresholded bandpass filtering techniques developed by Peli (1990), together with contrast sensitivity functions associated with different levels of reduced acuity and contrast sensitivity. We validated the filtering method by applying it to photographs of letter-acuity charts. We measured the performance of normally-sighted subjects using these filtered images to determine each filter's effective acuity. The resulting calibrated filters can be used to predict the visibility of features in architectural spaces.

P2 Chromatic and Luminance Contrast Sensitivity in Preterm and Fullterm Infants: Possible "Sleeper" Effect of Early Postnatal Visual Experience.

Rain Bosworth, University of California, San Diego, Psychology
Karen Dobkins, University of California, San Diego, Psychology

We previously investigated chromatic and luminance contrast sensitivity (CS) in preterm and fullterm infants (JOV, 2009). Here we analyze a larger sample of 104 preterm and 148 infants between 1-8.5 months postnatal age (PNA). We hypothesized the maturational effect of PNA (of which visual experience is a large component) may depend upon when infants were born relative to due date (which is linked to biological maturity). We pooled all infants together and analyzed the effect of PNA (Groups: 2, 3, 4, 5, 6, and 8 mos) and "gestational age (GA)-at-birth" (Groups: -10 to -8, -7 to -5, -4 to -2, -1 to 0, and +1 to +3 weeks around due date). ANOVA results revealed significant interactions between PNA and GA-at-birth for both luminance ($p = 0.003$) and chromatic ($p = 0.004$) CS. At 2 and 3 mo (equivalent to 0.7 and 1.8 mos postterm age), both luminance and chromatic CS were worse for infants with lower GA-at-birth than those near-term, but by 6 and 8 mos, infants with the lowest GA-at-birth surpassed other groups. Results suggest an interesting beneficial "sleeper" effect of early postnatal visual experience, which has been reported for detrimental effects of congenital cataracts (Maurer et al, 2007).

P3 Static and Dynamic Measures of Visual Performance in Athletes

Emily R. Bovier, The University of Georgia, Vision Sciences Laboratory
Kevin J. O'Brien, The University of Georgia, Vision Sciences Laboratory
Stephanie Ross, The University of Georgia, Human Biofactors Laboratory
Lisa M. Renzi , The University of Georgia, Human Biofactors Laboratory

Introduction: Baseball performance requires the ability to perceive and react to temporally varying stimuli under lighting conditions that are known to be most detrimental to visual function. Macular pigment (MP, lutein and

zeaxanthin in the retina) is known to improve performance under such conditions and may also improve neural efficiency. The purpose of this study was to assess static and dynamic visual performance in college baseball players in order to (a) define performance ability in athletes and non-athletes, and (b) improve athletes' performance with zeaxanthin supplementation. Methods: Static measures of visual function included glare disability, photostress recovery, and contrast enhancement. Dynamic measures included coincidence anticipation timing (CAT); fixed and variable position reaction time (FRT and VRT) and the temporal contrast sensitivity function. Results: Athletes performed equally to non-athletes on static visual function measures, but performed significantly better on dynamic measures (e.g., VRT, $p < 0.05$; CAT accuracy at higher velocities). Supplementation is ongoing, but preliminary data indicate increases in MP and improvements in both static and dynamic visual performance after 20mg/d of zeaxanthin. Conclusions: Supplementation to increase MP density may be especially beneficial for baseball players, given the tasks performed and outdoor lighting conditions.

P4 Aging and Dementia in Human Visual Cortex: Visual Field Map Organization and Population Receptive Fields

Alyssa Brewer, University of California, Irvine, Cognitive Sciences
Brian Barton, University of California, Irvine, Cognitive Sciences

Aging typically results in reduced visual acuity, both from changes within the eye and from acquired neural deficits. It is not known, however, to what extent aging affects visual field map organization in human cortex. In addition, patients with Alzheimer's disease (AD) often present with visual deficits as one of their earliest complaints. It is possible that measurements of changes in visual cortex in these patients could aid early detection, accurate diagnosis and timely treatment of dementia. Here we investigate the differences and similarities of visual fields map organization and population receptive fields (pRFs) between patients with mild-to-moderate AD and healthy age-matched controls.

We measured visual field map organization and pRFs across visual cortex using fMRI in healthy young volunteers ages 20-40, normally-aging subjects ages 55-85, and age-matched patients with mild-to-moderate AD. Retinotopic stimuli consisted of black and white, drifting checkerboards 11° in radius comprising wedges, rings, and/or bars.

Normally-aging subjects do not show major visual field map organizational deficits, but do have increased pRF sizes in the central foveal representations of occipital and parietal visual field maps. AD patients do show visual field map organizational deficits and increases in pRFs increase in size and variability relative to age-matched controls.

P5 Optical Illusions on the Slopes of Hills

Bruce Bridgeman, University of California, Santa Cruz, Psychology

Observers are known to overestimate the slopes of hills, and estimates of slope are significantly greater when estimated verbally than with a proprioceptive measure. Since neurons in the premotor cortex have been found to respond differently to objects within arm's reach, we hypothesized that slope estimations might show a break where distances are no longer reachable. A second hypothesis assumes that observers take into account the effort that would be needed to climb the hill to the required distance, predicting a linear increase in apparent slope. We tested apparent slope at a range of distances on a hill of constant real slope. Verbal measures greatly overestimated the actual slope, and increased logarithmically with distance from the observer, while proprioceptive estimates were more accurate but still increased logarithmically. The results also fit exponential functions. Thus neither of the original hypotheses was supported. The results can be interpreted as an implicit slope, previously measured only in darkness, modulated by depth cues available at near distances. Observers use a transformation of the angle between the line of sight and the surface of the hill to inform their estimates.

P6 Rod Hue Biases Produced on CRT Displays

Steven L. Buck, University of Washington, Psychology
Ryan Juve, University of Washington, Psychology
David Wisner, University of Washington, Psychology
Aldebert Concepcion, University of Washington, Psychology

Studies of rod hue biases (RHBs) using Maxwellian-view displays have shown that rod stimulation can shift the balance of hues at mesopic light levels. We investigated the prevalence of RHBs on CRT displays, which present broader-band stimuli against dark-grey veiling backgrounds, typically without control of observer pupil size. Observers saw a 4°-diameter stimulus centered 7° from fixation on a conventional CRT. Observers adjusted stimulus hue to each of the 4 unique hues, following the perimeter of the triangle formed by the 3 phosphors, at equal photopic luminance. Rod influence was estimated from chromaticity differences measured under dark-adapted (rod maximum) and cone-plateau (rod minimum) conditions.

The CRT produced all 3 previously-identified RHBs, which affected all 4 unique hues at low mesopic light levels. Effects occurred at 2.6 cd/m2 for some observers but never at 26 cd/m2. At optimal light levels below 0.5 cd/m2, rods (1) enhanced green vs. red at unique yellow, (2) enhanced blue vs. yellow at both unique green and unique red, and (3) enhanced red vs. green at unique blue. Effect magnitudes varied considerably among observers and could be reduced or eliminated by using smaller foveal stimuli.

