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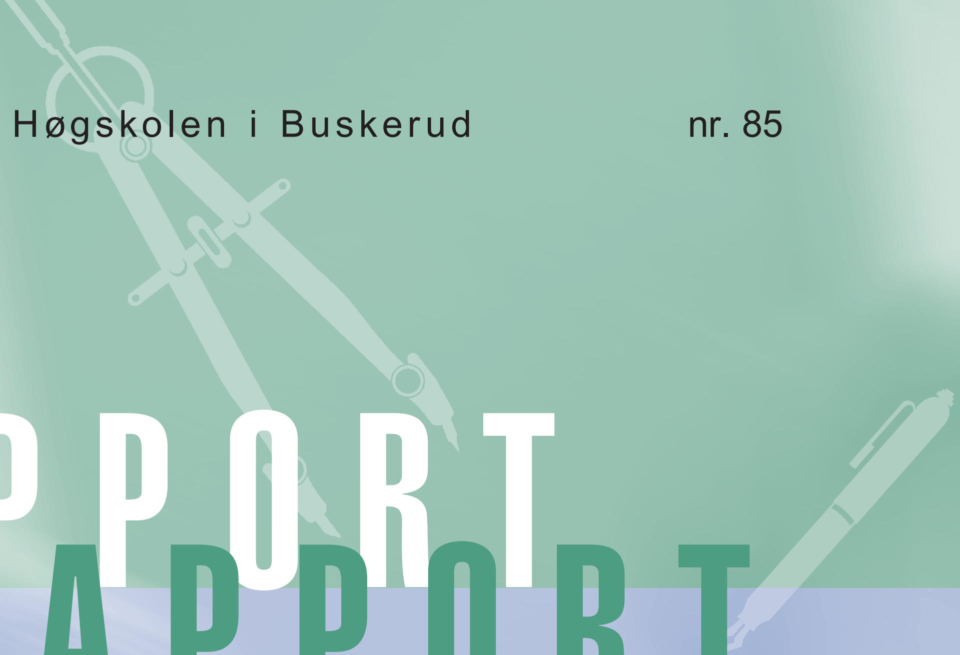

RAPPORT

RAPPORT

The 21st Symposium of the International Colour Vision Society Abstract Book

Editor: Rigmor Baraas

HØGSKOLEN
i Buskerud

Rapporter fra Høgskolen i Buskerud

Nr. 85

The 21st Symposium of the International Colour Vision Society Abstract Book

Redigert av

Rigmor Baraas

Kongsberg 2011

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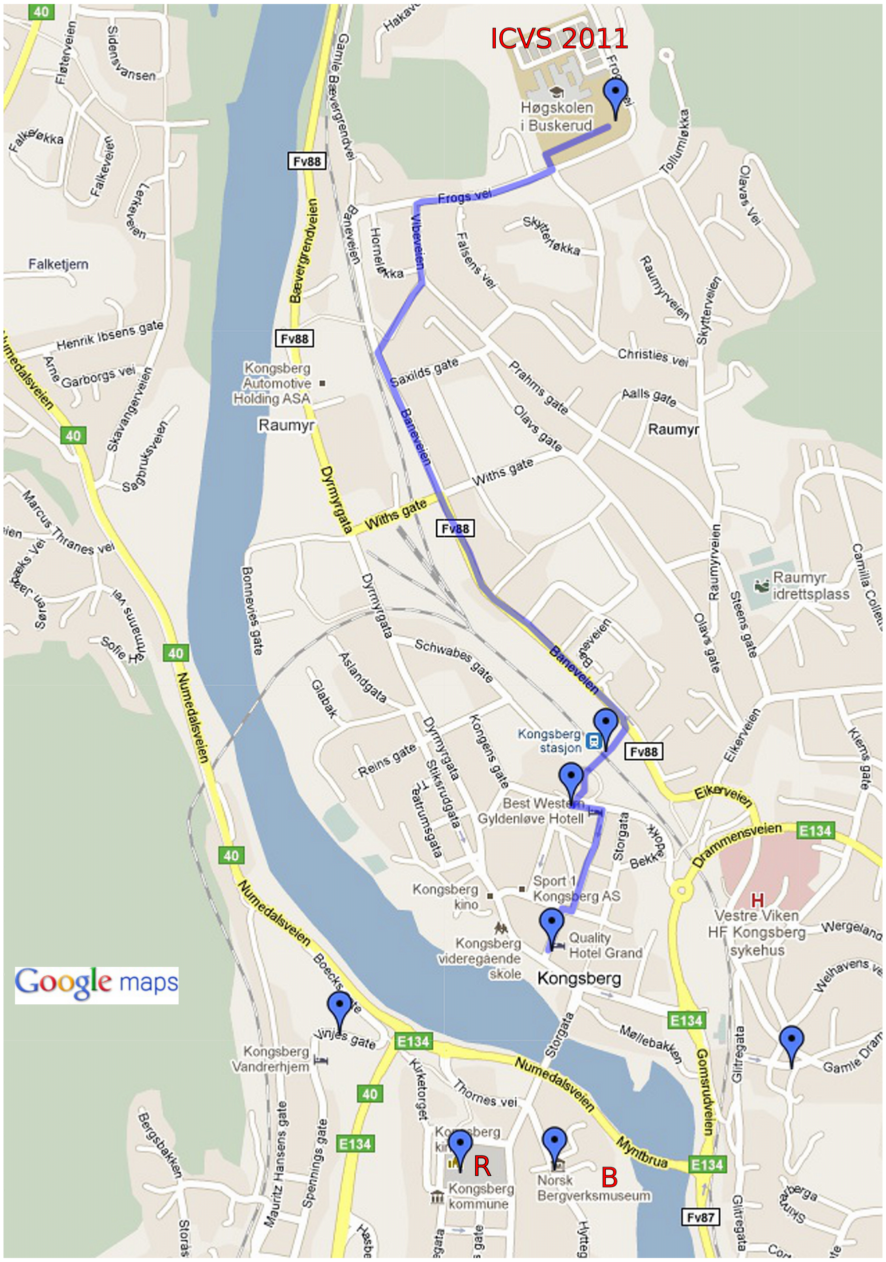
ICVS 2011

JULY 1-5, 2011

BUSKERUD UNIVERSITY COLLEGE

KONGSBERG, NORWAY



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OSA

Walking routes from Quality Grand Hotel and Best Western Gyldenløve Hotel to Buskerud University College (ICVS 2011).

Placemarks are added for Kongsberg Vandrerhjem and some museums and attractions in Kongsberg.

The reception (R) on Friday will be under the Tubaloon on Kongsberg Church Square.
The banquet (B) on Monday will be at Norsk Bergverksmuseum (Norwegian Mining Museum).

THE 21ST SYMPOSIUM OF THE

INTERNATIONAL COLOUR VISION SOCIETY

ABSTRACT BOOK

JULY 1-5, 2011
KONGSBERG, NORWAY

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Abstract Book
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PREFACE

Dear Colleagues,

It is with great pleasure that we welcome you to Norway, Kongsberg and Buskerud University College for the 21^{st} Symposium of the International Colour Vision Society.

The interest of the members of the society, ranging from basic to applied and clinical research in to colour vision and its mechanisms, is reflected in the symposiums scientific programme. The interdisciplinary scope of the society and its biennial symposium has yet again attracted colour vision scientists from five continents and of all ages.

The social and cultural programme will reflect the serenity of the Scandinavian summer. We hope this will create an atmosphere for open and informal interaction and that it will add an extra dimension in our celebration of the society.

We are most grateful for the support and help from our sponsors and ICVS officers, and thanks in particular those locally who have made an extra effort in preparation for the society's 21^{st} symposium.

Kongsberg may well be the smallest city to have hosted the symposium and most certainly the most northern. We hope the city's history and the long summer days will inspire to great scientific discussions about light and colour from dawn till dusk. We wish all participants a wonderful stay.

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VERRIEST MEDAL WINNER 2011

Professor Steven K. Shevell, Ph.D

The International Colour Vision Society (ICVS) is pleased to announce that the 2011 Verriest Medal will be awarded to Steven K. Shevell at the 21st Biennial ICVS Symposium to take place at Buskerud University College in Kongsberg, Norway (July 1-5, 2011). This award was established in 1991 in memory of the founding member of the Society, Dr. Guy Verriest, and honours outstanding contributions in the field of colour vision.

For over 35 years, Professor Shevell has contributed to the vision and particularly the colour vision community in breaking new ground in research, training new researchers and providing service to the community. In his experimental work, he has carefully integrated theoretical and experimental approaches in studies of how early mechanisms and context influence colour perception. He has artfully exploited the technique of hue cancellation to study adaptive processes, spatio-temporal constraints, memory and binocular integration in colour perception. Professor Shevell is the Eliakim Hastings Moore Distinguished Service Professor in the Department of Psychology at The University of Chicago, Professor in the Section of Ophthalmology and Visual Science, Department of Surgery, and in the Committee on Computational Neuroscience, and, also, immediate-past Chair of the Integrative Neuroscience Graduate Program. In addition, he has served, over the years, on editorial boards of leading journals, review panels of leading granting agencies and on the boards of major research societies. He is currently a member of the Directors' Committee of the ICVS. His wise and equilibrated advice is sought after in our deliberations and personifies the voice of careful research, integrity and reason.

FRIDAY

08:30 – 18:00	Registration desk open	
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12:45 – 14:00	Directors' lunch	
14:00 – 14:30	Opening of the Symposium	

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Moderator: John S. Werner

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14:45 – 15:00	***Effects of macular pigment on color vision*** M. Snodderly	13
15:00 – 15:15	***Chromatic discrimination across four life decades: Cambridge Colour Test*** G. V. Paramei, T. G. Speight, S. Šiaulytytė, C. Shyamdasani	14
15:15 – 15:30	***Capturing the signals of the dark: Effects of ageing and light level on colour vision*** J. L. Barbur, E. Konstantakopoulou	15
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Session: Rod and cone interaction

Moderator: Steven L. Buck

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16:15 – 16:30	***Rod and S-cone interactions in the blue-yellow colour opponent pathway*** A. J. Zele, J. Kremers, B. Feigl	17
16:30 – 16:45	***"Do I have to worry about rod influences on hue with my CRT display?"*** S. L. Buck, R. Juve, D. Wisner	18

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Moderator: Gordon T. Plant

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09:30 – 09:45	***Epidemic nutritional optic neuropathy*** G. T. Plant	23
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10:15 – 10:30	***A mutant opsin allele associated with cone-type specific degeneration*** J. Carroll, A. M. Dubis, M. Genead, V. Williams, P. Sommer, K. E. Stepien, T. B. Connor, Jr, G. Fishman, A. Dubra, M. Neitz	26
10:30 – 10:45	***Assessment of chromatic sensitivity in female carriers of colour-vision deficiency*** E. Konstantakopoulou, M. Rodriguez-Carmona, J. L. Barbur	27

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Session: Colour and cone function
Moderator: Rigmor C. Baraas

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11:45 – 12:00	***Does cone mosaic influence equiluminance thresholds?*** D. Meary, D. Alleysson	29
12:00 – 12:15	***ERG responses to sine-wave cone and rod selective stimuli as a function of temporal frequency*** J. Kremers, G. Pangeni	30
12:15 – 12:30	***Cone isolating ON-OFF electroretinogram for studying chromatic pathways in the retina*** J. A. Kuchenbecker, M. Neitz, J. Neitz	31
12:30 – 12:45	***Presence of S-opsin in co-expressing mouse cone photoreceptors suppresses M-opsin ERG response but not M-Opsin expression*** S. H. Greenwald, J. A. Kuchenbecker, D. K. Roberson, M. Neitz, J. Neitz	32

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Session: Colour vision deficiencies: Neurological and congenital II

Moderator: Joseph Carroll

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14:15 – 14:30	***Assessing the severity of colour vision loss*** M. Rodriguez-Carmona, M. O’Neill-Biba, J. L. Barbur	34
14:30 – 14:45	***Reaction times for human colour-vision deficiency*** B. M. O’Donell, D. M. O. Bonci, D. F. Ventura, E. M. Colombo	35
14:45 – 15:00	***Colour naming by dichromats with and without the functional spectral filters for optical simulation of dichromats in colour discrimination*** S. Nakauchi, K. Shinomori	36
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Moderator: Sérgio M. C. Nascimento

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17:15 – 17:30	***Psychophysical optimization of lighting spectra for naturalness and chromatic diversity*** S. M. C. Nascimento, O. Masuda	38
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Moderator: Jay Neitz

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10:00 – 10:30	***On the worldwide prevalence of red-green colour deficiency*** J. Birch	44
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Moderator: Janice Nerger

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11:45 – 12:00	***Abney effects in the fovea and periphery*** S. F. O'Neil, K. C. McDermott, M. A. Webster	47
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Moderator: David H. Foster

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09:30 – 09:45	***Contrast edge colors under different natural illuminations*** J. L. Nieves	51
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10:00 – 10:15	***Effect of spatial structure on colorfulness-adaptation in natural images*** Y. Mizokami, C. Kamesaki, H. Yaguchi	53
10:15 – 10:30	***How many human cone pigments are needed to reliably identify surfaces in natural scenes?*** D. H. Foster, S. M. C. Nascimento, K. Amano, I. Marín-Franch	54
10:30 – 10:45	***A three-dimensional colour space from the 13th Century*** H. Smithson, G. Gasper, M. Huxtable, T. McLeish	55

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Session: Colour in context (cont.)

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11:30 – 11:45	***Linearity and asymmetry of the Watercolor Illusion with luminance elevation*** K. Knoblauch, F. Devinck	57
11:45 – 12:00	***Brightness phenomena depend on object size, not visual angle*** A. G. Shapiro, E. L. Dixon, Z. Lu	58

Session: Colour mechanisms
Moderator: Valérie Bonnardel

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12:15 – 12:30	***Hue discrimination and naming*** V. Bonnardel, R. Bachy, J. Dias, D. Alleysson	60
12:30 – 12:45	***The retention and disruption of colour information in human visual short term memory*** D. J. McKeefry, V. Nemes, N. R. A. Parry, D. Whitaker	61
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Session: Colour mechanisms (cont.)