P7 Orientation Bandwidth Requirement for Face Identification in Foveal and Peripheral Vision

Andrea Chai, University of California, Berkeley
Deyue Yu, University of California, Berkeley
Susana Chung, University of California, Berkeley

Recent findings suggest that horizontal spatial information is more informative than vertical information in conveying the identity of face images. In this study, we examined (1) the orientation bandwidth requirement for identifying face images that contain primarily horizontal or vertical spatial information; and (2) whether the orientation bandwidth requirement is different in normal foveal and peripheral vision. Six observers identified familiar face images that have been filtered using a bandpass orientation filter centering at 0° (horizontal) or 90° (vertical), with bandwidths ranging between 10° and 60°. Face images were presented at the fovea for a duration of 80 ms, or at 10° in the right visual field for 200 ms, so that the performance for the unfiltered conditions were matched. In general, the accuracy for identifying faces increased with orientation bandwidth up to the threshold bandwidth (the bandwidth corresponding to 64% accuracy). The threshold bandwidth was smaller for horizontal (fovea: 34.9°, 10°: 37.8°) than for vertical orientation (fovea: 44.8°, 10°: 46.6°), a difference that can be attributed to the fact that horizontal information is more informative about the identity of face images. Our results indicate that the orientation bandwidth requirement is largely similar between the normal foveal and peripheral vision.

P8 Ability of the Visually Impaired to Perceive Distance from Auditory Cues

Silvia Cirstea, Anglia Ruskin University, Computing and Technology
Andrew Kolarik, Anglia Ruskin University, Vision and Eye Research
Komal Ramlagun, Anglia Ruskin University, Vision and Eye Research
Shahina Pardhan, Anglia Ruskin University, Vision and Eye Research

The study investigated how visually impaired subjects use level and reverberation cues to discriminate distances to sound sources in comparison with a control group of normal vision subjects. Pairs of broadband noise sounds were

presented at distances between 1 and 8 m in a reverberant virtual room simulated using an image-source model. Listeners performed discrimination judgments in three conditions: level only (Level-Only), reverberation only (Equalized), and both cues available (Normal). Percentage correct judgments of which sound was closer were measured. Data indicate that level provided more accurate discrimination information than direct-to-reverberant ratio for both impaired and normal vision subjects. When comparing the performance of the two groups, it has been found that the visually impaired show higher performance in using both level and reverberation cues separately, both in the near and further field. Reverberation is shown to become a useful cue for the normal vision group only for sounds in the far field of the listener (over 5 m), while the visually impaired display better performance in the use of the reverberation cue in both near and further field. This shows that the visually impaired have superior ability to process early reflections from indoor environments.

P9 Individual differences in cone ratio: Measurements by counterphase modulation photometry and by spatial acuity

Marina Danilova, I.P. Pavlov Institute of Physiology, Visual Physiology
Chloe Chan, Cambridge University, Experimental Psychology
John Mollon, Cambridge University, Experimental Psychology

Within the normal population, there are believed to be large individual differences in the ratio of long-wave (L) to middle-wave (M) cones. Do these variations reveal themselves in psychophysical measures? We propose a temporal and a spatial measure that both appear to be sensitive to the L:M ratio:
(i) Heterochromatic counterphase modulation photometry using a test originally introduced by Estévez et al (1983, American Journal of Optometry and Physiological Optics, 60, 892) as a test for color deficiency. Red and green lights are flickered in counterphase and the subject adjusts their relative depth of modulation to minimize the apparent flicker.
(ii) Spatial acuity for Landolt C targets that isolate individual cone mechanisms. Targets are briefly presented in the parafovea, where acuity is thought to be limited by the sampling density of the cones, rather than in the fovea, where acuity is limited by optical factors. A steady white background is continuously present.
Each of these measures shows good test-retest reliability and the settings are readily made by untrained subjects. The two measures correlate well: in one study of 20 young adults, we find a Spearman rank-order correlation of rs=0.78, p=0.0006.
Support: Gatsby Charitable Foundation

P10 A New Genetic Assay for Color Vision Deficiency Outperforms Behavioral Tests

Candice Davidoff, University of Washington, Ophthalmology,
Jay Neitz, University of Washington, Ophthalmology,
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The Sequenom MassArray instrument allows genotyping at known polymorphic sites using specially designed PCR primers followed by mass spectrometry. This technique is ideally suited to diagnosis of color vision deficiency, a condition whose genetic underpinnings are well understood. Though it does not provide a full gene sequence, the MassArray replaces a cumbersome, multistep PCR while still offering accurate, detailed analysis of the cone opsin genes that underlie color vision. The multiplexed assay format allows rapid, high throughput genetic characterization of cone opsin array length and composition in a single well. In preliminary results from 46 subjects, the MassArray easily distinguished normal individuals from those with anomalous color vision and correctly classified protanopes, deuteranopes, deuteranomalous and protanomolous individuals, and female carriers. Color vision diagnosis including presence vs. absence, type and severity using the MassArray is more accurate than behavioral color vision tests such as the HRR, Dvorine, and Ishihara pseudoisochromatic plates, the Farnsworth-

Munsell D15 and the anomaloscope. Genetic screening with the MassArray maintains high accuracy eliminating the need for experimenter training and lengthy subject testing while removing inconsistencies from variability in spectral content and intensity of illumination, viewing distance, communication problems and cheating that can decrease the reliability of behavioral tests.

P11 Measuring the Temporal Contrast Sensitivity Function and Macular Pigment Optical Density in Older Adults with and Without Cognitive Impairment

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Introduction: Reduced temporal processing speed is characteristic of age-related neurodegenerative diseases, such as age-related macular degeneration and Alzheimer's disease, and may be a useful indicator of disease status. Whether or not the full temporal contrast sensitivity function (tCSF) can be accurately measured in adults with cognitive impairment (CI) is unknown. The purpose of this study is 1) to determine whether or not the tCSF and macular pigment optical density (MPOD), a measure of retinal lutein and zeaxanthin, also known to vary with temporal processing speed, can be accurately measured in subjects with CI, and 2) to determine whether MPOD and tCSF differ in patients with CI.

Methods: 28 subjects (65-89 years), including 7 patients with CI, were tested. tCSF was measured psychophysically using a custom-built device. MPOD was measured using heterochromatic flicker photometry. Psychophysical techniques were adapted for MCI patients.

Results: High-frequency portions of the tCSF were significantly reduced in impaired individuals ($p < 0.03$). MPOD was not significantly different in impaired vs. unimpaired individuals. Variability on both measures was not significantly different from young subjects and did not differ between impaired and unimpaired elders.

Conclusions: tCSF and MPOD can be assessed using adapted psychophysical techniques in older adults with CI.

P12 Color Appearance of Monochromatic Test Stimuli: An Analysis of Unique Hue Loci in the Vertical and Horizontal Meridians

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Our laboratory has proposed that foveal color perception of monochromatic stimuli differs from that in the peripheral retina even when stimulus size is appropriately scaled and rod signals are minimized. The precise nature of the color differences and what they imply about neural processing of color perception remains somewhat elusive, though data from our laboratory and others are beginning to converge on a possible explanation for these differences. In this study, hue-naming functions were obtained in the fovea and at 10° retinal eccentricity along the vertical and horizontal meridians at various test sizes (0.098° to 5.0°) and under experimental conditions chosen to minimize (bleach) and maximize rod input (no bleach). Unique hue loci were assessed directly from the hue-naming functions as well as derived from the Uniform Appearance Diagram. Preliminary analyses show that each unique hue locus converges to essentially the same value across the four retinal quadrants with the larger stimulus size. The

peripheral unique hue loci from both the bleach and no-bleach conditions, however, are at shorter wavelengths than comparable foveal unique hue loci. The results will be discussed in relation to stimulus size, retinal location, and rod signals, as well as from an ecological perspective.