14:00 – 14:15	***Colour categorisation in Mandarin-English speakers: Evidence for a left visual field (LVF) advantage*** S. Wuerger, K. Xiao, Q. Huang, D. Mylonas, G. V. Paramei	62
14:15 – 14:30	***Individual differences in higher-order chromatic mechanisms measured with Classification Image technique*** T. Sato, T. Nagai, S. Nakauchi	63
14:30 – 14:45	***Two-stage misbinding of color*** Y. Sun, S. K. Shevell	64
14:45 – 15:00	***Co-occurrence of luminance and chromatic edges affect depth perception consistently across different depth profiles*** S. Clery, M. Bloj, J. M. Harris	65
15:00 – 17:00	Posters and coffee	

Session: Colour induction and constancy
Moderator: Hannah Smithson

17:00 – 17:15	***Estimate of an illuminant color based on the luminance balance of surface colors*** K. Uchikawa, K. Fukuda, Y. Kitazawa, D. I. A. MacLeod	66
17:15 – 17:30	***Do individual differences in eye movements explain differences in chromatic induction between subjects?*** J. Granzier, M. Toscani, K. R. Gegenfurtner	67
17:30 – 17:45	***Multiple perceptual references for colour in space and time*** R. Lee, H. Smithson	68
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08:30 – 12:45	Registration desk open	

Session: Ecology of colour vision
Moderator: Almut Kelber

09:00 – 09:30	***Bird colour vision: From tetrachromacy to learning about novel objects*** D. Osorio	70
09:30 – 09:45	***Bowerbird colour vision: Spectral tuning in avian short-wavelength sensitive (SWS1) visual pigments*** I. N. van Hazel, B. S. Chang	71
09:45 – 10:00	***Molecular genetics and spectral tuning of warbler visual pigments: a comparative approach to avian color vision*** N. I. Bloch, B. S. Chang, T. Price	72
10:00 – 10:15	***The detection of colour patterns in birds*** O. Lind, A. Kelber	73
10:15 – 10:30	***Behavioural evidence of dichromacy in a species of South American marsupial*** E. de. A. Gutierrez, B. M. Pegoraro, B. Magalhães-Castro, V. F. Pessoa	74

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Session: Ecology of colour vision (cont.)

11:00 – 11:15	***The relative importance of chromatic, achromatic, and tactile floral guides in a nocturnal and a diurnal hawkmoth*** J. Goyret, A. Kelber	75
11:15 – 11:30	***Relationship between flowers and vision of bees*** M. Vorobyev, N. Hempel de Ibarra	76

Session: Physiological processes of colour vision
Moderator: Jan Kremers

11:30 – 11:45	***Further evidence for cone-selective connectivity in midget retinal ganglion cells of the macaque monkey*** B. B. Lee, R. Shapley, E. Kaplan, C. Reid, H. Sun	77
11:45 – 12:00	***Neural locus of color after-images*** Q. Zaidi, R. Ennis, B. B. Lee	78
12:00 – 12:15	***Can power functions – not DOGs – describe receptive fields of cone-opponent cells?*** T. O. Seim, A. Valberg, B. B. Lee	79
12:15 – 12:30	***Revisiting pupil colour responses*** W. Bi, J. L. Barbur	80
12:30 – 13:00	ICVS 2011 closes	

POSTERS

FRIDAY

COLOUR VISION IN AGEING

Session: Colour vision in ageing **Time:** 14:30 - 14:45

Shape and color organization: Why do we say a “red square” and not a “square-shaped red”?

Maria Tanca,[1*] Baingio Pinna[2]

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2 Department of Architecture, Design and Planning, University of Sassari, Palazzo del Pou Salit, Piazza Duomo 6, Alghero, 07041, Italy
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Pinna & Reeves (2006) extracted some “principles” of object formation by different luminance gradient profiles across boundary contours, thus defining the phenomenal appearance of the visual object – its shape, color and spatial volume, seen under an apparent illumination. Given two adjacent contours as in the watercolor illusion, the juxtaposed contour with the highest luminance contrast in relation to the homogenous surrounding regions tends to appear as the outermost boundary of the figure. This contour was called “boundary line”. The contour with lower luminance contrast in relation to the homogenous surrounding regions, adjacent to the boundary line, defines the color of the object. This is the “object color line”. The aim of this work is to demonstrate these results by studying the microgenesis of the organization of shape and color. The idea of “microgenesiso” is that the object perception and creation takes time to develop and follows a defined order. Our hypothesis is that the roles of shape and color are extracted in sequential order (shape coded before color) and in the same order these roles are also used by children. This was demonstrated (i) by analyzing the paintings of more and more complex colored shape descriptions by children of different ages (4-18), and (ii) by analyzing the linguistic sequence and organization in a free naming task of different colored shapes. The results (e.g. “a red square” and not “a square-shaped red”; a red square was painted as a square with black boundary contours filled with red color) supported the idea of the microgenesis of the object perception. The results suggested two sequential stages in visual development: juxtaposition and integration.

Acknowledgements: Supported by Regione Autonoma della Sardegna, L.R. 7 agosto 2007, n. 7 and Fondo d’Ateneo ex 60

Session: Colour vision in ageing **Time:** 14:45 - 15:00

Effects of macular pigment on color vision

Max Snodderly

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We are generally not aware that each of us has a yellow filter in our eye in the form of the macular pigment. Furthermore, we do not ordinarily perceive differences in color or brightness between regions of the retina with high or low macular pigment. Consistent with these observations, our past data have shown that the visual system compensates for filtering of short-wave light by macular pigment (MP). Compensation is evident from the fact that S-cone sensitivity and yellow-blue color perception are unaltered when comparing foveal responses, where MP is dense, to parafoveal responses where MP density (MPOD) is unmeasureable. Yellow (575 nm)/blue (440 nm) and red (600 nm)/green (501 nm) cancellation functions, as well as increment thresholds (using conditions that were designed to isolate the S-cone pathway) were obtained at 0,1, 1.75, 3 and 7°. MPOD was measured using heterochromatic flicker photometry. Ten young subjects were studied. When using conditions that isolate the S-cone pathway, the S-cone system behaved univariantly and scaled sensitivity to offset differences in MPOD across the retina. Since the spectral shapes of these components differ, the effects of compensation were a function of wavelength. Adjustment of the S-cone pathway predicts overcompensation at 520 nm for foveal, sites and undercompensation at 460 nm for parafoveal sites. S-cone sensitivity changed with eccentricity consistent with a gain mechanism. Hue cancellation values for the Y-B system did not change significantly across the retina. R-G sensitivity, in contrast, changed as a function of MPOD. These results are consistent with the idea that the visual system increases gain of the S-cone system, but not other systems, to compensate for light absorption by MP. A similar compensation mechanism may reduce the effects of yellowing of the lens during aging as well.

Session: Colour vision in ageing **Time:** 15:00 - 15:15

Chromatic discrimination across four life decades: Cambridge Colour Test

Galina V. Paramei,[1*] Thomas G. Speight,[1] Simona Šiaulytytė,[2] Chandni Shyamdasani[1]

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Chromatic discrimination was measured in normal trichromats (N=150; 75 females) aged 20–59 years using the Cambridge Colour Test (CCT). Exclusion criteria were ophthalmologic complaints, diabetes and colour abnormality. Observers were dark adapted and tested binocularly. The Trivector test estimated thresholds along Protan, Deutan and Tritan confusion lines and the Ellipses test mapped MacAdam ellipses for the L-, M- and S-cone systems. For the 20-29 group, mean chromatic discrimination indices were similar to those for the 18-30 year old (Ventura et al., In: Normal & Defective Colour Vision, 2003). To assess age effect across all groups, the Kruskal-Wallis *H* test was applied. In the Trivector test, age-related effects were significant for Tritan (*p*=.037) and marginally significant for Deutan thresholds (*p*=.056). Post hoc analyses (Mann-Whitney *U* test) indicated elevated Tritan thresholds for the 40+ and 50+ decades (*p*=.027 and *p*=.015 respectively; compared to 20+) and Deutan thresholds (*p*=.008 and *p*=.058; compared to 30+). In the 50+, in addition, Protan thresholds were elevated (*p*=.045). The Ellipses test found age-related stretching of Long Axes for Ellipse 1 (*p*=.019), Ellipse 2 (*p*=.003), Ellipse 3 (*p*=.006). As shown by post hoc analyses, for Ellipses 2 and 3 the Long Axis increase manifested in the 40+ group, and for Ellipse 1 in the 50+. Further, in the 50+ decade, Axis Ratios were extended, for Ellipse 1 (*p*=.004; compared to 20+) and Ellipse 3 (*p*=.018; compared to 30+). The present findings are consistent with parallel decline in sensitivity in all chromatic systems with advancing age, with the S-cone mechanism being most vulnerable (Werner & Steele, J. Opt. Soc. Am. A, 5, 1988). The CCT measures reveal onset of chromatic discrimination deterioration between 40-49 years of age, initially as senescence effects in the S-cone system, accompanied by incremental decline of the M-cone and, decade later, the L-cone system.

Acknowledgements: Supported by a grant from the Liverpool Hope University (REF 1011/20). We would like to thank Robert Hewertson for assisting in the data collection.

Session: Colour vision in ageing **Time:** 15:15 - 15:30

Capturing the signals of the dark: Effects of ageing and light level on colour vision

John L. Barbur,* Evgenia Konstantakopoulou

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As one grows older colour is arguably affected most because of the more extensive spatial processing associated with the extraction of colour signals in the retina and this effect becomes more pronounced at lower light levels. Diseases of the retina are also more common in old age and almost invariably these lead to rapid worsening of colour vision. The purpose of this study was to capture information about the health of the retina (HR) by measuring the rate of loss of chromatic sensitivity with decreasing light level. We introduce a new “Health of the Retina” (HR) index that captures the loss of chromatic sensitivity with decreasing light level and derive the limits of variability. This investigation is based on 65 healthy subjects, 16-79 years. The short-wavelength optical density of the lens and the macular pigment profile were measured using the MAP test. Red-green (RG) and yellow-blue (YB) chromatic sensitivity was measured using the CAD test at four light levels (65, 26, 7.8 and 2.6 cd/m^2), while the measurement of pupil size at each light level enabled an estimate of retinal illuminance. The 65 normal subjects provided the data needed to define the statistical limits for normal colour vision (NCV) against which every subject was then compared. The HR index is defined as the % difference between each subject’s rate of change in either RG or YB thresholds with retinal illuminance and the NCV limits. The HR captures significant differences in colour thresholds as well as the rate of increase in threshold with reduced retinal illuminance. In normal eyes, the HR index is largely independent of age ($r^2 \approx 0.1$). Approximately 14% of subjects over 50 years of age showed larger HR values, whilst subjects with some form of identified retinal disease exhibited HR values well outside the normal range.

Session: Rod and cone interaction **Time:** 16:00 - 16:15

Dark-adapted rods do not suppress mesopic rod flicker detection

Yolanda Lu,* Dingcai Cao

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Previous studies have shown that dark-adapted rods suppress cone flicker detection. This study investigates whether dark-adapted rods also suppress rod-mediated flicker detection since anatomical and physiological studies have identified that rod signals are transmitted via the rod-cone gap junction pathway at mesopic light levels. The stimuli field of a 2° circular field within a 6° surround were presented at 6.5° temporal retina in a four-primary photostimulator that provided independent control of rod and cone stimulations. Isolated rod or cone luminance signals in the center field were modulated sinusoidally at 30% contrast with a time-average illuminance of 2, 20, and 200 Td. Mesopic critical fusion frequencies (CFFs) for the isolated rod and cone stimuli were measured in the presence of various surround illuminances varying from scotopic to mesopic range that were dimmer than the center. Rod CFFs at 2, 20 and 200 Td and cone CFFs at 2 Td did not vary with different surround illuminances. Cone CFFs at 200 Td remains constant for scotopic surround illuminances ($\leq$ 0.02 Td) but increased monotonically at surround light levels above 0.2 Td. Compared with equiluminant surround, the scotopic surrounds reduced cone CFFs by 4-10 Hz. At 20 Td, cone CFFs had similar patterns to those at 200 Td, except the overall CFFs were lower and the reduction in CFFs due to dim surround was smaller (2-4 Hz). Thus dark-adapted rods only suppress cone-mediated flicker detection at higher mesopic levels, but not rod-mediated flicker detection. Impulse response functions (IRFs) explain this phenomenon, where rod dark-adaptation could prolong integration time and decrease IRF amplitude. This suggests after dark adaptation, lateral suppressive rod-cone interaction only occurred when the amplitude of impulse response function is high and the time-to-peak is short.

Acknowledgements: R01EY019651 (D. Cao)

Session: Rod and cone interaction **Time:** 16:15 - 16:30

Rod and S-cone interactions in the blue-yellow colour opponent pathway

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We analyzed interactions between rod and S-cone modulations in terms of their underlying contributions to the blue-yellow opponent pathway. Stimuli were generated using a 4-primary colorimeter (Pokorny et al 2004 Vis Neurosci 21:263-267) under mesopic illumination (20 Td). Experiment 1 implemented a phase paradigm in which thresholds for mixed rod and S-cone modulations (2Hz, 3 cycles) were measured as a function of relative phase (constant L-, M-cone excitation). Modulation amplitude was equated in threshold units (1:1TU). Experiment 2 measured thresholds for mixed rod and S-cone modulations as a function of the contrast ratio (0.5:1, 1:1, 2:1) of the mixed rod and S-cone modulation for two fixed phase offsets (0 and 180 degrees). A control experiment confirmed that mixed rod and L-cone thresholds (2Hz, 1:1TU; constant M-, S-cone excitation), measured as a function of phase, show probability summation between independent pathways (Sun et al 2001 J Vision, 1:42-54). The experiments identified three interaction types. A linear and antagonistic rod:S-cone interaction is identified in the phase paradigm in observers in which the threshold contrasts to selective rod and S-cone stimulation were different. Observers with similar thresholds for selective rod and S-cone stimulation displayed probability summation. A third interaction is revealed in the contrast ratio experiment. When the rod:S-cone contrast ratio increases (2:1), mutual nonlinear reinforcement decreases contrast threshold. The degree of symmetry between the in-phase and counterphase data depends on the linear interaction in the phase paradigm. Observers with linear interactions had asymmetric contrast responses. Observers with probability summation displayed symmetric contrast responses. We conclude that linear rod:S-cone interaction under mesopic light levels occurs at a common locus, possibly within the blue-yellow opponent pathway. The shift to probability summation involves signaling by different pathways, with rod thresholds likely to be signaled via the inferred magnocellular pathway. The nature of the nonlinear reinforcement is unclear.

Acknowledgements: Supported by the Australian Research Council ARC-DP1096354 (AJZ), a VC Research Fellowship (BF) and a QUT IHBI Visiting Researcher Fellowship (JK).

Session: Rod and cone interaction **Time:** 16:30 - 16:45

"Do I have to worry about rod influences on hue with my CRT display?"

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Studies of rod hue biases (RHBs) have shown that rod stimulation can shift the balance of hues at mesopic light levels. Most studies have used Maxwellian-view (MV) displays, which differ in important ways from CRT displays, typically presenting monochromatic lights as aperture colors with a deeply dark background and known retinal illuminance, thanks to the small fixed exit pupil. In contrast, the CRT uses broader-band lights that may appear more as surface colors against a dark-grey veiling background amidst features of the surroundings made visible by the display or ambient lighting. Actual retinal illuminance will vary with variation of natural pupil size among conditions and observers, unless an artificial pupil is used. We used a conventional CRT (ViewSonic G90fB) and photopically equiluminant stimuli (CIE 1964 10°) mimicking those that produced RHBs in MV studies: 4° diameter disk centered 7° from fixation. Observers adjusted stimulus hue to each of the 4 unique hues, following the perimeter of the triangle formed by the 3 phosphors. Rod influence was estimated from unique-hue chromaticity differences measured under dark-adapted (rod maximum) and cone-plateau (rod minimum) conditions. We found that the CRT produced all 3 previously-identified RHBs, which affected all 4 unique hues at low mesopic light levels. As expected, these were not found at the maximum equiluminance of the CRT display (26 cd/m^2). However when luminance was reduced by 1.5–2 log units, 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 (at least in part due to variations of pupil size) and could be reduced or eliminated by using smaller foveal stimuli or by increasing ambient illumination.