P13 Pediatric Retinal Imaging with SD-OCT

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Objective: Optical coherence tomography (OCT) allows routine examination of the human retina. While conventional OCT devices are limited mainly to adults, the availability of a handheld system enables expansion of the technique to pediatric populations, with the primary clinical applications being shaken baby syndrome and retinopathy of prematurity. It is thought that some aspects of foveal development continue after birth; thus we sought to apply this technique to examine the postnatal aspects of foveal development in a series of pediatric patients.

Methods: Twenty-seven subjects ranging in age from 30 weeks gestation to 4 years of age were imaged using Bioptigen Hand Held Probe SD-OCT (HHP-SDOCT) (Bioptigen, Research Triangle Park, NC, USA). Sixty-three total imaging sessions were performed, with some subjects being followed for several weeks during their stay in the NICU or undergoing several exams under anesthesia (EUA). We evaluated the success rate of obtaining useable images, instrument usability, occurrence of sub-clinical pathology, and the appearance of the fovea compared to adults.

Results: We obtained usable images in 71% of awake infants in the NICU (39/55) and 100% (8 of 8) of subjects imaged as part of an EUA. These numbers are comparable to other reports. The size and weight of the handheld probe was generally well tolerated by six users, though smaller hands had some difficulty manipulating the probe. Qualitatively, foveal pit morphology in the younger infants was clearly distinguishable from the adult retina – specifically, the excavation of the inner retina was incomplete in the young infants. Retinal lamination also differed from adults – the outer photoreceptor layers (ELM and IS/OS junction) were absent in the earliest retinas and emerged around postnatal week 10, starting in the periphery and moving towards the fovea. These features were consistent with those previously documented using histological techniques.

Conclusions: Hand-held OCT imaging is a viable technique for assessing normal and diseased neonate retinas. Longitudinal imaging should offer the opportunity to characterize the postnatal aspects of foveal development.

P14 Influences of Macular Pigment on Visibility

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Purpose: A major factor limiting the ability to see in the distance is veiling due to environmental haze. Like skylight, this haze is dominated by short-wave light. Wooten and Hammond (2002) first suggested that yellow filters (in this case, the macular pigments, MP) that absorb this haze could extend visual range. This Visibility hypothesis was tested on subjects with differing MP levels.

Methods: 23 healthy subjects (mean = 28.0, s.d. = 8.2) were assessed. Both MPOD and visibility were measured psychophysically and in free view. Visibility was measured (using the methods of limits and constant stimuli) by varying the amount of simulated blue haze (produced with broad-band xenon light and a special interference filter) needed to veil a sine-wave grating (8 cyc/deg). Results: MPOD ranged from 0.11 to 0.85. Visibility thresholds varied

by over a factor of 2. MPOD was significantly related to the amount of blue veiling required to lose sight of the grating ($r = .62$, $p < .01$).

Conclusions: Subjects with higher MP were able to perceive a grating target despite significantly higher levels of haze compared to subjects with lower MP. These empirical data are consistent with the original modeling by Wooten and Hammond.

P15 The Luminance Balance and Color Appearance Mode of Surrounding Colors Affect Color Constancy

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On color constancy, we previously demonstrated that changing luminance balance of surrounding bright colored surfaces with constant chromaticity affected the illuminant estimation (Uchikawa, et al., 2010), however, the surrounding colors exceeding certain brightness seemed ineffective (Fukuda, Uchikawa & MacLeod, 2011). The question here is whether this ineffectiveness of bright colors on color constancy is caused by the appearance mode of bright colors, which transits from surface to illuminant.

In the experiments, we used the stimulus consisting of a central test stimulus and 60 surrounding stimuli of six colors (bright and dim red, green and blue). The variable was the luminance of the brighter red and blue colors. The observers adjusted the chromaticity of the test stimulus so that it appeared as an achromatic surface, and evaluated the color appearance mode of the surrounding colors with the number of 0 (surface-color mode) to 10 (illuminant-color mode). The correlation between the luminance balance of surrounding colors and the illuminant estimate was compared with the color appearance score of the brighter red and blue surrounding colors.

The results showed that the effect of brightest surrounding color on illuminant estimate diminished at the luminance balance where the brightest color appeared as an illuminant. This suggests that the visual system might be able to get rid of illuminants in the surrounding colors and accomplish color constancy using only surfaces.

Uchikawa, K., Kitazawa, Y., MacLeod, D. I. A., Fukuda, K. (2010) Degree of color constancy obtained by luminance balance of color samples. J Vis December 22, 2010 10(15): 8.
Fukuda, K., Uchikawa, K., MacLeod, D.I.A. (2011) Influence of surrounding colors in the illuminant-color mode on color constancy, Asia-Pacific Conference on Vision, p. 53

P16 Range Normalization in the Luminance-to-Lightness Mapping

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We report strong distortions of the ratio principle using low dynamic range, but highly articulated, mondrian patterns. Our stimulus consisted of two perpendicular planes, meeting at a dihedral corner and viewed in a vision tunnel. Although the two planes were equally illuminated, one plane was covered with a pattern of strictly light gray patches ranging from middle gray (Munsell 4.5) to white (9.5), while the other plane was covered with a pattern of strictly dark gray patches ranging from middle gray (4.5) to black (2.0). The two mondrians had either 5, 25, or 150 patches on each side. In each case, the mondrians appeared differently illuminated, each tended towards a white anchor, and the perceived range of gray shades in each plane was expanded relative to the actual range. Moreover, the amount of expansion was proportional to the number of patches (articulation). In the 25-patch condition, for example, the 5.8:1 actual range of luminance on the lighter side was perceived as an 11:1 range of matched reflectances. On the darker side, 5.2:1 expanded to 10:1. The visual system seems to exhibit a strong tendency to normalize the range of luminance toward a canonical, 30:1, white:black range.

P17 S-opsin Knockout Mouse Models Cone Dysfunction Associated with a Toxic L/M-opsin Interchange Variant

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Amino acid sequence variability in the human long (L) and middle (M) wavelength opsins arose due to successive, combinatorial interchanges between the L and M opsin genes. One such sequence combination, dubbed LIAVA according to the amino acids present at positions 153, 171, 174, 178 and 180 respectively, has never been associated with a normal human photoreceptor. Cones expressing an LIAVA pigment do not contribute to vision, and appear abnormal by adaptive optics imaging and optical coherence tomography. In adult humans, the LIAVA combination appears to interfere with production of photopigment and outer segment formation. Remarkably, despite being morphologically and physiologically compromised, imaging data indicate that cones expressing an LIAVA L or M opsin remain viable. A strikingly similar pattern of cone dysfunction is seen in the S-opsin knockout mouse. By immunohistochemistry, a subset of cones, presumably those that would have ordinarily expressed mostly S opsin with some M opsin, contain an unusually low amount of opsin and have deteriorated outer segments. The morphology is consistent with dramatically attenuated light responses recorded with the full-field electroretinogram. If these cones are viable, as these data suggest, then using gene therapy to express normal opsin to rescue photoreceptor function seems feasible.