Acknowledgements: UW Royalty Research Fund

VERRIEST MEDAL LECTURE

Session: Verriest Medal Lecture **Time:** 17:00 - 18:00

Insights about color from its colleagues: Space, time, motion

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The color of a chromatic stimulus depends on the accompanying context. The scientific literature abounds with discoveries of how spatial and temporal properties of light affect the colors we see. There is, however, another benefit of investigating chromatic stimuli within a context where chromaticity varies over space, time or direction of motion: these contexts reveal otherwise concealed neural mechanisms of color vision. Spatial variation uncovers multiple mechanisms of brightness and color perception at distinct levels of the visual pathway. Moreover, spatial variation that corresponds in chromaticity and luminance is a powerful determinant of three-dimensional shape; this highlights the significance of neural coding of chromaticity for percepts other than color. Temporal modulation of chromatic light exposes a nonlinearity in a visual pathway carrying time-varying chromatic responses, and also two distinct levels of neural representation: one before the nonlinearity that is driven predominantly by independent L/(L+M) and S/(L+M) responses, and another following the nonlinearity driven by a higher-order chromatic representation. Chromatic objects in motion expose the surprisingly weak link between the chromaticity of a moving object and its perceived color. Consider two regions. In one, a random pattern of 'green' objects moves vertically upward and a separate pattern of 'red' objects downward; in the second region, the colors are reversed ('red' objects move upward, 'green' objects downward). Under certain conditions, all 'green' objects in both regions appear to move upward and all 'red' objects downward. Critically, the likelihood of this illusory percept (that all objects moving in a given direction appear the same color) increases with the shape correspondence among objects in the two regions. Thus, the color of a particular moving object can depend on non-chromatic shapes of objects rather than the object's chromaticity. Space, time and motion – color's colleagues – unveil the richness of chromatic neural processing.

Acknowledgements: Supported by NIH EY-04802

SATURDAY

COLOUR VISION DEFICIENCIES: NEUROLOGICAL AND CONGENITAL I

Session: Colour vision deficiencies: Neurological and congenital I **Time:** 09:00 - 09:30

Color vision impairment in workers exposed to neurotoxic chemicals

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Several studies show that occupational exposure to various neurotoxic chemicals can affect visual function, but knowledge in this field is certainly incomplete. An impairment of color vision was observed in workers exposed to industrial solvents (e.g. styrene, toluene, perchloroethylene, carbon disulphide and n-hexane, as well as solvent mixtures) and metals (as mercury and lead). In most epidemiological studies in workers hue discrimination tests are applied. The Lanthony D-15 desaturated panel (D-15d) is usually preferred as it can be rapidly administered directly at the workplace, is inexpensive, well accepted by workers, and is sensitive enough for early detection of mild acquired dyschromatopsia. Other advantages of this test are the good reproducibility, and the possibility of a quantitative evaluation of the results, e.g. by calculating Bowman's Color Confusion Index (CCI), or Vingrys and King Smith's Confusion Index (CI). In most cases color vision impairment appeared related to the exposure-level, and available data also suggest a progression with increasing exposure time. The reversibility remains unsettled: some results suggest an almost complete regression if exposure is discontinued or adequately reduced, whereas others are conflicting. The pathogenesis of chemical related colour vision loss has not been elucidated, even if the so-called "Köllner's rule" suggests a retinal location. In this case, the impairment may be due to a direct action of neurotoxins on receptors, possibly on the cone's membrane metabolism, or an interference with neurotransmitters within the retina. Nevertheless, other mechanisms, such as a direct effect on the optic nerve or brain, cannot be ruled out. As a conclusion, several industrial chemicals can induce an early sub-clinical impairment in color vision in workers. This effect can be evaluated directly at the workplace using non-invasive, simple methods, and is possibly reversible. Accordingly, color vision testing should be included in the evaluation of the neurotoxicity of chemicals.

Session: Colour vision deficiencies: Neurological and congenital I **Time:** 09:30 - 09:45

Epidemic nutritional optic neuropathy

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For more than 100 years epidemics of an optic neuropathy have been reported in association with poor nutrition. The most recent have been in Cuba (1990—1991) and Tanzania (1988—current). The clinical features are similar to some cases of toxic aetiology and there is an overlap with cases related to tobacco smoking. The author has studied cases in both of these epidemics but also in Somalia, the Gambia and similar endemic cases seen in London mostly in alcoholics and vegetarians. Colour vision deficiencies are key to the identification of cases. A screening protocol has been established that recruits cases of visual loss where: 1) visual acuity is bilaterally 6/9 or worse with no more than two lines interocular difference and 2) errors are made on the Ishihara plates with either eye. This protocol results in very few false positive cases. Pathological examination of cases has been carried out rarely in the first half of the 20th Century: examination of the dorsal lateral geniculate nucleus has suggested that there is selective damage to the parvocellular layers. The clinical features of epidemic neuropathy are reviewed along with the evidence for a selective vulnerability of the parvocellular projection.

Session: Colour vision deficiencies: Neurological and congenital I **Time:** 09:45 - 10:00

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99 Years of Köllner's Rule

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Hans Köllner's 1912 monograph has had an important influence on this Society and in neuro-ophthalmology for the heuristic it provided in identifying sites of neural change associated with acquired deficiencies of colour. With respect to acquired tritan defects that are not due to ocular media changes, Köllner's Rule suggests that colour vision abnormality is mediated by the outer retina. Yet, some optic neuropathies (e.g. glaucoma) are associated with tritan defects. As a result, the rule has been largely ignored. We quantified inner and outer retinal morphology *in vivo* for 16 glaucomatous and nonglaucomatous optic neuropathy patients. Custom, ultrahigh-resolution imaging modalities were used to evaluate segmented retinal layer thickness in 3D volumes, cone photoreceptor density, and the length of inner and outer segments of cone photoreceptors. Quantitative comparisons were made with age-matched controls, or by comparing affected and nonaffected retinal areas defined by changes in short-wave automated perimetry. Here, we focus on a subgroup of patients with specific tritan deficiencies. In these patients, losses in photoreceptor density accompanied changes in the nerve fiber layer. Their photoreceptor outer segments were shorter and exhibited greater variability in retinal areas associated with visual field losses compared to normal or less affected areas of the same patient's visual field. These results demonstrate acquired tritan defects in optic neuropathies that are associated with outer retinal changes consistent with Köllner's Rule.

Session: Colour vision deficiencies: Neurological and congenital I **Time:** 10:00 - 10:15

Colour discrimination in Oligocone Trichromacy

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Oligocone Trichromacy (OT) is a cone dysfunction syndrome that has been associated with normal colour vision, despite reduced cone function. Recently it has been shown that some individuals with OT have reduced cone density. Adaptive optics retinal imaging and colour discrimination measurements were performed in two unrelated females (aged 26 and 50 yrs) previously diagnosed with OT. High-resolution images of the cone mosaic were obtained with the Kongsberg Adaptive Optics Ophthalmoscope. Colour discrimination was measured with a battery of standard colour tests including Rayleigh and Moreland anomaloscopy. Colour-discrimination thresholds were measured in three directions along the protan, deutan and tritan confusion axes with the Cambridge Colour Test. First binocularly with natural pupils and then monocularly with the preferred eye and a pupil aperture of 2.8 mm under three conditions: on the cone-plateau at two different retinal illuminance ranges (12.3-92.3 Td and 1.2-9.2 Td) and after 30-min dark-adaptation at 1.2-9.2 Td. For cone-plateau conditions they were bleached followed by a 4-min waiting period prior to testing. A 1.0 ND filter was added in front of the pupil aperture for the 1.2-2.9 Td condition. Results were compared with those obtained from normal trichromats. Both females with OT were hypermetropic with best-monocular-corrected Snellen acuity $\geq$0.8. Imaging results reveal a disrupted cone mosaic in both individuals. Match-midpoints were within normal limits on the Rayleigh match, but not the Moreland match. Colour discrimination at different retinal illuminance ranges reveal that both perform as if they have no functioning S-cones and significantly reduced L- and M-cone function at mesopic light levels when compared with normal trichromats. This indicates that OT may give rise to poorer cone function in dim light, questioning the idea that individuals with OT have completely normal colour vision.

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Session: Colour vision deficiencies: Neurological and congenital I **Time:** 10:15 - 10:30

A mutant opsin allele associated with cone-type specific degeneration

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Through a sequence of evolutionary events, human L and M genes have been subject to a genetic mechanism that produced an extraordinarily high rate of mutation in which amino acid differences that distinguish ancestral L from M pigments are intermixed in human L/M pigments. One of these mutants, LIAVA, has been associated with dichromacy in males with two L/M genes and with blue cone monochomacy (BCM) in individuals with one L/M gene (see Carroll *et al.*, Proc. Natl Acad Sci, USA, 101, 2004; Mizrahi-Meissonnier *et al.*, Invest. Ophthalmol. Vis. Sci., 51, 2010). These disorders appear to be stationary; for example, no changes were observed by adaptive optics retinal imaging in one patient with the LIAVA mutant who was followed over a period of 8 years. These advances in high-resolution imaging enable examination of the effect of different deleterious variants on cone structure. Here, we imaged two unrelated males, with only one L/M opsin gene, which encoded a different mutant pigment, LVAVA. This variant was not observed in a large sample of normal control males, and differs by one interchanged L/M amino acid from the LIAVA mutant described earlier. Both patients self-reported progressive vision loss from early childhood and were diagnosed with cone-rod dystrophy indicating that LVAVA results in a progressive loss of cone function. In both cases, imaging results were similar to BCM phenotypes where mutations, such as LCR deletions, cause an early complete loss of functional cones expressing the mutant. This suggests that in younger eyes, cones with LVAVA function, but cones with LIAVA do not. However, over the first decades of life, cones with LVAVA progressively lose function. Presumably, in older patients either with LIAVA or LVAVA mutations L/M cones will have lost function, but both types of patients will maintain functional S-cones and rods. In summary, high-resolution retinal imaging is a useful approach for discriminating important cellular differences among patients with disorders in cone function. Imaging and genetic analysis of similar progressive cone-rod dystrophy patients. Further longitudinal imaging of patients harboring these mutant pigments is needed to clarify their effect on the cone mosaic and to elucidate any meaningful differences between different pigment variants.

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Session: Colour vision deficiencies: Neurological and congenital I **Time:** 10:30 - 10:45

Assessment of chromatic sensitivity in female carriers of colour-vision deficiency

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Despite numerous studies, colour vision in female carriers remains controversial with some studies reporting improvement and others a worsening of red/green (RG) chromatic sensitivity. The purpose of this study is to investigate the extent to which the additional photopigment that is expressed in female carries of colour deficiency affects their RG chromatic sensitivity. Thirty six (36) heterozygote females were examined, aged 22–73 years of age. RG and yellow/blue (YB) chromatic sensitivity was measured using the Colour Assessment Diagnosis (CAD) test. Four background light adaptation levels (i.e. 65, 26, 7.8 and 2.6 cd/m^2) were employed and measurement of pupil size at each level provided a measure of retinal illuminance. The optical density of the crystalline lens and the macular pigment optical density (MPOD) were measured using the Macular Assessment Profile (MAP) test. 41 male subjects (age range 23 to 71 yrs) were used as controls. The carriers were divided into four groups: carriers of deuteranomaly (DA), deuteranopia (D), protanomaly (PA) and protanopia (P). Carriers of DA and D showed lower RG chromatic sensitivity than normal trichromats ($p<0.05$), whereas carriers of PA or P carriers showed similar RG sensitivity to controls ($p>0.05$). Differences in RG colour vision between controls and P and PA carriers are not statistically significant. This is not the case for D and DA carriers, who show significantly reduced RG chromatic sensitivity. The results suggest that a relative increase in the number of LL' cones in the retina, as expected in the D and DA groups can cause a significant worsening of RG colour vision, whilst an increase in the number of MM' cones, as expected in the P and PA groups, does not cause a significant decrease in RG sensitivity. The processing of the fourth photopigment could play a significant role in carriers of anomalous trichromacies.

COLOUR AND CONE FUNCTION

Session: Colour and cone function **Time:** 11:15 - 11:45

Color and the cone mosaic

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Human color vision necessarily depends on the characteristics of the underlying retinal mosaic. For example trichromacy, correctly reasoned by Young to be consequence of three types of retinal pigments with different sensitivities, successfully explains human color discrimination and color matching. Similarly tight links have been posited between color *appearance* and the different retinal receptors, exemplified by the early association of L, M, and S cones with sensations of red, green, and blue respectively. This assumption has persisted implicitly or explicitly (as evidenced by the unfortunate, but still common, use of R, G, B for L, M, and S cones) even after direct spectral measurements showed that the pigments are not maximally excited by red, green, and blue light. Nor, as evidenced by physiological and psychophysical experiments, do excitation of the three cone types cause unitary sensations of redness, greenness, and blueness. The indirect relationship between cone activations and resulting color appearance has lead to a search to discover rules for combining cone inputs, and the neural correlates of these transformations, that would lead to mechanisms that appropriately describe human color appearance. We discuss an alternative approach towards understanding the way individual cones contribute to color appearance by considering how an optimal system should combine cone inputs to best cope with information loss due to retinal sampling. A Bayesian appearance model based on this strategy predicts that the contribution of an individual cone to color appearance will be a consequence of its local retinal neighborhood as well as the pigment it contains. This finding is consistent with adaptive optics experiments precluding unitary hue percepts for cones within a given class. The ultimate test of this model is to probe these ‘single cone’ contributions to vision and color perception in vivo. We discuss the challenges involved in, and our progress toward, achieving this ideal.

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Session: Colour and cone function **Time:** 11:45 - 12:00

Does cone mosaic influence equiluminance thresholds?

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Our work focuses on knowing how the visual system deals with cone mosaic variability and achieve colour coherence in spite of the large variations in cone ratios from individual to individual. We used the minimum motion technique (Anstis et al. In Colour vision: Psychophysics and physiology, 1983) to estimate equiluminance thresholds for Red/Green gratings. Psychophysical estimation of L/M-ratio is usually computed from the response of the L and M cones to Red and Green at equiluminance, weighted by their relative number. Assuming constant cone proportions, estimates of L/M ratio should be fairly equal under different experimental conditions. In a series of experiments, we manipulated green intensity, background adaptive field, yellow composition and apparent motion direction on a calibrated VSG 2.5 display (Cambridge Research). The analyses show that the isoluminant red is linearly related to green luminance and that background adaptive fields modulate both the intercept and the slope of the linear fit. Linearity was expected from the L/M ratio formula but the effects of background intensity were not. We develop a novel approach for L/M ratio calculations that integrates background/foreground contrast. Other important results were the stability and the directional independence of the estimated ratios despite large variations in the Red and Green contributions to the dark and bright yellows used for motion induction. These suggest that L/M cone ratios influence the perception of yellow in such a way that it is not biased toward Red or Green. These latter observations extend the results by Neitz and colleagues (Neuron, 2002) to the case of motion induction.

Acknowledgements: This work was supported by a grant from the French CNRS (ST 997-03-UMR5105).

Session: Colour and cone function **Time:** 12:00 - 12:15

ERG responses to sine-wave cone and rod selective stimuli as a function of temporal frequency

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The ERG may have different retinal origins. To be able to obtain a more complete description of the response characteristics and the underlying mechanisms, ERG responses to selective photoreceptor stimulation and to different combinations of L- and M-cone modulation were measured as a function of temporal frequency. Using a four primary stimulator, we measured electroretinograms to S-, L-, M-cone and rod isolating sinusoidal stimuli. In addition, the responses to in-phase (L+M) and counter-phase (M-L) modulation of the L- and the M-cones at equal strength were measured. The measurements were performed with reddish backgrounds (CIE coordinates: $x = 0.583$ $y = 0.384$) at 71 and 284 cd/m^2. At most temporal frequencies, the responses were mainly determined by the fundamental Fourier component that displayed two frequency regions with different response characteristics. Below 8 Hz, the response amplitudes to all conditions were similar and decreased with increasing temporal frequencies. The response phase decreased strongly with increasing temporal frequency suggesting delay times of about 80 ms. Above about 12 Hz, the response characteristics depended on stimulus condition. In conditions with large luminance components (L+M and L-cone isolating) the amplitudes increased again and peaked at about 36 Hz. The phases decreased moderately with increasing temporal frequency but differently for the different conditions corresponding to delay times of about 20 ms in L-cones, L+M M-L and rods, 22 ms in M-cones and 32 ms in S-cones. Multiple post-receptoral mechanisms determine the ERG responses. At low temporal frequencies, the responses are possibly determined by photoreceptor and non-neuronal activity (that have long delays). Above 12 Hz, the ERG responses may reflect postreceptoral neuronal activity (that have shorter delay times).

Session: Colour and cone function **Time:** 12:15 - 12:30

Cone isolating ON-OFF electroretinogram for studying chromatic pathways in the retina

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The components of the electroretinogram (ERG) have different cellular origins and analysis of the ERG waveform can provide insight into the underlying retinal physiology. A long-flash, or ON-OFF protocol, allows ON and OFF responses to be studied independently allowing further separation and analysis of contributions from different neural subtypes. Chromatic adaptation has been used to study the different cone pathways using the ERG. For example, ERGs enriched in S-cone contribution have been obtained using long-wavelength adaptation. However, no adaptation conditions have been found to completely isolate one cone class. Moreover, to compare responses of different cone pathways it is desirable to obtain measurements at the same state of adaptation. Through 'silent substitution' or 'spectral compensation' it is possible to selectively stimulate single cone pathways without changing the sensitivities of any of the cones through adaptation. Silent substitution has been useful in isolating L and M cone responses to trains of light pulses at temporal frequencies in the 10 to 30 Hz range, however at these stimulation rates the underlying neural components are not manifest as separate waveforms. Here, we have implemented a silent substitution paradigm for obtaining S, M and L cone isolated ON-OFF ERGs. S-cone mediated signals are of special interest because of their distinct circuitry compared with L and M-cones. The cone isolating ON-OFF ERG is a powerful tool for studying chromatic circuits in the retina when used in conjunction with pharmacological agents in animals and to study humans with mutations that affect specific neural components. For the S-cone ERG a Roland Consult Q450 Color Ganzfeld was modified to include high powered 420 nm LEDs. S-cone silent substitution conditions were empirically determined for each subject by adjusting the relative light intensities and monitoring distinctive spatiotemporal dynamics of L and M cone components until perfect S-cone isolation was achieved.

Session: Colour and cone function **Time:** 12:30 - 12:45

Presence of S-opsin in co-expressing mouse cone photoreceptors suppresses M-opsin ERG response but not M-Opsin expression

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Dual expression of S- and M-opsin in mouse cone photoreceptors provides a remarkable opportunity for investigating mechanisms underlying cone opsin expression and function. Here, retinal responses of wild-type mice were compared to those of S-opsin knockout mice, generated using targeted gene replacement technology to delete exons 1 through 4 of the *OPN1SW* gene on chromosome 6, and human subjects using full-field, photopic 1 Hz ON-OFF, cone isolating electroretinography (ERG). A 520 nm light (0.4 W/mm^2 to 11.8 W/mm^2) isolated M cone responses while the S/UV responses were isolated by alternating a 365 nm light (414 nm for human) with a 520 nm light (50% duty cycle) in a silent substitution paradigm. Exposing the same wild-type mice (n=9-10) at 1.5, 3, 6 and 9 months old to 20 seconds of S-opsin stimulating light suppressed retinal responses to subsequent, near saturation, M-opsin stimulating lights by 40-45% depending on age. The time required to recover M-opsin function was 10-15 minutes; however, increasing the S-cone stimulus duration further suppressed the M-response and greatly extended the recovery period. The percent M-response suppression induced by this conditioning was logarithmically related to the intensity of the test light. These suppressive effects were nearly absent in an age-matched *OPN1SW*$^{-/-}$ mouse cohort (9.1%±1.9; 5.4%±1.3; 3.7%±0.6; and 10.6%±4.5) and in two adult human subjects whose cones naturally express only a single class of opsin (7.9%). Interestingly, in the absence of S-opsin stimulating pre-exposure, 9 month old wild-type mice had significantly larger ERG responses to 520 nm light in comparison to the *OPN1SW*$^{-/-}$ mouse across the intensity response series. This result, along with anatomical data, confirms that M-opsin expression is not up-regulated in mature *OPN1SW*$^{-/-}$ mice to achieve the same total opsin concentration found in the dually expressing cones of wild-type mice.

COLOUR VISION DEFICIENCIES: NEUROLOGICAL AND CONGENITAL II

Session: Colour vision deficiencies: Neurological and congenital II **Time:** 14:00 - 14:15

The Farnsworth Flashlight is not equivalent to the Farnsworth Lantern

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The Farnsworth Lantern has been accepted in a large number of occupational applications as the test of choice for up to 50 years. When production was discontinued, replacement instruments purporting to be equivalent were inevitable give the ubiquity of its use. The OPTEC900® (Stereo Optical) has been validated and adopted as an acceptable substitute although the fail rate is slightly higher than the Farnsworth Lantern. More recently the Farnsworth Flashlight (Gulden Ophthalmics) has been marketed at a fraction of the price. It has not been validated at this stage. Before moving to a full clinical evaluation, there are some simpler initial evaluations that can indicate the appropriateness of the test design and construction. The colour and luminous intensities of the stimuli of a Farnsworth Lantern, an OPTEC900® Lantern and a Farnsworth Flashlight were measured using a Topson SR-3 telespectroradiometer and compared with Farnsworth's specifications. Since the Farnsworth Flashlight is battery powered, this was also done with new batteries, at the nominal voltage of 4.5VDC and underrun by 5 to 20%, representing partially discharged batteries. The OPTEC900® chromaticities comply with Farnsworth's specifications but the luminous intensities are rather different. The Farnsworth Flashlight differs from the Farrnsworth Lantern in both chromaticity and luminous intensities. The problem is exacerbated by battery depletion. While a cheap and portable equivalent to the Farnsworth Lantern is a highly attractive product, the failure to come sufficiently close to the Farnsworth Lantern means that a clinical evaluation of the Farnsworth Flashlight is, as this time, neither an economic nor a viable option.

Session: Colour vision deficiencies: Neurological and congenital II **Time:** 14:15 - 14:30

Assessing the severity of colour vision loss

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The Ishihara Test (IT) is arguably the most sensitive and commonly used colour vision test within occupational environments, but when no errors are allowed, 20% of normal trichromats also fail. When 3 or more errors are allowed, most normal trichromats pass, but in addition some colour deficients, particularly deuteranomalous subjects, also pass. The number of allowed errors varies from none to eight in different occupational environments in order to reflect the level of difficulty of the colour-related tasks. The implicit assumption is that the plates can be ranked in order of difficulty and that this order remains unchanged for deutan and protan deficients. The principal aim of this study was to investigate whether appropriate 'weights' can be attached to each IT plate to reflect the likelihood the subjects have of producing a correct response. CAD (Colour Assessment and Diagnosis) test thresholds relate approximately linearly to the corresponding cone-contrasts generated by the coloured stimuli and therefore provide a reasonable good measure of the severity of both red-green (RG) and yellow-blue colour vision loss. We investigated 742 subjects (236 normals, 340 deutans and 166 protans) using the first 25 plates of the 38 plate IT and measured RG chromatic sensitivity using the CAD test. The IT error scores provided plate-specific 'weights' which were then used to calculate a Severity Index (SI) of colour vision for each subject. On a logarithmic scale the CAD RG thresholds relate almost linearly to mean SI values. In spite of the good linear correlation, there is a large spread in SI values for subjects with similar RG chromatic sensitivity in each of the three subject groups. In conclusion, the number of errors on the IT plates does not provide a good measure of the severity of colour vision loss, even when plate-specific weights are applied.

Session: Colour vision deficiencies: Neurological and congenital II **Time:** 14:30 - 14:45

Reaction times for human colour-vision deficiency

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Previous research (Ramaswamy et al, Optom.Vis.Sci.86: 964-70, 2009; Atchison et al, H.Factors, 45:495-503, 2003) has shown that observers with colour deficiencies in the red-green present higher colour reaction times than normal ones to identify a traffic signal. We present results from a pilot experiment, analyzing the effect of colour-vision deficiency on reaction times (RT) of chromatic stimuli. We measured RT for 11 normal observers and two colour-deficient (protanope and deuteranope) observers. The test was a modified Cambridge Colour Test (Regan et al, Vision Research 34: 1279-99, 1994). The stimulus of square shape differs from the achromatic background along one of three significant lines in colour space: protan, deutan and tritan confusion lines. RT values as a function of distance from background chromaticity show a similar pattern for all normal subjects, decreasing when distance from background increases, showing an abrupt decrement towards an asymptotic value. In contrast, colour-deficient observers present RT values larger than those for normal ones, with greater dispersion and a tendency towards a less pronounced asymptotic value. As we expected, RT values for normal observers along the tritan line are higher than those for deutan and protan line, while for the dichromatic observers this relationship is reversed. At the same time, chromatic discrimination threshold corresponding to deutan line or protan line, depending of the colour deficiencies, is higher for dichromatic observers than for normal subjects, showing a greater difference for deutan or protan line. If there are no M or L cones, the L/M channel is impaired; therefore perception of colours along deutan or protan line, respectively, is affected. Finally, RT measurements could be an appropriate way for analyzing not only the interaction between the chromatic channels but also the type of chromatic deficiencies.

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Session: Colour vision deficiencies: Neurological and congenital II **Time:** 14:45 - 15:00

Colour naming by dichromats with and without the functional spectral filters for optical simulation of dichromats in colour discrimination

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Some previous literatures show that dichromats can name colours accurately as good as normal trichromats even though they cannot discriminate among red-green hues. We can recall two traditional hypotheses. First one is that dichromats have a kind of an additional chromatic channel consisting of two kinds of cones and the rods. The second hypothesis is that dichromats can assign colour names of red and green correctly with the information from residual chromatic channel, e.g. intensity, like as brighter brown should be red, and vice versa. The present study investigated this issue by use of the functional spectral filters (Variantor P- and D-types) with one of the filters, discrimination ability of trichromats is modified to be almost identical to protanope or deuteranope, by passing or blocking certain wavelength-bands. Traditional colour naming experiment was performed for dichromatic observers with and without these filters. In the experiment, observers named colour chips one by one in a random order in 3 sessions. If one observer used the same name three times, these chips made the area of one categorical colour in the coordinates of OSA colour chips. These areas were compared among normal trichromats and dichromats without and with the filter. Interestingly, for all dichromats, the naming results with the filter were almost identical to those without the filter, meaning that the chromatic information blocked by the filters does not substantially influence for dichromats to name colours. This result strongly implies that the first hypothesis would not be true because the hypothesized additional chromatic channel should not work due to the filters blocking the most of hue variations except for residual blue-yellow. Thus, we expect that dichromats are mostly using information about intensity in addition to blue-yellow hue information, to put colour names in such the extreme case.

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Session: Colour applications **Time:** 17:00 - 17:15

Colour and gaze as predictors of target detection in natural scenes

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The ability of an observer to detect a small object in a natural scene depends on many factors, including the spatial structure of the scene and the pattern of the observer's eye movements over the scene. The point of gaze is known to be critical in such detection tasks but it often appears to be random. By contrast, the colour properties of scenes are often assumed not to be influential. To quantify the predictive role of colour properties, a target-detection task was performed with coloured images of natural scenes presented for 1 s on a computer screen. The target, which appeared with probability 0.5 at one of 130 possible locations, was a shaded sphere subtending approx. 0.3 degree of visual angle at a viewing distance 1 m. To allow comparisons across scenes and to reduce luminance confounds, the target was spectrally neutral and was matched in average luminance to its local surround. Each image subtended approx. 17×13 degrees of visual angle. In each trial, observers had to report whether they saw the target. Observers' gaze positions were recorded during the task. In all, twenty natural rural and urban scenes were tested. Detection performance, quantified by the discrimination index d' from signal-detection theory, was regressed on the local colour properties of the image (quantified by CIECAM02) and the distribution of gaze over the image. The best account of the variation in d' over each scene was provided by chroma, which explained 33% of the variance on average. Together, chroma and lightness accounted for 41% of the average variance. Point of gaze alone also accounted for 41% of the average variance. It seems that the local colour properties of natural scenes can be significant predictors of target-detection performance, reaching a level similar to that provided by the point of gaze.

Acknowledgements: Supported by EPSRC grant no. EP/F023669/1.

Session: Colour applications **Time:** 17:15 - 17:30

Psychophysical optimization of lighting spectra for naturalness and chromatic diversity

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The capability to render objects with natural colours and the potential for revelling many different colours in complex scenes are two of the most important colour rendering. Although these aspects are usually quantified with rendering indices it is unknown what spectral profiles are actually preferred by observers for naturalness and chromatic diversity of complex scenes. We addressed this question in experiments in which observers selected a spectral profile from a set of metamers of daylight to optimize different aspects of complex scenes. A large set of metamers of daylight with correlated colour temperature of 6667K but variable degree of spectral smoothness was generated. A database of hyperspectral images of natural scenes including urban, rural and indoor scenes was used to simulate the appearance rendered by the metamers. The images were displayed on a calibrated CRT display driven by a ViSaGe (Cambridge Research Systems). The colorimetric accuracy was such that images had at most 5% of the pixels out of the gamut of the CRT. In the experiments the observers could select the illumination on each of the scenes by scanning the possible set of metamers with a joystick connected to the computer. In the first experiment the observers were instructed to select the illumination optimizing the naturalness perceived in the scenes. The metamers selected had spectral distributions markedly different from daylight and had an average colour rendering index of 70. In the second experiment the observers were instructed to select the illumination producing maximum chromatic diversity in the scenes. It was found that the spectral distributions were much more spectrally structured than in the first experiment and could not be easily predicted by existing indices of chromatic diversity. These experiments show that observers' choices for naturalness and chromatic diversity may require more complex predictors than simple rendering indices.