P18 Objective Measurement of Transverse Chromatic Aberration with the Adaptive Optics Scanning Laser Ophthalmoscope

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Transverse chromatic aberration (TCA) is one manifestation of chromatic dispersion of the ocular media, in which the images formed by light of different wavelengths are displaced angularly on the retina. The amount of displacement is a function of wavelength difference and the displacement of the chief ray from the achromatic axis, along which - by definition TCA is zero. While the impact of TCA on foveal vision is perceptually small, high-resolution retinal imaging, as exemplified by the adaptive optics scanning laser ophthalmoscope, demands correction of chromatic aberrations if light of different wavelengths is wished to be targeted to specific retinal locations. Here, an image-based measurement technique is presented that bears the possibility to record and correct TCA in real-time. By a spatially interleaved light delivery configuration, the images of two (or more) illumination channels can be recorded simultaneously. Using a fast cross-correlation algorithm, the spatial offset between correspondent video frames is computed and output as a vector field of offsets across each frame. Inversion of each vectors' direction serves to correct for two-dimensional TCA across the imaging field with sub-pixel precision, to make possible the acute delivery of cone targeted stimuli. Preliminary results are presented that were validated with a psychophysical hyperacute five-dot alignment task. Future applications for multi-wavelength retinal imaging and stimulation are discussed.

P19 Physiological Correlates of Apparent Modulation Frequency

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In a phenomenon termed “asynchronous contrast,” Shapiro et al. (2004) demonstrate the dissociation and relative dominance of contrast signals over luminance signals when the luminance of two circles changes synchronously in the temporal domain and are surrounded by annuli of differing luminance. Here we report an electrophysiological correlate of these contrast and luminance signals. Participants were shown a field of circles sinusoidally modulating in luminance (4 Hz) against differing gray backgrounds. VEPs were recorded from Oz, and Fourier components were extracted from the responses. A 4 Hz component, the luminance frequency, as well as an 8 Hz component, the stimulus contrast frequency, were present in the VEP. The relative amplitude of these components varied with background luminance. Psychophysical measures of apparent modulation frequency were also obtained. The dependence on background luminance of the relative changes in the 4 and 8 Hz components of the VEP were mirrored by the psychophysical judgments of modulation frequency. Results indicated that the 8 Hz component of the VEP reflects the contrast signal observed psychophysically by Shapiro et al. Whether or not local contrasts or more global contrast mechanisms are responsible for the signal in the VEP is a subject for further experimentation.

P20 Intraretinal Axon Collaterals of Melanopsin Cells in Primate and Mouse Suggest a Novel Synaptic Pathway for Feedback of Irradiance Information to the Retina

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The axons of retinal ganglion cells are unique in that they typically do not provide synaptic feedback to the retina via recurrent axon collaterals. Such collaterals, however, have been rarely but consistently observed in many species, including primate. The ganglion cells bearing these collaterals have large, sparsely branching dendritic trees, suggesting the collaterals are not a developmental aberration but are associated with a single, low-density ganglion cell type. Here we show that, in both mouse and primate, intraretinal collaterals arise from a subset of melanopsin-expressing cells, suggesting a critical role for this novel feedback pathway in retinal circadian rhythms. Using a transgenic mouse (Opn4 CreERT2; Z/AP) in which the density of labeled melanopsin cells is controlled by tamoxifen injection, we show axon collaterals that terminate in either the inner or outer IPL and can be clearly traced to individual melanopsin cell primary axons (~8% of cells). In macaque retina, a subpopulation (~11%) of melanopsin immunoreactive cells also exhibit axon collaterals. It has been shown that dopaminergic amacrine cells, a modulator in retinal circadian rhythms, also show a melanopsin driven light response [1]. We hypothesize the melanopsin-associated collaterals provide the synaptic pathway by which the intrinsic, irradiance coding signal reaches the dopaminergic circuit.
*The presenting and second authors contributed equally to this work.
[1] Zhang, et al., PNAS, 105; 14181, 2008

P21 Cortical Visual Function in Infants with Polymicrogyria (PMG) Compared to Controls

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Purpose: Examine visual acuity and visual evoked potentials (VEP) in humans with cortical migration defects (polymicrogyria or PMG).

Methods: Five infants with PMG (0.4 – 1.6 yrs age) were compared to 5 age matched controls. PMG was documented via multiple MRI sequences. Acuity was assessed Teller acuity cards. VEPs were recorded across the occiput to reversing checks and onset of sinewavegratings. VEP epochs were examined for amplitude/phase coherency at 16 harmonics.

Results For infants with PMG, all had microcephaly, 2 had diffuse polymicrogyria, 1 had bilateral parietal involvement, 1 with right parietal-frontal and 1 with bilateral parietal-temporal. Three infants had normal acuity; 2 had no visual tracking. VEP lateralization was seen in infants with polymicrogyria confined to one hemisphere.
All subjects had amplitude/phase coherency with systematic phase shifts with increasing frequency. Coherency could be detected in infants with PMG and no visual behaviors; however the time domain VEP was abnormal. Selecting epochs with stronger coherency at one harmonic had the similar effects across harmonics indicating coherency of across frequency bands. Selective averaging of epochs with phase coherency improved VEP amplitudes 337% in PMG and 60% in controls.

Conclusions: Reproducible and large amplitude VEPs can be recorded from infants with polymicrogyria and no visual behaviors. Reduction in VEP is associated with loss of VEP coherency. We argue the results reflect a loss of cortical organization and/or feedback into visual cortex.

P22 Effects of Luminance and Color Conditions on Color Spreading in Flank Transparency Displays

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Adding narrow colored flanks to black lines where these lines fall within a virtual square induces the perception of a colored transparent square with illusory contours, an illusion called flank transparency (Wollschlager et al., 2001). We investigated luminance and color conditions for the perception of color spreading in a static flank transparency display. Luminances of the flanks, lines, and background in the display were systematically varied. The flanks were either colored (green) or achromatic, and the lines and background were always achromatic. Observers rated the certainty of color spreading with a five point scale. The results revealed that color spreading depended upon color as well as luminance conditions. Moreover, the results could mostly be accounted for by an episcotister model of perceptual transparency generalized to a cone contrast metric; i.e., color spreading was reported when the color conditions in the display satisfied the conditions predicted by the model. Consistently with the findings using neon color spreading displays (Ekroll & Faul, 2002), the present findings suggest that perceptual scission of color and luminance information in a flank region into a transparent layer and a background plays a critical role in producing color spreading in flank transparency displays.

P23 Can Subjects Tailor Their Detection Strategy to Match Expected Stimulus Size at Absolute Cone Threshold?

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Foveal cone detection is often modeled as if subjects pool signal information over the extent of the stimulus. We sought to determine if subjects use this optimal detection strategy by measuring detection thresholds for stimuli presented either in blocks of known size or with the same sizes randomly intermixed.

Detection thresholds and color appearance were simultaneously measured in 4 subjects using multiple response criteria. Dim, brief (30 ms), monochromatic (550 nm) spot stimuli of 4 sizes (1.7', 4.1', 9.9' and 25') were presented to the dark-adapted fovea through a 2 mm artificial pupil. Thresholds and color reports were compared between blocked and intermixed conditions, and detection thresholds were compared to model predictions.

Detection thresholds and color appearance were not significantly different in the blocked and interleaved conditions, indicating that subjects employed the same detection strategy in both cases. This precludes the optimal

strategy in which pooling is flexible based on a priori stimulus information. In a linear response framework, performance was also inconsistent with both independent cone detection and summation over a single, fixed pooling area. Results were consistent with a model of detection incorporating independent signal combination across multiple channels pooling over various spatial extents.