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Session: Colour applications **Time:** 17:30 - 17:45

Spectral alteration and color vision performance

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The proliferation of lasers in aviation and maritime working environment has brought about the requirement for Laser Eye Protection (LEP). LEP devices selectively alter the spectral environment and affect the ability to identify and discriminate color. As with many occupations, the ability to discriminate colors is important for pilots and mariners who must make decisions based on colored lights and objects. These abilities can be compromised with LEP. Determining the level of degradation caused by LEP remains challenging; LEP devices are not uniform in construction and results from laboratory tests may be poor indicators of user performance. In addition, performance deficits in the maritime and aviation environment can be exacerbated by cognitive distracters. However there is little known about the interaction of attentional effects with color performance deficits from the use of LEP. Several studies were conducted to determine 1) the effect of LEP on color vision performance in the aviation and maritime environments as well as the laboratory and 2) the interaction of LEP and cognitive distracters on color vision performance. The first study examined performance on the FM-100, modified Color Symbology Identification (MCSI), and navigation chart search with three different LEP. Two tests had an additional condition of cognitive distraction. The second study examined performance with two different LEP devices on measures of the FM-100 and a new type of color vision test, the chromatic Aidman Visual Screener (AVS). The third study examined performance on the FM-100 and the MCSI with and without cognitive distraction. Results for human performance suggest that LEP does not affect individuals equally, that cognitive distraction interferes with occupational color vision performance, and that LEP may compound this interference. Lastly, the chromatic AVS shows potential promise as a tool for determining the influence of filters on color perception.

SUNDAY

THE WAALER SYMPOSIUM

Session: The Waaler symposium **Time:** 09:00 - 09:30

Georg H. M. Waaler: pioneer of the genetics and physiology of colour vision

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Georg H. M. Waaler was a pioneer in the study of the genetics and physiology of colour vision who has left an extraordinary legacy. In 1925 and 1926 he conducted a large-scale study of nearly 20 thousand school children in Oslo allowing him to precisely define the frequencies of red-green colour-vision defects for people of European descent. He also set a standard of methodology for surveying the population frequency of congenital colour vision deficiency by first screening with Ishihara's plates not only to identify children who failed but also those that read the plates with "uncertainty" to insure that few, if any, children with deficiencies were missed. This was followed by anomaloscope testing to separate normals from colour defectives and to classify the latter into subtypes. Because of the large size of the study population he was able to establish a highly statistically significant discrepancy between his observed 0.441% for affected females and the 0.64% value expected from the frequency of 8.01% males with colour vision defects. In search of an explanation, as described by Linksz (1964), "with genius and perseverance he dug into the pedigrees of afflicted females studying both the paternal and maternal background and came up with an explanatory hypothesis [the two locus hypothesis] which is one of the most brilliant and remarkable solutions to a biological puzzle." Moreover, in studying the families of the affected boys and girls he anticipated modern experiments using the Rayleigh match to investigate the possibility of differences in colour vision between normals and female carriers. Following this line of investigation of studying individual differences in colour normals he was the first to discover an inherited variability in extended Rayleigh matches – a colour vision polymorphism that has since been traced to variation in the sensitivities of the normal photopigments. Reference: Linksz, A. An Essay on Color Vision and Clinical Color-Vision Tests (Grune and Stratton, New York, 1964).

Session: The Waaler symposium **Time:** 09:30 - 10:00

Quantal and non-quantal color matches

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Color matching is a procedure in which an observer matches the appearance of a test light with some mixture of primary lights; usually the test and primary lights are arranged side by side. According to the classical theory of color matching, a color match is achieved when the quantal catch per unit time for each of the active photopigments is the same for both fields. Thus for the Rayleigh Match (589 nm matched to 546 nm + 671 nm), based on the theory, a match is achieved when the L- cones receive the same number of quanta/sec for the test and primary mixture half fields, and the same is true for the M- cones. This is an elegant quantitative theory whose origins can be traced back to Grassmann over 150 years ago. The problem is that biological features of the retinal architecture produce conditions that are incompatible with the requirements of the classical theory. For example, a half-degree Rayleigh match requires less 671 nm light than does a two-degree match. The two matches are sufficiently different that the two-degree setting is not an acceptable match when viewed in a half-degree field, yet the half-degree field is the central portion of the two-degree field. Thus, the two-degree match, that appears homogeneous to the observer, contains a region where there is not a quantal match between the two halves of the field. Color matches in the short-wavelength region also can be incompatible with the classical theory. Literature studies document a discrepancy between color matches in the short-wavelength region when the method of maximum saturation (matches made near the spectrum locus) is compared with the Maxwell match method (matches made to a desaturated standard). I will discuss the biological causes of these failures and how observers are generally unaware of retinal inhomogeneities.

Session: The Waaler symposium **Time:** 10:00 - 10:30

On the worldwide prevalence of red-green colour deficiency

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Large surveys that established the prevalence of red-green colour deficiency were made in the first half of the 20th century. A critical review is made of these and subsequent data obtained with the Ishihara plates and/or the Nagel anomaloscope. The emphasis is on surveys that included 5,000 individuals that obtain a figure within narrow confidence limits. The method of recruitment and the experience of the examiners in setting meaningful pass/fail criteria are also considered. The investigation made by Georg Waaler in 1927, that included 9,000 boys and girls was pivotal in showing that the prevalence of deficiency in Northern Europe is about 8% in men and 0.4% in women and that the ratio of types deficiency in men is approximately 1 protanope: 1 protanomalous trichromat: 1 deuteranope: 5 deuteranomalous trichromats. Similar figures have been obtained in other European populations in which the Hardy Weinberg principle applies. Evidence that the prevalence is about 5% in Chinese and Japanese men is reviewed. Data obtained prior to 1950 is difficult to access and often poorly documented. However when both males and females are examined, the female prevalence is always greater than expected for an X-linked recessive trait if the ratio of different types of deficiency in men is the same as in Europe. Ethnic differences in the number and structure of photopigment genes at Xq28 have been found and the high frequency of the A-71C substitution, in the promoter of a normal M gene positioned second in the array, that is associated with deutan deficiency in Japanese men, offer possible explanations. The reported low prevalence of deficiency in Black Americans is largely derived from surveys of fewer than 400 men. The large investigation by the US Health Department in 1974, using the AO HRR plates, found no significant difference in the prevalence of deficiency in White and Black Americans.

COLOUR IN THE PERIPHERY

Session: Colour in the periphery **Time:** 11:15 - 11:30

Color appearance at ±10° along the vertical and horizontal meridians

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Hue-scaling data were collected for 3 observers using the 4+1 color-naming procedure for circular (0.25-5°), monochromatic (440-660 nm) stimuli. Stimuli were presented to the fovea and at ±10° along the vertical and horizontal meridians under conditions selected to include both rod and cone signals (no bleach) and to minimize rod contribution (bleach). All color-naming data were analyzed and compared using Abramov et al.'s (Attention, Perception & Psychophysics, 71, 2009) Uniform Appearance Diagram (UAD), a 2-D color space with orthogonal axes based on the four elemental hue sensations (blue, yellow, green, red). Results from this experiment confirmed findings from earlier studies that color appearance in the periphery is less saturated than in the fovea unless the stimulus size is increased; once stimulus size is sufficiently large, however, color appearance among the four 10° locations is equated. In the bleach condition, color appearance was approximately the same at all four peripheral (10°) eccentricities when the stimulus size was 3°; a larger stimulus (5°) was necessary to equate appearance in the no-bleach condition. This result is consistent with earlier work in our lab demonstrating that rod input increases the size of perceptive fields for the four elemental hues. The primary difference between the bleach and no-bleach conditions was seen in the perception of green, where less green was perceived when the rods contributed to the hue judgments in the no-bleach condition. When the bleach and no-bleach data obtained in the periphery are compared to the foveal data, even with the largest test sizes, there remain differences in color appearance; at the longer wavelengths, observers report stimuli appear more yellow and more red in the peripheral locations than in the fovea.

Session: Colour in the periphery **Time:** 11:30 - 11:45

Red/Green color naming declines in the periphery. Blue/Yellow does not. What happens in visual search?

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The ability to name red and green declines earlier in the periphery than the ability to name blue and yellow (Hansen, Pracejus & Gegenfurtner, 2009; Newton & Eskew, 2003). This is thought to be due to differences in retinal wiring. In the fovea, midget retinal ganglion cells receive a single L or M cone input to their central receptive fields and multiple, random, cone input to the surround, yielding chromatic opponency. In the periphery, however, midgets receive multiple cone central input, reducing chromatic opponency (Gunther & Dobkins, 2002; Mullen & Kingdom, 1996, 2002), and apparently also reducing subjects' ability to name red and green stimuli. The ability to name blue and yellow (unique blue and yellow or retinal/physiological violet and chartreuse), however, remains farther into the periphery. These colors are processed by the small bistratified cells, which receive S vs. L+M cone input throughout their entire receptive fields, without center/surround organization, across the entire retina. Thus, "blue"/"yellow" performance would not be predicted to vary with eccentricity. Here we test the effect of this red/green peripheral drop-off in a visual search task. We first mapped out color naming performance, and found that red/green performance declines sharply beginning around 40° eccentricity, whereas violet/chartreuse performance declines less sharply around 45-50°. In a feature visual search task (e.g., red target dot amongst green distractor dots; twelve, 2.5° diameter dots; 0, 20, and 45° eccentricity; 12 subjects), these differences in retinal wiring significantly impaired red/green visual search more than violet/chartreuse visual search at 45°.

Session: Colour in the periphery **Time:** 11:45 - 12:00

Abney effects in the fovea and periphery

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The Abney Effect refers to changes in the hue of lights as they are desaturated. Normally the purity of the light is varied by adding a desaturant with a fixed spectrum. Mizokami et al. (Journal of Vision, 2006) instead varied purity by using Gaussian spectra and increasing their bandwidth. Under these conditions the hue of the lights, especially at short wavelengths, tended to remain constant and thus tied to a fixed property of the stimulus like the spectral peak. The authors suggested that this might reflect a compensatory process that corrects color appearance for the spectral filtering effects of the eye. Here we test this account more completely by comparing the form of the Abney Effect in the fovea and near periphery, in order to assess the potential effect of differences in macular pigment screening on color appearance. Stimuli were generated on an Agile Light Source (Optronics Labs) which allowed the spectra of lights to be shaped in arbitrary ways, and were viewed as a 2 deg uniform field corresponding to the aperture of an integrating sphere. Over a range of wavelengths purity was varied by adding either a fixed spectrum or by varying the spectral bandwidth. Changes in perceived hue were measured with a hue matching task by adjusting the peak wavelength of test lights so that they matched the hue of the wavelength shown at a reference purity. Compensation for macular pigment screening predicts that observers should show invariant hue percepts for Gaussian spectra with a fixed peak wavelength in both the fovea and periphery, and consequently different magnitudes of Abney Effects at the two retinal loci when the effects are instead measured with conventional stimuli, since they must apply different corrections for the spectral screening at the two loci. Our measurements (still ongoing) thus provide a stronger test of functional accounts of the Abney Effect.

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Session: Colour in the periphery **Time:** 12:00 - 12:15

Real-world stimuli show colour-dependent peripheral hue distortion

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Some colours, particularly in the purple and yellow-green regions of colour space, show a distortion in hue when comparing peripheral with foveal viewing. Most recent work on this topic has used a 3-primary colour monitor. In order to establish the possible role of metamerism, we have replicated the experiment with real objects under real and simulated broadband daylight. Using Munsell chips of constant value and chroma (7/4), observers changed the hue of a peripheral (18° nasal) target, diameter 3°, in Munsell hue steps of 2.5, until it matched a parafoveal (1° nasal) target, diameter 1°. The background was grey (value = 7) and the test was performed outdoors under shaded afternoon north sky. Both targets were simultaneously presented on and off at 1Hz. The task was repeated under illuminant C, using a 3-primary illuminator (tungsten projectors with red, green and blue filters). The Munsell hues corresponding most closely to the maximal distortion on a CRT monitor are 5P and 10GY. All 7 observers needed more red in the peripheral stimulus when matching the 5P target, between 7.5P and 2.5RP, an average anti-clockwise rotation of 33.6° in CIE 1931 colour space. Matches to the 10GY target were between 2.5G and 10G, 33° towards blue. Similar results were obtained under the 3-primary illuminator. Thus the same hue distortions are seen in the near periphery when real objects are viewed under either real or simulated (3-primary) daylight or when matching is done on a CRT monitor. We have attributed this to reduction in L-M channel activity with eccentricity, while the S-(L+M) channel remains unchanged. It seems that the peripheral hue distortion is independent of the nature of the stimulus and of the illuminant and that it is indeed a function of retinal inhomogeneity.

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MONDAY

COLOUR IN CONTEXT

Session: Colour in context **Time:** 09:00 - 09:30

Natural surface colours in context

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Simultaneous chromatic contrast is potentially a powerful contributor to colour constancy, but its strength depends on a number of factors, including relative luminance, spatial scale, and spatial configuration. Surface texture in either the target or background also reduces the effect of simultaneous contrast (Hurlbert and Wolf, 2004). Because natural surfaces tend to possess both chromatic and luminance texture – due, for example, to pigment inhomogeneity or physical microstucture – simultaneous contrast is likely to play an insignificant role in colour constancy of natural surfaces. How, then, might natural surface textures contribute to colour constancy? I will discuss the effects of chromatic texture on mean colour discrimination, natural surface discrimination and object classification, and show, both theoretically and empirically, that chromatic texture improves colour constancy despite blocking spatial contrast.

Session: Colour in context **Time:** 09:30 - 09:45

Contrast edge colors under different natural illuminations

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The key prediction of the efficient coding hypothesis proposed by Barlow (Barlow, Sensory Communication, 217-234, 1961) of sensory coding in the human visual system is that sensory processing in the brain should be adapted to natural stimuli. An example of this adaptation is how color vision has evolved in response to natural image regularities. Although image gradients and their distributions have also been analysed for natural images (Hansen and Gegenfurtner, Vis. Neurosc., 26, 35-49, 2009) little data is available concerning the chromatic edge contrast deviations across natural illuminant changes. The purpose of this work was to study how daylight illuminant changes images edges. We selected 50 different phases of daylight from sunrise to sunset and computed the edge contrast for the Luminance, Red-Green (RG) and Blue-Yellow (BY) opponent responses at each image edge-pixel for different natural scenes. Results suggest that edge gradients increase as illuminant changes along a clear day. In addition average edge contrast also changes as daylight changes for the color vision mechanisms tested. However, the effect seems to be particularly relevant only for some color temperatures. These results suggest the human visual systems evolved in such a way to take adavantage of this behavior (Sumner and Mollon, The Journal of Experimental Biology, 203, 1987–2000, 2000).

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Session: Colour in context **Time:** 09:45 - 10:00

How good is the Munsell set to predict colour changes in complex scenes?