P24 The Neural Locus Where Cone Signals Are Combined for Hue Perception

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Jay Neitz, University of Washington, Ophthalmology

Thomas Young famously proposed that three receptor types account for “three principal colors" and Helmholtz echoed that three cone types directly account for hue perception saying “Young’s hypothesis is only a special case of the law of specific sense energies.” However, Mach and Hering recognized that trichromatic theory could not account for hue perception which is based on opponent processes responsible for four “primordial” hues, blue-yellow and red-green. Trichromacy and opponency have been reconciled by “zone theories” first proposed by G. E. Müller and refined by Judd and Hurvich and Jameson in which the outputs of the cones are neurally recombined early in visual processing. However, more recently an even more central reorganization of L vs. M and S vs. (L+M) ganglion cells has been proposed to account the details of hue perception. We have reexamined this issue by studying people whose visual pathways are greatly simplified because of GRM6 mutations that block all signaling between photoreceptors and ON-bipolar cells. We have found that these patients have S-cone driven bipolar cell responses as assessed by ERG and normal hue opponent vision. This suggests that inhibitory feedback between adjacent cone pedicles is the site where signals responsible for hue perception originate.

P25 The Source of Overlay Masking in the Human Visual System

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The cortical response to an oriented pattern is influenced by the superimposition of a pattern of orthogonal orientation. This phenomenon, termed overlay masking (alternatively, cross-orientation suppression), manifests as a reduction in effective contrast that could be attributed to either primarily cortical or subcortical mechanisms. Here, we used source- imaged electroencephalography (EEG) to identify the source of overlay masking in the human visual system. We measured the response of neurons in primary visual cortex (V1) to an oriented test component of varying contrast, and examined how this response was altered by the superimposition of an orthogonal mask presented to the same eye (monoptic) or different eye (dichoptic). We found that a monoptic mask changed the effective contrast of the test component, consistent with overlay masking, while a dichoptic mask preserved the effective contrast of the test component and hence circumvented overlay masking. Given that dichoptic presentation precludes subcortical interactions between components, we identify subcortical mechanisms as the primary source of overlay masking in the human visual system.

P26 Effects of Lightness on Chromaticity Regions to Yield Gold, Silver and Bronze Colors

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Metallic colors, such as gold, silver and bronze colors, appear on a surface depending on its chromaticity and

glossiness. Lightness of the surface also seems to influence on perceiving metallic colors. In this study we investigated what effects the surface lightness could have on chromaticity region of gold, silver and bronze colors. In the experiments we used CG simulated spheres, presented on a LC display, with various glossiness and chromaticity as stimuli. The lightness of the sphere, which varied with diffuse reflectance of the surface, was set as a variable. The observer performed categorical color naming and estimated degree of gold, silver or bronze color appearance of the stimulus. The results showed that the size of chromaticity regions to yield gold, silver and bronze colors reduced as the lightness increased. There was only a small chromatic region of a metallic color when the surface had low glossiness and high lightness. Similarly the degree of gold, silver or bronze color appearance decreased as the lightness increased. These results indicate that the surface with certain glossiness appears gold, silver or bronze color only below some level of lightness.

P27 Optical Design of Hyperspectral Two-dimensional Display and its Application

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A system with the hyperspectral camera and display can reproduce spectral information of objects. With this technology, a gamut of the system covers a full color range, and it is possible to avoid observer metameric failure. In this presentation, we introduce a novel optical system of the two-dimensional hyperspectral display and propose a new method to examine the metameric failure of each individual.

We modified a programmable light source to build a new type of hyperspectral display. The spectral components of the light were arbitrarily set by controlling a digital micromirror device (DMD). Seven-hundred-and-sixty-eight independent combinations of the monochromatic light, of which wavelength and intensity were selected by the horizontal direction of 1024 pixels of the DMD, were composed as a line image. And then the line image was scanned to form a two dimensional hyperspectral image. We performed a preliminary experiment using the one dimensional version of the display. We combined three monochromatic wavelength components to match white using a spectroradiometer. Three different wavelength combinations, RGB1: 450, 560, 600 nm, RGB2: 470, 560, 600 nm, and RGB3: 470, 570, 600 nm, were used. The subjects were asked to answer the order of the three RGB whites that resembled equal energy white (EEW) presented as a surround stimulus. At the same time, the subjects answered the magnitude of the difference between each RGB white and EEW. Seven color normal subjects (ages: 26 to 53) participated in the experiment. We found noticeable difference in the responses RGB1 among subjects. The younger subjects called the color green, while the older called it yellow or red. We speculate that the short wavelength components in RGB1 were absorbed by older crystalline lenses. This simple test shows a potential of our system as a useful tool for detecting absorption of the crystalline lens.

P28 An Eye-Movement-Defined Hierarchy of Visual Stimuli

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Reverse correlation of stimulus velocity with eye velocity can be used to infer pursuit latency in a task in which a subject attempts to follow a target undergoing random motion. Using a binocular dual Purkinje image eye tracker equipped with stimulus deflectors, we measured tracking responses to four-dimensional motion, produced by

delivering an independent random walk to each eye, analyzing the results in terms of horizontal and vertical vergence and version. High-contrast luminance-defined stimuli produce the shortest latencies (around 100 msec); varying texture contrast increases the delay by approximately 50 msec / log unit. Nulling the first-order luminance contrast in a second-order contrast-modulated target produces a dramatic increase in latency (over 100 msec additional delay), and abolishes the vertical vergence response - the only one of the four types of movement that cannot be executed voluntarily. We propose a model of the system in which a fast reflexive system responds to a limited class of stimuli, while a slower voluntary system is capable of tracking anything that can be seen.

P29 The Effect of Dot Speed and Density on the Maturation of Global Motion Perception

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Global motion stimuli are commonly used to study motion perception, including its development, in human and nonhuman primates. The age at which this aspect of motion perception matures to adult levels is currently a point of contention, with published values ranging from before 3 years of age (Parrish et al., 2005) to after 12 years of age (Lewis et al., 2010). Specific stimulus attributes such as dot speed and density vary considerably across previous studies, which may explain the conflicting results. We measured coherence thresholds for global motion direction discrimination in 5 year-old children and in adults (18-23 years) at two dot speeds (1 and 4 deg/s) and three dot densities (1, 15, 30 dots/deg2). Adult coherence thresholds were constant at approximately 10%, regardless of speed or density. Child coherence thresholds were significantly higher, and were most immature at the slow speed and at the sparsest density. The speed finding confirms previous results (Ellemberg et al., 2004; Hayward et al., 2010). The novel density finding can account for much of the discrepancy in the current developmental literature. These results caution against drawing firm conclusions about visual maturation or deficits in clinical populations based on only a single measurement at a specific combination of speed and density.

P30 Influence of Luminance vs. Chromaticity Distribution of Surrounding Surfaces on Luminosity Threshold of a Surface Color

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The luminosity threshold of surface colors depends on luminance of surrounding colors. When there is no or low-luminance surrounding colors a colored light appears as an illuminant, whereas when luminance of surrounding colors are high enough the same colored light appears as a surface [1]. It is unclear, however, what statistics of luminance and chromaticity distribution of surrounding colors determine the surface color's luminosity threshold. In this study, we investigated whether differences in luminance vs. chromaticity distribution of surrounding colors influence the luminosity threshold of the test color. In experiments, we used the 15deg surrounding stimulus consisting of randomly overlapping 2deg circles with three different distributions of luminance vs. redness; natural surface, uniform and V-shape distribution. The observer adjusted the luminance of the 2deg circular test stimulus, presented at the center of the display, so that it appeared neither as a complete surface nor a complete illuminant. The results showed that the luminosity threshold changed as a function of redness of the test color, and resembled the luminance vs. redness distribution of natural surfaces in shape. Since the luminance of natural surface colors spreads within the luminance limit of the optimal colors the visual system might recognize the optimal color luminance as the luminosity threshold.

[1] K. Uchikawa, K. Koida, T. Meguro, Y. Yamauchi and I. Kuriki, Brightness, not luminance, determines transition from the surface-color to the aperture-color mode for colored lights. J. Opt. Soc. Am. A, 18, 737-746, 2001.

P31 Determining Heterochromatic Flicker Photometry Frequency for Macular Pigment Optical Densitometry by Critical Flicker Fusion Frequency

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Accurate clinical assessment of Macular Pigment Optical Density (MPOD) using Heterochromatic Flicker Photometry (HFP) requires the HFP stimulus be presented at or near a specific "ideal" frequency. If the frequency is too low, fusion never occurs and the task is difficult for naive patients. If the frequency is too high, fusion occurs in a wide range of values, and measurement error is high. Determining this frequency is time consuming and difficult to determine in a clinical setting. Critical Flicker Fusion (CFF) frequency is easy to assess using standard densitometry equipment in naive patients. By correlating CFF and the "ideal" frequency for HFP densitometry for a given densitometer, HFP frequency selection can be made quickly and accurately from the comparatively easier CFF assessment. A methodology for determining "ideal" HFP frequency was developed using a Macular Metrics II (tm) Macular Pigment Optical Densitometer. "Ideal" HFP frequencies show positive correlation to CFF frequency allowing a straightforward algorithm to be derived.

P32 Mid-level Pattern Masking: Contrast or Response Gain Control?

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Masking in fine orientation or spatial frequency discriminations can be observed when masks of very different spatial frequency or orientation, respectively, are overlaid on a target sinusoid. Masking (or slight facilitation) can also occur when masks of similar spatial frequency and orientation are presented in as annulus surrounding the target patch. We evaluated the relative contributions of contrast and response gain in accounting for the contrast response functions in these tasks, which shift curves horizontally (contrast gain) and/or vertically (response gain). The target was always a 15 cpd grating, upon which spatial frequency or orientation discriminations were made. In different sessions, masks were either overlaid or positioned as an annulus, and were presented either at 2% or 25% contrast. Within each session, target contrast was randomly varied equal linear steps from 3.1% contrast to 25% contrast (3.1%, 6.3%, 9.4%, 12.5%, 15.6%, 18.8%, 21.9%, and 25%) to generate contrast response functions. We fit Naka-Rushton functions to the data, with parameters C50 and Rmax free to vary. The functions accounted for the data well. There was no contribution of contrast gain in the 2% mask conditions, but at the higher mask contrast, combined contributions from both types of gain were required.

P33 Comparison of Macular Pigment Optical Density Spatial Profiles Measured Using Two-Wavelength Autofluorescence with Foveal Pit Mmorphology

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We compared macular pigment optical density (MPOD) spatial profiles measured by customized heterochromatic flicker photometry (cHFP) and two-wavelength autofluorescence (AF) imaging. Spectral domain optical coherence tomography (SD-OCT) was used to compare the MPOD distribution with foveal architecture. Thirty healthy subjects

were recruited to measure their MPOD spatial profiles out to 7° retinal eccentricity using cHFP and two-wavelength AF methods (Heidelberg HRA MP). Measurements of central foveal thickness, width of the foveal pit, and arrangements of the foveal layers were extracted from OCT scans in a subset of the subjects to investigate relationships to the MPOD distribution using the Heidelberg Spectralis SD-OCT. OCT B-scans and corresponding infrared fundus images were co-aligned with MPOD spatial profiles to examine MPOD with respect to foveal location. Our preliminary results support the idea that a wider fovea is associated with a wider macular pigment spatial profile that can include a central peak and flanking peaks. A narrow fovea is likely to have a steeper macular pigment distribution that more closely approximates an exponential spatial profile. OCT raster scans of the foveal pit are being co-aligned with MPOD spatial profiles for more detailed comparisons of spatial features.

P34 Adaptation to Alterations of Three-Dimensional Space Perception in Stereoscopic Displays

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Stereoscopic displays are currently used in a number of military, surgical and entertainment applications. However, stereoscopic displays potentially introduce distortions in the metrics of the visual space by altering horizontal disparity and vergence cues. To assess the adaptability of the perceptual and perceptual-motor systems to alterations of three-dimensional space perception, we performed a series of psychophysical experiments using either base-out prisms or a telestereoscope to modify disparity and vergence. We observed a “compression” of visual-space during exposure to these optical distortions. By manipulating visual feedback, we were able to demonstrate that adaptation occurred at three different levels: oculomotor (changes in tonic vergence), perceptual (visual recalibration), and behavioral (reorganization of limb motor commands). The implications of these findings for applications of stereoscopic displays in ecological and operational environments are discussed.

P35 Numerosity Estimation Is Not Derived Only from Density and Size Judgments

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A previous study (Morgan et al, 2011) has shown that when observers estimate the numerosity of a large number of dots (> 60) drawn in a notional circle they could be combining separate estimations of size and density. We predicted from this that if estimates of size could be made noisier, errors in dot numerosity estimation would rise. We made size estimation more difficult by drawing the dots in irregularly shaped notional polygons with random numbers of vertices. We used a 2AFC task with a 64 dot standard and a test that either changed in size (covarying with numerosity) or in a separate session in density (co-varying with numerosity). The test and standard had different pseudo-randomly generated shapes that also varied from trial to trial. The subjects were asked to chose which stimulus was larger or denser depending on the condition. In a third condition we mixed size and density varying trials and asked subjects to estimate which stimulus had the larger number of dots. The arrangement of dots in notional polygons did indeed increase the Weber fraction for size judgment substantially relative to the previous experiment with circles. However contrary to our prediction this had little effects on thresholds for numerosity. Numerosity, size and density Weber fractions were not significantly different. A model with a single noise source for numerosity limiting performance in all three tasks is a better fit to the data than the Morgan et al (2011) model with different noise sources for size and density and no numerosity mechanism. Our results therefore are consistent with a pure numerosity mechanism (Ross & Burr, 2010) or with a mechanism that encodes numerosity as the ratio of responses from a pair of filters tuned to low and high spatial frequencies as suggested by Dakin et al (2011).

P36 The McCollough Aftereffect Strength Varies with Test Chromaticity: Local Distortions in Color Space?

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Donald MacLeod , University of California, San Diego, Psychology

We used the McCollough color/orientation aftereffect to investigate the cortical representation of color. Previous researchers have measured the apparent color shift visible on neutral gray test patterns, whereas here we use colored tests. Subjects adapted to pairs of perpendicular gratings of different colors, and aftereffect strength was assessed by nulling the resulting aftereffect on test gratings. We organized test and adapting gratings on a color line running from green (-) to yellow (0), to red (+) in cone excitation space, summarized here as (adapting colors),test color. In condition (-4,+4),0 subjects adapted to medium saturated green & red pairs of perpendicular gratings and then aftereffect strength was measured on neutral yellow gratings. This gave a larger effect than in condition (0,8),0 with yellow & saturated red adapting gratings. We also measured color aftereffects on red test gratings. Here we found the reverse: the green & red adapter (-4,+4), 4 produced the same or less of an effect as the yellow & red one (0,8),4. This shows that the effectiveness of adapting colors depends on the test colors, and is suggestive of a non-linear distortion of color space that is the largest in the region in between the adapting colors.