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Some rendering properties of light sources are evaluated using only 8 or 15 standard coloured samples. Others, like colour diversity, can be quantified by the volume of the Munsell set (J.M.M. Linhares, P.A. Pinto, S.M.C. Nascimento, "Chromatic diversity index–an approach based on natural scenes" Proceedings of CGIV2010, 2010). But can the Munsell set also be used to predict the way colours change within specific colour volumes? We addressed this question by comparing the effects of different illuminants on the CIELAB colour volume of scenes derived from hyperspectral images with the effects of the same illuminants on the Munsell set. 85 hyperspectral images of natural, indoor and art paintings scenes and the reflectance spectra of 1269 Munsell coloured samples were used to estimate the influence of a set of 55 illuminants and 5 LED light sources. The colour difference in the CIELAB space between the colour of each reflectance rendered under the test and the reference illuminant was estimated. Data was analysed in 16 CIELAB sub-volumes covering all colour volume. The CIE D65 illuminant was used as the reference illuminant in all cases. The average of the colour differences obtained from the hyperspectral images were plotted as a function of the average of the colour differences of the Munsell surfaces for each illuminant in each of the 16 sub-volumes. Unweighted linear regression, and the proportion of variance accounted for R^2 in the regression were estimated for each sub-volume. It was found that the R^2 was higher than 0.6 in all cases, except in the sub-volume [$L^* < 100$, $a^* > 40$, $b^* < -40$] where it was 0.5 and in the sub-volume [$L^* < 50$, $a^* < -40$, $b^* < -40$] where no Munsell data is available to compare. These results suggest that Munsell set may be used as good predictor of the chromatic effects of illuminant on the CIELAB colour volume of complex scenes.

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Session: Colour in context **Time:** 10:00 - 10:15

Effect of spatial structure on colorfulness-adaptation in natural images

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Colorfulness perception changes with adaptation to chromatic contrast modulation and to surrounding chromatic variance. We showed that the impression of an image was less colorful after exposing to saturated images and vice versa, suggesting colorfulness-adaptation worked in natural images and actual environments (APCV 2010, VSS 2011). However, the effect was weaker when jumbled images were used for adaptation instead of natural images. Here, we examine whether the effect of colorfulness-adaptation changes depending on the recognition of spatial structure in images. Two types of images were compared: a natural image consisting of natural scene or objects, and a jumbled image consisting of the collage of randomized color blocks cut from the original image with 20 by 20 blocks. Both were used as adaption and test images. Metric chroma of images was modified by multiplying a modulation coefficient to control the saturation of images. Two saturation-levels (low and high) were examined for each adaptation image. Four combinations of an adaptation (natural/jumbled) and a test (natural/jumbled) images were tested. An observer adapted to an image for 2 minutes, and then judged a test image at one of the eleven saturation levels. The judgment whether the test image was colorful or not was made each time a test image was presented following to 6 seconds re-adaptation. The method of constant stimuli was used. Results showed that the effect of colorfulness-adaptation was stronger with adaptation to the natural image than the jumbled image in the case of the natural test image. However, little adaptation effect was shown for adaptation to neither the natural nor the jumbled image in the case of the jumbled test image. These suggest that a colorfulness-adaptation mechanism works better for natural images including recognizable scenes than jumbled images, and the adaptation has stronger effect on natural images.

Session: Colour in context **Time:** 10:15 - 10:30

How many human cone pigments are needed to reliably identify surfaces in natural scenes?

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Identifying the constituent elements of a scene by their colours depends on the spectral reflecting properties of the surfaces in the scene, the spectrum of light illuminating it, and the number and spectral shape of the cone pigments of the eye. It might be assumed that the number of cone pigments is reasonably well matched to that needed for surface identification, but cone-pigment number varies across primate species, and even within humans. To test the optimality of the normal number of human cone pigments for surface identification, computer simulations were performed in which the number of pigments, their spectral locations along a log-wavelength axis, and the post-receptoral interactions were allowed to vary. Stimuli were generated from high-resolution hyperspectral images of 50 close-up and distant images of natural scenes. From each scene, 1000 points were chosen spatially at random and the cone signals at each point calculated for illuminants selected at random from combinations of direct sunlight and blue skylight and these same lights filtered by a leafy canopy. Allowance was made for absorption in the ocular media. The Shannon information retrieved across different illuminants was estimated for one, two, three, and four cone pigments, as a percentage of the information available in the sample. The average information retrieved was approximately 57% with one cone pigment, 83% with two, 92% with three, and 95% with four. This dependence was well fitted by a saturating exponential function of pigment number, with an asymptote of approximately 96% with arbitrarily large numbers of pigments. Although the normal number of human cone pigments is not quite optimal for surface identification in the natural world, it seems that the loss in information by having three and not four or more pigments is small.

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Session: Colour in context **Time:** 10:30 - 10:45

A three-dimensional colour space from the 13th Century

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Robert Grosseteste (c. 1175-1253), Bishop of Lincoln and Lecturer to the Oxford Franciscans, was a theologian, scientist, pastor and politician. We present a new commentary on one of his scientific works, *De Colore* – Concerning Colour. In this manuscript Grosseteste constructs a linguistic combinatorial space of colour. In contrast to previous commentaries (e.g. Kuehni & Schwarz, 2007, Color Ordered: A Survey of Color Order Systems from Antiquity to the Present, pg. 36) we argue that the space Grosseteste describes is explicitly three-dimensional. Grosseteste does not mention any colours by name. He uses his overarching theory of matter to inform his theory of colour and refers to technical expertise in manipulating colour in materials to navigate the three-dimensional space he describes. We seek the appropriate translation of Grosseteste's key terms and discuss their relationship to contemporary constructions. Interpretation of *De Colore* requires reference to Grosseteste's other works and to the broader intellectual context of the 13th Century. Our commentary is part of a larger research project in Durham that aims to develop and apply a new collaborative methodology for the interpretation of medieval scientific thought in England between 1100 and 1400.

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COLOUR IN CONTEXT (CONT.)

Session: Colour in context (cont.) **Time:** 11:15 - 11:30

Chromatic discrimination: Differential contributions from two adapting fields

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Chromatic discrimination depends on the chromaticity difference between the test and adapting fields. In the presence of one adapting field, discrimination is best at the adapting chromaticity. Discrimination in the presence of two adapting fields, however, is rarely studied. In this study, L/M discrimination was measured using an equiluminant 14°-16° test annulus [18.37 cd/m^2, S/(L+M)=1.0] surrounded by an inner and an outer adapting field. The L/(L+M) chromaticities of the adapting fields were 0.64 (“green”), 0.665 (“white”) or 0.70 (“red”), leading to six inner-outer adapting field combinations (“red”-“green”, “green”-“red”, “red”-“white”, “white”-“red” “green”-“white” and “white”-“green”). Discrimination was determined by a spatial 2AFC procedure for annulus chromaticities between 0.64 and 0.70. Control experiments that included identical chromaticity in the two adapting fields confirmed that discrimination was best at the adapting chromaticity. However, two adapting fields differing in chromaticity altered discrimination. When one adapting fields was “white” (“red”-“white”, “white”-“red” “green”-“white” or “white”-“green” pair), discrimination was almost identical whether it was located inside or outside the annulus, with the best discrimination near the “white” chromaticity, suggesting the “white” adapting field weighted more heavily than the “red” or “green” adapting field. Using a “red”-“green” or “green”-“red” pair of adapting fields, as the annulus chromaticity increased, discrimination thresholds decreased with a “red” inner adapting field, but increased with a “green” inner adapting field, suggesting the inner adapting field had a stronger influence on the state of adaptation. These results cannot be accounted for by adaptation to the weighted average of two adapting chromaticities or a peak detector model. The data is well described by a PC ganglion-cell response based model, which determined threshold by a summation of weighted PC responses with different adapting chromaticities. These results indicate that a higher-order mechanism must be involved in determining the contribution weights of two adapting fields.

Session: Colour in context (cont.) **Time:** 11:30 - 11:45

Linearity and asymmetry of the Watercolor Illusion with luminance elevation

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The Watercolor Effect (WCE) (Pinna et al., Vis. Res., 41, 2001) is a long-range assimilative phenomenon in which colour borders along dark contours delineating a figure produce an extended filling-in of the interior edge color. The effect has proven difficult to quantify because of its subtlety. We measured its strength using Maximum Likelihood Difference Scaling (MLDS) (Maloney & Yang, J. Vis., 3, 2003) as a function of positive and negative luminance elevations of the inner color from a mid-grey in DKL space. The WCE was generated with orange interior and purple exterior contours along a rectangular region defined by a closed, wiggly contour. For all sessions, the luminance elevation of the purple contour was fixed at a level lower than that of the orange contour. On a given trial, an observer was presented with 3 instances (a, b, c) of the stimulus ordered with respect to the luminance elevation of the inner contour. The task was to choose whether the strength of the fill-in color of stimulus b was more similar to that of a or c. MLDS estimates the interval scale that best predicts the observer's choices. Positive and negative luminance elevations were tested in separate sessions. The results for positive elevations display a linear increase of illusion strength until an elevation of 0.7, after which the strength begins to saturate. For negative elevations, the effect is less than half as strong and displays a sigmoidal shape with elevation. A control condition with interrupted contours shows a much attenuated effect. The results confirm the previous suggestion of an increase in the WCE with an increase in the luminance contrast difference between interior and exterior contours and demonstrate an asymmetry of the effect with respect to positive and negative luminance elevations of the inducing contour.

Session: Colour in context (cont.) **Time:** 11:45 - 12:00

Brightness phenomena depend on object size, not visual angle

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Shapiro and Lu (under review) have shown that many “hard-to-explain” brightness illusions can be accounted for by removing low spatial frequency information from the images—that is, the brightness differences observed in most brightness illusions actually correspond to physical differences in the image once low spatial frequency content has been removed. Here we examine whether the visual system sets the amount of low spatial frequency content removed from the image in terms of object units (i.e. corresponding to the size of the measurement disk relative to the image content) or retinal units (size of a fixed visual angle, e.g., 1°). Ten observers ranked the perceived brightness of seven physically identical test disks placed on grayscale images of natural scenes (brightest test disk = 7; darkest test disk = 1). The test disks varied in size between images (i.e., in any image, the diameter equaled 20, 40, 80, 120, or 160 pixels), and each observer viewed the images from four distances (50.8, 101.6, 203.2, 304.8 cm). The model contains one parameter that controls the amount of low spatial frequency content removed from the image (the cut-off frequency). We report the correlations (r) between the observer rankings (perceptual values), and the rankings of the pixel values of the disks (physical values) as a function of the cut-off frequency. The correlation values typically peak with r > 0.90 when the cut-off frequency is at or slightly greater than the pixel size of the test disks. For each disk size, the peak correlation occurs at the same filter level regardless of the viewing distance. The results are therefore consistent with a model in which removal of blur depends on the size of the object, and are inconsistent with a model in which filtering occurs at a fixed retinal size.

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Session: Colour mechanisms **Time:** 12:00 - 12:15

Conditions under which an increase in S-cone excitation enhances discrimination on the L/M axis

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The axes of the MacLeod-Boynton chromaticity diagram have been thought to correspond to two independent channels in the early visual system: one that extracts the ratio of L- and M-cone excitation and a second that extracts the ratio of S-cone excitation to a sum of the other two. Can colour discrimination be accounted for in terms of two independent channels of this kind? The experimental arrangements resembled those we have used to measure discrimination orthogonal to the caerulean line. The discriminanda were the two halves of a 2-deg foveal field and were presented for 150 ms on a background metameric to D65. Guided by auditory feedback, the observer indicated which field had the lower L-cone excitation. We made measurements along three horizontal lines in the MacLeod-Boynton diagram: one passed through the background chromaticity and the other two had higher values of S-cone excitation. Along each line, S-cone excitation was constant and discrimination could depend only on changes in the ratio of L- and M-cone excitation. On each line, we measured discrimination around 11 reference points, which had the same L/(L+M) values on all lines. hese reference chromaticities were never themselves presented: the two test chromaticities always straddled the reference and their separation was adjusted according to observers' performance. The luminance of each half-field was independently jittered, to prevent use of luminance cues. In the upper-right quadrant of the MacLeod-Boynton diagram, chromatic discrimination is paradoxically improved when the S-cone excitation on the two sides of the stimulus field is concomitantly increased. Thresholds – expressed in terms of the change in L/(L+M) – may be halved. We suggest that observers are exploiting a neural channel that is not aligned with either axis of the MacLeod-Boynton, a channel that may be most sensitive near the subjective transition from reddish to greenish hues.

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Session: Colour mechanisms **Time:** 12:15 - 12:30

Hue discrimination and naming

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Unlike monochromatic lights, Sinusoidally Modulated Spectral Power Distributions (SSPDs) defined by their frequency (f: cycles/300 nm), phase (p: degree) and amplitude (m) can be considered as idealised models of natural colour signals. In the present experiment, SSPDs of 1.5 c/300 nm with phase p varying from 0 to 360 degrees were used to determine the minimum perceived difference between two phases (which corresponds to a shift along the wavelength axis). The three observers who participated were subsequently requested to provide a name for each of the 12 different colour stimuli. Performances were characterised by plotting sensitivity in function of the phase ($\Delta p/p$). Across observers, the Hue Discrimination Curve (HDC) consistently displayed two minima corresponding to stimuli identified as pale pink (100 degree) and pale blue (330 degree) and two maxima for stimuli identified as green (30 degree) and magenta (180 degree). These minima and maxima are in agreement with those obtained by Holtsmark & Valberg (*Nature*, vol. 224, no. 5217, 1969) using optimal colour stimuli, however the HDCs fail to indicate a third minimum reported by the authors for blue-green colours. Since phase variation induces sinusoidal modulations of cones and colour opponent mechanisms responses, the computed hue discrimination curve describes a periodical profile with two minima and two maxima whose periodicity does not depend on f nor m. This characterisation offers the possibility to describe hue discrimination for the full colour gamut by the single parameter p.

Session: Colour mechanisms **Time:** 12:30 - 12:45

The retention and disruption of colour information in human visual short term memory

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The retention of information in visual short term memory (VSTM) for basic visual attributes can be disrupted by the presentation of masking stimuli during inter-stimulus intervals (ISIs) during delayed discrimination tasks. The selective nature of these 'memory masking' effects suggests a modular organisation for VSTM which contains parallel stores each tuned to a relatively narrow range of stimulus parameters. We wanted to exploit these effects in order to determine whether VSTM displays similar selectivity for stimulus colour. A delayed hue discrimination paradigm was used to measure the fidelity of stored colour information. The task employed a 2AFC procedure and colour normal observers (n=5) were asked to discriminate between coloured reference and test stimuli (1° diameter circles) which were presented 2.5° either side of a central fixation mark and temporally separated by an ISI = 5s. The points of subjective equality (PSEs) on the resultant psychometric matching functions provided an index of performance. Measurements were made in the presence and absence of mask stimuli which were presented during the ISI. The mask stimuli varied in hue around the equiluminant plane in DKL colour space.We found a consistent mask-induced, hue-dependent disruption of performance in the case of all reference colours. Masking stimuli were found to interfere with the stored representations of the reference stimuli inducing shifts in PSEs compared to the 'no mask' conditions. These shifts were found to be tuned in colour space, only occurring for a range of mask hues that fell within bandwidths of 29–37°, centred on the reference stimuli. Outside of these ranges, masking stimuli had little or no effect on measured PSEs. The pattern of these results suggests that memory masking for colour exhibits selectivity similar to that which has already been demonstrated for other visual attributes such as motion and spatial frequency.