P37 Measuring Volume Scotoma in Bitemporal, Binasal and Central Field Loss

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Volume scotoma (blind areas projected in depth) is theoretically predicted from combining monocular visual fields. However, computation from monocular perimetry assumes known retinal fixation locus. Conventional perimeters (Humphrey and Goldmann) are not suitable to measure volume scotoma since the visual fields are mapped at the fixation plane. We developed methods to directly measure volume perimetry in cases of interest.
Using computerized dichoptic perimeter and a fixation target in front of the screen a volume field behind fixation is measured. Such scotomas are expected in bitemporal (hemianopic) and in central field loss (CFL). Volume scotoma in front of fixation occurring with binasal and CFL can be measured using a transparent screen placed in front of the fixation and targets presented over it using a laser pointer.
Measurements of volume fields are consistent showing scotomas behind fixation or in front, for bitemporal and binasal field loss, respectively, and a rapid shrinking scotoma behind closer fixation for patients with small CFL.
With direct binocular measurements of volume scotoma no assumptions are needed. The measurements done binocularly demonstrate volume scotoma and if done dichopticaly can show each eye's contribution, and the results may have important implications for various daily activities.

P38 Image Correlates of Peripheral Contour Discrimination in Natural Scenes

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Natural visual environments are replete with contours, and the phenomenon of crowding demonstrates that contours are difficult to discriminate when viewed peripherally. Here we examined the discrimination of spatial structure in natural scenes by asking observers to locate a circular patch of artificial contours superimposed on a greyscale natural image. These contours were "dead leaves": ellipses of random size and aspect ratio matched in luminance and contrast to the image segment they replaced. Three observers identified the location of the dead leaves patch relative to fixation (N, S, E or W) at three eccentricities (2, 4 and 8º), with the size of the patch varied by an adaptive staircase. A logistic GLM was used to model task performance as a function of both the manipulated task parameters of patch size, eccentricity and visual field location, as well as the stochastically varying local image

statistics of the background image. Hierarchical model selection suggests that, after considering task parameters, the local RMS contrast in an image segment and correlated statistics such as edge density and phase congruence are the most significant predictors of task performance. These models give principled predictions of the likelihood of crowding in a given natural image segment.

P39 Abnormalities in Distribution and Transformation of Visual Iinputs in Children with CVI

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Purpose: Cerebral visual impairment (CVI) is a common visual disorder in children. In this study we report 10 children with subnormal or absent visual orienting behaviors in whom cortical activation was demonstrated by VEP and reflexive eye movements were present.

Methods: Testing included assessment of visual acuity Teller Acuity Cards or Snellen optotype), transient visual evoked potentials (VEPs) to check reversal and pattern-onset stimuli, eye movement recordings (EOG or IR video-oculography) and neuroimaging studies (CT or MRI).

Results: All of the children had abnormal visual behaviors ranging from complete lack of visually guided eye movements to reading disability. Visual acuities ranged from 20/20 to <20/2700. . In general, reflexive eye movements were present (VOR and OKN) whereas visually guided eye movements (smooth pursuit and saccade gains) were variably reduced. The eye examinations were otherwise normal. Neurodevelopment was uniformly delayed. Neuroimaging revealed delayed myelination or dysmyelination in 8 children; the remaining 2 children had hydrocephalus or diffuse polymicrogyria sparing the occipital cortex. Transient VEPs were normal or mildly abnormal in terms of amplitude, latency and waveform.

Conclusions: We report 10 subjects with normal or mildly abnormal visual cortical activation and the presence of VOR and OKN who demonstrate variable deficits or absence of visually guided eye movements. These findings are consistent with abnormalities in the distribution and transformation of visual inputs into accurate smooth pursuit and targeted saccades.

P40 Evaluation of the Relationship between Fusional Range and Visual Fatigue

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We verified the relative contribution to visual fatigue of misalignment executed as crosstalk and vertical shift by using binocular stereoscopic display. Our investigations were executed with two cases by objective and subjective evaluation. The objective evaluation by double images recognition method can reveal the range of fusional area. The subjective evaluation by simulator sickness questionnaire (SSQ) can clarify the influence quantity as visual fatigue. When the 3D demonstration as the still image was performed with misalignment, the range of fusional area decreased according to the increase of misalignment. On the other hand, SSQ score for visual fatigue increased in proportion to the amount of misalignment. A further experiment was conducted to the motion images. As the result of this experiment, the total score of SSQ dramatically indicated higher value for visual fatigue than the case of still image. From the relationship between the fusional area and SSQ score, it is suggested that the fusion area is almost lost at the observation of motion image. We ensure that the accommodation is hardly done in motion image, since it is well known that the response of accommodation is relatively slow in comparison to the response of convergence.

P41 Visual Perception of Surfaces with Transparent Layers

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Kazuho Fukuda, Tokyo Institute of Technology, Information Processing
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Recent psychophysical studies have investigated the visual processes underlying the perception of homogeneously transparent, or translucent, materials such as glasses and milk (Fleming & Buelthoff, 2005; Motoyoshi, 2010). Here, we explored critical image features that support visual perception of a surface with multiple layers like human skin and foods, in which an opaque body is covered with a transparent material. We first created real objects that consisted of an opaque urethane body covered (vacuum-formed) by a transparent sheet of polyvinyl medium, and found that the transparent layer was perceived only when the object had sharp bumps or when the air was occasionally interleaved between the inner body and the superficial layer. We next used computer-generated images to systematically examine the effects of physical parameters including color, glossiness, transparency, refraction, and thickness of the superficial layer. Observations with these images revealed at least three parameters that might be important for perceiving the transparent layer; (1) visible separation between the outside edge of the superficial layer and that of the opaque body, (2) specular highlights on the outer layer, (3) color fluctuations within the object image. We speculate that appropriate relationships between them support visual impression of transparent layers.

Where to eat?

A quick glance up "The Ave" (the odd nickname for University Way NE) will make clear that there are a lot of places to eat economically. Here are some of our favorites, representing a range of types of food and located close to the meeting, mostly between NE 40th St. and NE 45th St. There are many other good places: just because it isn't listed, doesn't mean it isn't good.

Walking directions to University Ave from Kane Hall: Cross the footbridge overpass. The Ave is the next street to the west. Restuarants are to the north along The Ave.

FRIDAY ONLY: There will be food trucks in Red Square, right outside Kane Hall; sandwiches, salads, snacks in Suzzallo Library Café (to left as you exit Kane); and full-service grill, hot entrees, sandwiches, soups, etc. in By George (near statue of G. Washington, to right as you exit Kane).

Coffee houses/sandwiches

Allegro Coffeehouse
A classic Seattle hangout, the best espresso drinks…and atmosphere
On the alley, east of University Way NE, north of NE 42nd St., (206) 633-3030
Bulldog News
Espresso, best bet for international newspapers
4212 University Way NE, (206) 632-9650
The Ugly Mug Café
Espresso drinks, nice soups and sandwiches
1309 NE 43rd St, (206) 547-3219

Lunch

Big Time Brewery
Good microbrew, pizza, sandwiches, chili (veggie or not), 21 and over only
4135 University Way NE, (206) 545-4509
Cedars
Middle Eastern,
1319 NE 43rd St (just W of the Ave), (206) 632-7708
The Continental
Good Greek food.
4549 University Way NE, (206) 632-4700
Ichiro
Japanese and Korean
4124 University Way NE, (206) 632-6975

Jewel of India
Indian, lunch buffet, great bargain, great taste
4735 University Way NE, (206) 523-5275
Mi Charrito Taqueria
Extraordinarily good, taco-truck-style soft tacos, burritos, sopes, and Spanish-language sports TV, popular with local Latinos, very quick
1312 NE 45th, (206) 633-2236
Pagliacci Pizza
New York style, the best on the Ave.
4529 University Way NE, (206) 726-1717
Ruby Restaurant
Asian fusion inspired, slow paced so not best if you're in a hurry
4241 University Way NE, (206) 675-1770
Samir's Mediterranean Grill
Quick Middle Eastern, the best baba ganouj, tasty food, stark sefng
1316 NE 43rd, (206) 633-1778
Shalimar
Traditional Indian/Pakistani and wrap sandwiches
4214 University Way NE, (206) 633-3854
Shultzy's Sausage
Sassy and tasty, homemade sausage sandwiches, local brews, a great experience
4114 University Way NE, (206) 548-9461
Thai-ger Room
Very popular Thai
4228 University Way NE, (206) 632-9299
Than Brothers
Vietnamese –just pho, the classic noodle soup
4207 University Way NE, (206) 633-1735
Thanh Vi Restaurant
Full range Vietnamese, try the Vietnamese sandwich, quick, inexpensive
4226 University Way NE, (206) 633-7867

Places to go in the evening

Ivar's
A Seattle institution, grab fish and chips and sit by the lake or visit the restaurant for a meal overlooking Lake Union. Nice for dinner
401 NE Northlake Way (brisk 20 min walk) (206) 632-0767

Or take the 44 bus from the corner of 15th and 40th and go to Wallingford where there are some moderate (Kisaku, Bizzarro) and high end (Tilth, Elemental) restaurants that are nice for dinner.

What to do?

Walk around the UW campus.

A convenient and extensive collection of web-based information about the campus (including maps and virtual tours) and the surrounding University District is grouped on the UW Visitor Information web page. Printed information including walking tour pamphlets is available at UW Visitor's Information Center on the SE corner of University Way NE and NE Campus parkway.

Rent canoes or rowboats

Rent boats by the hour at the UW Waterfront Activity Center.
Waterfront Actvities Center
3900 Montlake Blvd. NE
Seattle, WA 98195

Visit the University Bookstore

4326 University Way NE, one of the largest college bookstores in the country, with an in-store espresso bar, of course!

Visit University Village shopping center

North of NE 45th St and east of 25th Ave NE. Huge, well-heeled, very California….

Walk, jog, or bike

North 17th Ave NE, then east on Ravenna Blvd NE, up to Green Lake (Seattle's most popular park) for people watching and more walking, jogging, biking.

Walk along the Ship Canal

At the far south end of UW campus between two drawbridges, the University Bridge on the west, the Montlake Bridge on the east. A very pretty walk with views
of yacht clubs, houseboats, lots of greenery.

Visit the Henry Art Museum

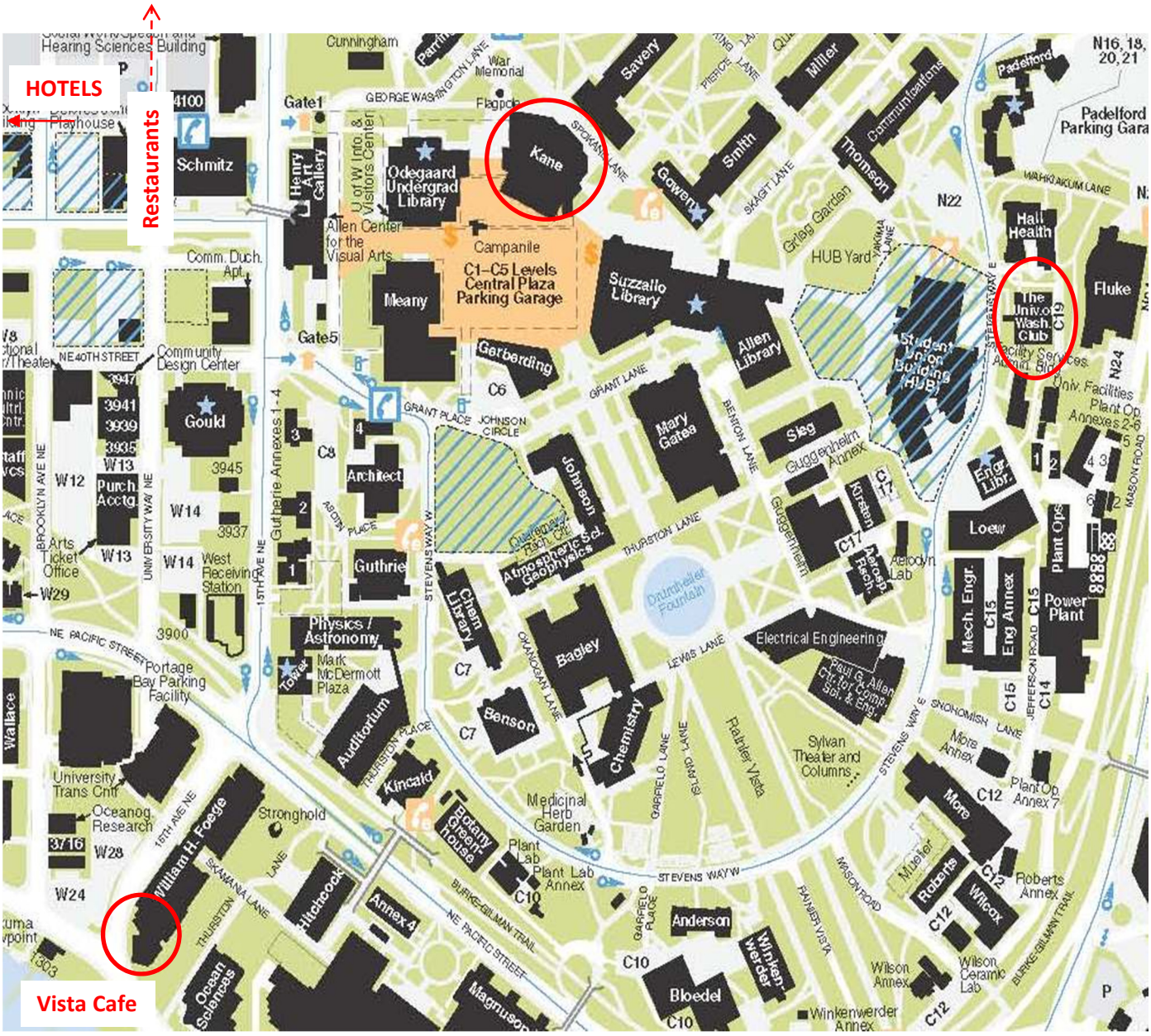
On campus at 15th Ave NE and NE Campus Parkway

Take the bus to Capitol Hill and visit Volunteer Park and the wonderful Asian Art Museum

Volunteer Park affords great views, especially from the enclosed top of the old brick water tower, accessible by enclosed stairs.

Take the bus to …

The bohemian neighborhood of Fremont
Downtown and visit Pike Place Market & the Space Needle
Ballard locks, if you're lucky you will see the salmon on the ladder



KEY TO MAP SYMBOLS

- Building
- Building (underground)
- Path/Sidewalk/Walkway
- Bridge/Overpass
- E5 Campus Parking Area
- P Public Parking Area
- Parking (underground)
- Gatehouse (with emergency phone)
- Automatic Parking Gate
- One Way Road (arrow indicates flow)
- Campus Entrances
- Bus Stop / Bus Route
- Emergency Phone
- Pay Phone
- Branch Library
- Bank Machine
- Road Gate
- Fence
- Construction Area
- Removable Bollards