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Session: Colour mechanisms (cont.) **Time:** 14:00 - 14:15

Colour categorisation in Mandarin-English speakers: Evidence for a left visual field (LVF) advantage

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Does language affect perception? Categorisation is faster when colour stimuli straddle a colour boundary (Bornstein & Monroe, Psychol. Res, 42, 1980). Recently a temporal advantage has been shown for stimuli presented in the right visual field (RVF) which is consistent with the dominance of the left hemisphere for language processing (Gilbert *et al.*, PNAS, 103, 2006). In the present study 40 late Mandarin-English bilinguals residing in the UK performed a colour categorisation task, either in L1 or L2. Colours (11) were chosen to straddle the blue-green colour boundary. As singletons these were presented for 160 ms, randomly in the LVF (20) or RVF (20). After stimulus presentation, colour names 'Blue' ('蓝') and 'Green' ('绿') were presented either on top or bottom of the screen and observers indicated their response as fast as possible via the corresponding button. For L1 and L2, the location of the colour boundary (hue angle in Luv space) and mean reaction times at the boundary were calculated. We report two results for the bilinguals: (1) The *location* of the blue-green boundary is independent of the visual field and the language. The average blue-green boundary is at 183° (range: 175°-190°) in Luv space. (2) *Mean reaction times at the colour boundary* were about 70 ms shorter in the LVF, but only in Mandarin as opposed to English ($F(1,39) = 6.84$, $p = 0.012$). These demonstrate temporal LVF advantage for Mandarin bilinguals in their native language – at odds with the RVF advantage for English monolinguals demonstrated by Gilbert *et al.* The discrepancy is conceivably due to the script nature of two languages: Mandarin logographic characters are analysed visuo-orthographically, in the right fusiform gyrus – compared to phonological analysis of English alphabetic characters in the left hemisphere fusiform gyrus (Guo & Burgund, Brain Lang., 115, 2010).

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Session: Colour mechanisms (cont.) **Time:** 14:15 - 14:30

Individual differences in higher-order chromatic mechanisms measured with Classification Image technique

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Previous studies have measured chromatic noise effects on chromatic detection performance to investigate properties of higher-order chromatic mechanisms. However, the mechanism properties are not fully understood in spite of those studies because there have been conflicting results. To examine chromatic noise effects more precisely, we analyze chromatic appearance on chromatically noisy textures using the Classification Image (CI) technique. The stimuli were two squares with identical signal chromaticities superimposed on two chromatic noise textures composed of small square elements, respectively. Both signal and noise chromaticities were defined in the isoluminant plane of the Derrington-Krauskopf-Lennie color space. Chromaticities of the noise texture elements were randomly chosen from a circular distribution whose center was on either of four non-cardinal color directions. The signal color directions were identical or perpendicular to the noise center directions. The observer was requested to respond which signal square had higher chromatic contrast. The differences in element colors between noise textures corresponding to 'higher contrast' and 'lower contrast' responses were averaged across all trials in each color condition to derive a CI. In addition, mean chromaticity within the signal square region of the CI was calculated as a chromatic preference (CP) of the observer. The results showed that the CP directions did not necessarily correspond to the signal directions and had large individual differences. To examine the effects of simple individual difference in the color space on CPs, we also measured relative perceived chromatic contrast along color directions using a uniform stimulus and the paired comparison method. In the results, although perceived chromatic contrast also had individual differences, the individual differences were much smaller than those for CP. These results suggest that some higher-order chromatic mechanisms may exist, whose individual differences get apparent only on heterochromatic texture stimuli but not in uniform stimuli.

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Session: Colour mechanisms (cont.) **Time:** 14:30 - 14:45

Two-stage misbinding of color

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Peripheral visual objects may be mistakenly perceived to have conjoined features from objects presented in only the central visual field (Wu *et al.*, Nature, 429, 2004). Central objects play a role in initiating peripheral misbinding of motion but are not the sole source of misbound motion (Sun & Shevell, VSS 2010). The role of central objects in peripheral misbinding of color remains an open question. If the central stimulus influences the color binding for peripheral objects, then the chromatic response to the peripheral objects should depend on whether a central stimulus is present. Furthermore, if the center contributes chromatic information to resolve color ambiguity in the periphery, then the misbound color should be in the central stimulus even when that color is not present in the periphery. Here, the central stimulus was either (1) blank or (2) had red dots moving upward and green dots moving downward. The peripheral stimulus had (1) only white dots or (2) white and red dots. Upward- and downward-moving peripheral dots were always 50% each. The percentages of red dots among upward- and downward-moving peripheral dots were varied independently, from 0% to 50%, with the rest of the dots white. Observers reported the colors of the majority of peripheral (1) upward-moving and (2) downward-moving dots. The results show that a central stimulus enhanced or suppressed the red responses depending on whether the peripheral dots moved in the same direction as the central red objects, supporting that the center influences misbinding of color to peripheral objects. Moreover, with central red and green dots presented peripheral dots were (1) never reported in red or green when all peripheral dots were white and (2) never reported in green when all peripheral dots were white and red, suggesting that the center need not contribute the misbound color feature.

Session: Colour mechanisms (cont.) **Time:** 14:45 - 15:00

Co-occurrence of luminance and chromatic edges affect depth perception consistently across different depth profiles

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When luminance and chromatic edges co-occur, depth from shading can be enhanced or suppressed ('colour shading effect', Kingdom, Nat. Neuro. 2003), but the effect does not occur for all observers (Clery, Bloj & Harris, VSS 2011). Here we compared the colour shading effect for a sinusoidal luminance pattern (delivering a roughly sinusoidal depth percept) and a square-wave luminance pattern (delivering a triangle-wave shaped depth percept). Stimuli were circular patches (4 deg diameter) containing either a sinusoidal luminance grating (0.75 c.p.d) or a square wave luminance grating (fundamental 0.75 c.p.d.). Superimposed on this was a chromatic grating of the same profile and spatial frequency, which could either be aligned with the luminance component, or orthogonal to it. Depending on the condition, we kept either the contrast of the luminance or chromatic component fixed, and varied the contrast of the other component. 14 participants were asked to adjust a disparity-defined depth pedestal to indicate how much depth from shading was perceived in the direction of the luminance component. For orthogonal components, we found that increasing luminance contrast increased the perceived depth similarly for both sinusoids and square waves. An increase in colour contrast also increased the perceived depth (colour shading effect). Again the effects were similar for both sinusoids and square waves. When luminance and chromatic components were aligned, we found two behaviours; one group (n=6/14) perceived more depth as colour contrast increased, whilst the other group (n=8/14) perceived less depth. Participants behaved in the same way for both luminance profiles. Perceived depth therefore seems not to be directly linked to the geometry of the shape defined by shading. The consistency of our results suggests a feed-forward mechanism of depth perception, with interaction between early luminance and chromatic filters.

Session: Colour induction and constancy **Time:** 17:00 - 17:15

Estimate of an illuminant color based on the luminance balance of surface colors

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The human visual system can discount the illuminant color to accomplish color constancy. A typical theoretical framework of color constancy uses the mean chromaticity shifts of surface colors associated with an illuminant change in order to discount the illuminant color. Our previous experiments, however, showed that changes in the luminance balance of surface colors of fixed chromaticity had significant effects on the estimate of illuminant color[1]. The question of the present study is whether the visual system might use the luminance balance or the means of L, M, S cone excitations of surface colors to estimate an illuminant color. In our previous experiments both the luminance balance and the means of L, M, S cone excitations changed in the condition where the mean chromaticity of surface colors was kept constant under different illuminants. We used a stimulus pattern consisting of 61 color hexagons, each subtended 2 degree, presented on a CRT. The center hexagon served as a test stimulus. The 60 surrounding hexagons were of six colors: bright and dim red, green and blue. We used simulated 3000, 6500 and 20000K black body radiations as test illuminants. Bright surrounding colors were set to be optimal colors under the corresponding illuminant. The observer adjusted the chromaticity of the test stimulus so that it appeared as a gray or white surface. The results showed that the observer estimated the illuminant color to be in the opposite direction of the test illuminant in a condition where the means of L, M, S cone excitations of surrounding colors were set invariant, the chromaticities of those colors shifted with the test illuminant, and the luminance balance of those colors varied in order to keep the mean cone excitation constant. This suggests that the luminance balance could be an effective cue for estimating the illuminant color independent of the mean cone excitations across surrounding colors.

[1] Uchikawa, K., Kitazawa, Y., MacLeod, D. I. A. and Fukuda, K. (2010b) Degree of color constancy obtained by luminance balance of color samples. J Vis December 22, 2010 10(15): 8.

Session: Colour induction and constancy **Time:** 17:15 - 17:30

Do individual differences in eye movements explain differences in chromatic induction between subjects?

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The colour of a surface is affected by its surrounding colour; chromatic induction. There exist large inter-individual differences in the amount of chromatic induction obtained (Ekroll & Faul, Vision Research, 49(18), 2009). One possible reason for these differences between subjects could be differences in subjects' eye movements. Golz (Perception, 39, 2010) studied whether subjects' grey settings depend on whether subjects visually explore the stimulus by looking around or fixate their gaze exclusively on the adjustable disk. He found a difference of 20% between these two viewing conditions. However, we are still left with the question whether differences in eye movements between subjects have an influence on the amount of chromatic induction under normal (free-looking) circumstances. To answer this question, we measured thirty (colour-normal) subjects and their eye movements while they made achromatic settings using four uniform and four variegated coloured surrounds. Results showed that when subjects could freely move their eyes, there was no correlation between the time subjects spent looking at the background and the amount of induction. We observed large differences between subjects in the amount of induction obtained. In a second experiment, a computer voice instructed subjects when to look at the background or when to look exclusively at the adjustable disk while they set the disk to grey. In line with the results of Golz (2010), we were able to find a significant difference in the amount of induction between the two viewing conditions. We could only detect an effect of eye movements on the amount of induction when we forced subjects to move their gaze. This suggests that eye movements can only play a role under artificial (forced looking) viewing conditions but eye movements do not seem to play a large role for chromatic induction under natural (free looking) viewing conditions.

Session: Colour induction and constancy **Time:** 17:30 - 17:45

Multiple perceptual references for colour in space and time

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Illumination conditions in our visual environment change across time and space. For a colour constant observer, a change in the spectral composition of the illumination is accompanied by a corresponding change in the chromaticity associated with an achromatic percept. However, maintaining colour constancy for different regions of illumination within a scene implies the maintenance of multiple perceptual references, which may need updating if the illumination conditions change over time or if eye-movements transform the spatial variation into temporal variation. We investigated the features of a scene that enable the maintenance of separate perceptual reference points for two displaced but overlapping chromaticity distributions, akin to the chromaticities of a set of materials under two illuminants. In separate sessions, chromaticities from different distributions were interleaved in the same retinal location or spatially separated across the retina, as well as being either interleaved in the same physical location on the stimulus display or separated in space. We manipulated the relationship between retinal and spatial locations by requiring observers either to maintain fixation or to saccade between the two locations. Additionally, we embedded the test samples in a background of chromaticities drawn from the same distribution, or from an inconsistent distribution. Colour constancy was better when the two chromaticity distributions were presented to separate retinal locations and when the background to each target contained chromaticities from the same distribution, as we would expect if both local retinal adaptation and spatially distributed cues to the illumination context are important determinants of colour constancy. Importantly we found that constancy improved when eye-movements were made across an illumination boundary, compared to a condition in which equivalent stimuli were interleaved on the retina whilst maintaining fixation, suggesting that these movements help to divide the temporal stream of samples from different chromaticity distributions.

TUESDAY

Session: Ecology of colour vision **Time:** 09:00 - 09:30

Bird colour vision: From tetrachromacy to learning about novel objects

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It is readily apparent that colour is important to birds, not least from their own colourfulness. Also birds seem to be 'intelligent', sometimes demonstrating cognitive abilities that are otherwise evident only in primates. Historically however work on avian colour vision — mainly done with pigeons — was complicated by ignorance of photoreceptor spectral sensitivities and colour discrimination thresholds. We now know the spectral sensitivities of the five types of avian cone, and that birds probably have tetrachromatic colour vision. The role of the fifth 'double cone' in colour vision is unclear. This knowledge of low-level mechanisms makes possible experiments to test phenomena such as colour categorization. Moreover, we have found that week-old poultry chicks learn colour remarkably accurately and quickly. These abilities allow us to investigate how young chicks — which otherwise seem to have rather poor spatial vision — classify food objects by colour and how they learn about novel objects in natural foraging behaviour. We find that when a chick confronts a potential food-item of an unfamiliar new colour it make a predictions about the likely value based on the experience of related but clearly discriminable colours. Interestingly chicks recognise both similarity and novel as shared — rather than mutually exclusive — attributes of an object. They treat their knowledge of the new object as provisional and learn quickly (in a single trial) about the new object. These findings have broad implications for understanding how colour is used by relatively simple animals, and more generally for how animals make judgements novel stimuli and learn from the consequences of their actions.

Session: Ecology of colour vision **Time:** 09:30 - 09:45

Bowerbird colour vision: Spectral tuning in avian short-wavelength sensitive (SWS1) visual pigments

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Bowerbirds are a model system in visual ecology and evolutionary biology, particularly with regard to the evolution of colourful courtship displays. Comparatively little is known about how bowerbirds perceive their visual environment, and the presence of ultraviolet (UV) reflectance in their bower and plumage displays raises the question as to whether they have visual sensitivity maximally tuned to perceive light in the UV range. In vertebrates, sensitivity to short wavelength light is mediated by the SWS1 class of visual pigments, whose wavelengths of maximal absorption (λ_{max}) are in either the violet or UV. We set out to characterize the vision of the great bowerbird (Chlamydera nuchalis), with particular focus on the SWS1 opsin. All five opsin types were isolated from a cDNA library: RH1, RH2, LWS, SWS2, and SWS1. All have important structural characteristics indicating they are functional pigments. The SWS1 has an atypical amino acid complement at known spectral tuning sites. To expand our understanding of the molecular bases of colour vision and mechanisms of spectral tuning in avian SWS1 pigments, mutant pigments were created and expressed alongside the wild type opsin to determine their effects on λ_{max}. We discuss our results in light of bowerbird behavioural ecology, avian evolution, and visual pigment biochemistry.

Acknowledgements: NSERC, CIHR, University Health Network Vision Science Research Program

Session: Ecology of colour vision **Time:** 09:45 - 10:00

Molecular genetics and spectral tuning of warbler visual pigments: a comparative approach to avian color vision

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Understanding the great diversity of color in the animal world requires understanding how animals perceive color, the environmental context, and the extent to which the color vision and color co-evolve. Here, we propose to assess how opsins, and thus color vision, vary in relation to colorful sexual ornaments (plumage color) and the environment, using the New and Old World warblers as a model system. We obtained complete coding sequences for all opsin genes in more than 15 New World warblers and 7 Old World warblers, and found substantial non-synonymous variation in all cone opsins. The spectral shifts caused by some of these variable sites have already been studied. However, the effects of substitutions at most of these sites remain unknown and we cannot predict their effect on the wavelength of maximum absorbance (λ_{max}) of the corresponding photopigments. To study how the observed variation translates into λ_{max} differences, we used transient transfection of mammalian tissue culture cells to express warbler opsin in-vitro. The λ_{max} of purified and reconstituted visual pigments were determined by absorption spectroscopy. For RH2 we found λ_{max} differences of about 3nm among RH2 in New World warblers and were able to identify C85F as the substitution responsible for this shift. On the other hand, for SWS2 we found differences of 3nm among New World warblers and 5nm among Old world warblers. In addition to within clade variation, SWS2 also differs between New and Old World warblers at 9 residues. Interestingly, the SWS2 consensus of both clades only differs by 1.5nm. According to previous studies and our data it seems S269A could be responsible for a +5nm shift while a S99W substitution compensates this shift, explaining why SWS2 in both clades has similar λ_{max}. In contrast to RH2 and SWS2, SWS1 and LWS opsins do not differ among warblers.

Acknowledgements: NIH Ruth L. Kirschstein NRSA Predoctoral Fellowship

Session: Ecology of colour vision **Time:** 10:00 - 10:15

The detection of colour patterns in birds

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Colour patterns play an important role in the ecology of birds as plumage colouration acts as an indicator of fitness in sexual communication. In bright light, birds encode visual information with two separate classes of photoreceptors; double cones, mediating achromatic information, and single cones, mediating chromatic information. Both pathways encode spatial information. However, while much is known about the spatial resolution of the achromatic pathway, there is little known about the spatial resolution of the chromatic pathway. We have used behavioural experiments with budgerigars (*Melopsittacus undulatus*) to establish contrast sensitivity functions for achromatic gratings as well as for red-green and blue-green gratings isoluminant to double cones. Our investigation shows that the achromatic pathway is tuned for higher spatial frequencies while the chromatic pathway is tuned for lower spatial frequencies. Furthermore, maximum contrast sensitivity is lower for blue-green gratings compared to red-green gratings. The reason for this might be related to the low density of blue-sensitive cones within the retina of budgerigars (about 5-10 %). Similarly, humans have an achromatic pathway tuned for higher spatial frequencies compared to the chromatic pathway and lower contrast sensitivity for blue-yellow than for red-green gratings. This suggests that our results reflect general visual properties of vertebrate vision. Our study makes it possible, for the first time, to model the detection of colour patterns by birds while accounting for the spatial arrangement of both achromatic and chromatic contrast. For example, budgerigars can detect a pattern with 2 mm wide stripes of 50% achromatic contrast from a 2 meters distance while the stripes of a pattern of 50% chromatic contrast have to be at least 6 mm wide to be detected from the same distance. Indeed, many birds display colours in larger patches while small detail contains mostly achromatic contrast.

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Session: Ecology of colour vision **Time:** 10:15 - 10:30

Behavioural evidence of dichromacy in a species of South American marsupial

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Colour vision in marsupials is a controversial issue, especially among the genus Didelphis (Didelphidae, Didelphimorphia). While behavioural tests have diagnosed these animals as trichromats and electrophysiological studies have diagnosed them as monochromats, recent molecular genetics studies provide evidence for dichromatic colour vision, having found two classes of cone opsins in a species of this genus. This study examines the colour perception of a male and female white-eared opossum, Didelphis albiventris, through a series of tasks involving a behavioural paradigm of discrimination learning. Both opossums succeeded in discriminating pairs of stimuli consisting of Munsell colour cards presented in random brightness values that are assumed to be easily discriminated by dichromats and trichromats (e.g. blues versus oranges). However, both subjects failed to discriminate between colours that are expected to be easily discriminated only by trichromats (e.g. greens versus oranges). The opossums were also unsuccessful in distinguishing a colour against itself (e.g. oranges versus oranges), demonstrating that discrimination was based only on visual cues. These results are consistent with recent predictions based on molecular genetics suggesting that the genus *Didelphis* is routinely a dichromat.

ECOLOGY OF COLOUR VISION (CONT.)

Session: Ecology of colour vision (cont.) **Time:** 11:00 - 11:15

The relative importance of chromatic, achromatic, and tactile floral guides in a nocturnal and a diurnal hawkmoth

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Recent research shows that a nocturnal hawkmoth, *Manduca sexta*, inspects flowers in search for nectar by means of a series of hovering and proboscis movements controlled by different sensory modalities, mainly vision and mechanoreception. The diurnal *Macroglossum stellatarum* is a closely related hawkmoth challenged with the same task, but under illuminances 6–8 orders of magnitude higher. Here, we use flower models presenting colour markings, 3-dimensional features, or both, to study innate flower movements and sensory cues involved in the innate inspection behaviour of *M. stellatarum*. On flat, plain coloured models moths scanned the whole corolla with their proboscis, attaining intermediate success levels. When models presented colour markings moths biased proboscis placement, which affected inspection efficiency. Three-dimensional features affected inspection behaviour and efficiency, by provoking strong "diving" responses. When both visual and tactile features were present, visual cues showed prevalence in the control of the inspection behaviour. Moreover, while *M. sexta* seems to use achromatic cues, here we show that *M. stellatarum* guides its proboscis placement using chromatic cues. Therefore, while motor responses appear to be shared by these hawkmoths, their sensory control shows important differences. We discuss results on flower inspection behaviour comparatively, evaluating whether these differences are the result of an evolutionary divergence associated with the switch of *M. stellatarum* to diurnal activity, or the result of a flexible use of sensory information by the naïve animals.

Acknowledgements: We thank the Swedish Research Council and the Wenner-Gren foundation for grants.

Session: Ecology of colour vision (cont.) **Time:** 11:15 - 11:30

Relationship between flowers and vision of bees

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Nearly 150 years ago Charles Darwin suggested that flower displays evolved to attract pollinators. However, it is still unclear which aspects of flower patterns are advertised to insect eyes. To establish the relationship between flowers and insect vision, we recorded multispectral images of bee-pollinated flowers and reconstructed the way in which flowers are seen through the honeybee eye. Previously, we have demonstrated that bees detect artificial flower-like targets using brightness vision, which is based on the signal of the green (L-) photoreceptor alone. Here we show that in bee-pollinated flowers the contrast of colour patterns as seen by green photoreceptor is highly correlated with flower size, while the contrast of UV patterns is not correlated with the size of flowers. When viewed through the low resolution eye of the honeybee, the majority of flowers look to the green photoreceptor like dim disks surrounded by bright rings. Such patterns have enhanced borders and are detected from further away than bright disks surrounded by dim rings. Our results suggest that patterns of bee pollinated flowers have evolved to maximise the distance from which they can be detected by bees and therefore to increase their advertising potential.

Session: Physiological processes of colour vision **Time:** 11:30 - 11:45

Further evidence for cone-selective connectivity in midget retinal ganglion cells of the macaque monkey

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The specificity of cone input to the surrounds of midget ganglion cells has been a contentious issue, although direct physiological measurement (Reid & Shapley, Nature, 356, 1992, J. Neurosci., 14, 2002; Lee *et al.,* Vis. Neurosci. 15, 1998; Benardete & Kaplan, J. Physiol., 519, 1999) has favored considerable selectivity. However, random connectivity has recently been suggested in peripheral retina (Crook *et al.,* J. Neurosci., 31, 2011). We present here further evidence for specific connectivity of ganglion cells in central retina (<15 deg). Spatial frequency (SF) tuning curves were obtained from macaque midget retinal ganglion cells and parvocellular LGN cells. Four stimulus conditions were used: achromatic, chromatic, M-cone and L-cone isolating gratings. The band-pass character of SF response curves indicates the degree of center-surround spatial interaction. A band-pass index was calculated as the response at low SFs relative to responses at the SF peak, where an index of 1 indicates no center-surround antagonism, and 0 means an antagonistic surround as strong as the center. For achromatic gratings, there was considerable variability in band-pass index with values ranging from 0.2 to 0.9. Both in midget ganglion cells and parvo-LGN cells, the index fell close to 1 for the center cone. This indicates little center-surround antagonism for the center cone, and is strong evidence for cone-selective connectivity in the surround for P cells within 15 degrees of the fovea. How connection specificity varies with retinal eccentricity is yet to be determined.

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Session: Physiological processes of colour vision **Time:** 11:45 - 12:00

Neural locus of color after-images

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In a new psychophysical method for measuring color afterimages, colors of two halves of a disk were modulated sinusoidally (1/16 to 2 Hz) from grey to opposite ends of a color axis and back, e.g. grey>red>grey on one half and grey>green>grey on the other. The two halves appeared identical initially, increased in difference, decreased to no difference, then increased again in opposite phase, so that when the physical modulation returned to grey, negative afterimages were perceived, the half modulated through red appeared green and vice versa. The physical contrast between the two halves, when they appeared identical, provided a quantitative measurement of the adaptation that leads to the afterimages. Aftereffects from modulation around the circumference of the color circle confirmed independence between the two cone-opponent mechanisms. To locate an early neural substrate for the afterimages, macaque parafoveal retinal ganglion cell (RGC) responses were measured during presentation of uniform circular patches modulated sinusoidally toward either pole of the preferred axis of the cell at 1/32, 1/16 and 1/8 Hz. The responses of parvocellular and koniocellular RGCs tracked modulation in their preferred direction (e.g., red for a +L-M cell), but decreased to the pre-stimulus rate 1-2 sec before the physical modulation returned to mid-gray, dipped below this level and then recovered. Cell responses to the opposite modulation (e.g. green for a +L-M cell) showed the reverse pattern. Together, the excitation and inhibition of RGCs tuned to opposite directions along a color axis provide an early neural explanation for the afterimages: cells responding at mid-grey after the cessation of the modulation, propagate an after-image signal to subsequent stages. RGC responses were well described by a cone-opponent subtractive adaptation with a time constant of 4-7 seconds, much slower than photoreceptor adaptation. Slow neural adaptation of the RGC population thus accounted for the after-image psychophysics.

Acknowledgements: NEI grants EY07556, EY13312, EY13112

Session: Physiological processes of colour vision **Time:** 12:00 - 12:15

Can power functions – not DOGs – describe receptive fields of cone-opponent cells?

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To serve colour vision, spatial sensitivity of receptive fields of cone-opponent cells requires a balanced input of signals from the opponent cone receptors. In this context, balanced means that the ratio of, for instance, excitatory L- and inhibitory M-cone inputs to a 'L-M' opponent cell stays constant for a colour stimulus of constant chromaticity, irrespective of intensity, stimulus size, and light adaptation. Such balance was often found for opponent cells of the lateral geniculate nucleus (LGN) and for the prepotential inputs to these cells. For stimuli larger than the centre, increasing stimulus size led to an attenuation of the firing rates. This attenuation followed a power law as a function of area. DOG functions usually failed to describe the L/M excitation balance, and the DOG model's spatial response terminates too quickly. These objections are removed by the use of power functions.

Session: Physiological processes of colour vision **Time:** 12:15 - 12:30

Revisiting pupil colour responses

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Pupil colour responses have been demonstrated in numerous studies (Young et al., Journal of the Optical Society of America 70, 1980; Tsujimura et al., Proc. R. Soc. Lond. B; 268, 2001; Barbur, The Visual Neurosciences, 2004), but the extent to which the measured pupillary responses to chromatic stimuli reflect the processing of colour signals or simply increments in photoreceptor signals through a light reflex pathway remains unclear. In this study we carried out a series of experiments with coloured stimuli that produced known cone- and rod-photoreceptor contrasts. The stimuli were isoluminant (according to the CIE standard observer) and were also buried in dynamic luminance contrast noise. The experiments were carried out in normal trichromats, in dichromats and in patients with absent rod photoreceptor responses. The results suggest that the measured pupil constrictions at stimulus onset reflect a combination of colour and light reflex signals and that the colour response components can be largely isolated using dynamic luminance contrast and light flux noise. Pupil colour responses also exhibit an increase onset response latency of 60 to 80ms when compared to equivalent light reflex responses. Pupil responses at stimulus offset can be accounted for almost entirely by a corresponding increment in photoreceptor contrast and can be minimized or totally eliminated using dynamic contrast noise. Deutan and protan subjects produce pupil responses which are totally determined by photoreceptor increments at both onset and offset, provided S-cone signals are absent. It remains of great interest to establish the extent to which the amplitude of pupil constrictions in response to L- and M-cone increments also reflects differences in their spatial densities.

POSTERS

Abstract N°: 1 **Saturday and Monday:** 15:00 – 17:00

Chromatic and achromatic VEP responses in pre-school children

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The purpose was to study chromatic and achromatic VEP responses in pre-school children. 30 children aged 2 to 6 years were binocularly tested. Chromatic VEP were recorded to isoluminant red-green (R-G) and blue-yellow (B-Y) stimulus. The stimulus was a circle composed of horizontal sinusoidal gratings with spatial frequency 2 cycles/degree and 90 % chromatic contrast. Two stimulus sizes (7 deg and 21 deg) and onset-offset mode of stimulation (on – 300 ms, off – 700 ms) were used. Achromatic stimulus of same stimulation characteristics was also used to test the luminance channel. VEP were also recorded to black and white checkerboard (50' square size), which was presented in pattern reversal (reversal VEP) and onset-offset (onset VEP) mode. Reliable responses were recorded in all children. Predominant part of the chromatic VEP response consisted of a positive (P) wave, which followed a less prominent negative (N) wave. P wave latency was shorter when using 21 deg R-G stimulus compared to 7 deg R-G stimulus (P=0.0016). P wave latency was shorter also when using 21 deg R-G stimulus compared to B-Y stimulus of same size (P=0.012). P wave amplitude was much more variable than latency. Coefficient of variation (CV) for P wave latency when using larger R-G and B-Y stimuli was around 4%, whereas for P wave amplitude it was around 40%. N wave latency was shorter when using 21 deg R-G stimulus compared to 7 deg R-G stimulus (P=0.012). N wave latency was shorter also when using 7 deg R-G stimulus compared to B-Y stimulus of same size (P=0.049). CV for N wave latency when using larger R-G stimulus was 16% (14 % for larger B-Y stimulus), whereas for N wave amplitude it was 50% (60 % for larger B-Y stimulus). Achromatic 2 cycles/deg stimulus, reversal VEP and onset VEP responses were analized and compared to chromatic VEP responses. We may conclude that chromatic VEP to R-G and B-Y stimuli are reliably recorded in pre-school children.

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Saturday and Monday: 15:00 – 17:00 **Abstract Nº:** 2

Hue-selective mechanisms in human visual cortex

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The present study demonstrates the presence of hue-selective neurons in human visual cortex, in addition to those for cone-opponent channels. We made an attempt to demonstrate the presence of hue-selective neurons by a pattern-classification analysis of brain activity, obtained with the functional magnetic resonance imaging (fMRI) technique. A pair of different combinations of colour stimuli, which was designed to equally stimulate two cone-opponent mechanisms under isoluminance, was used as visual stimulus. Each of them was a check pattern of two colours, which can be described as diagonal directions in the cone-contrast space (L- and S-cone contrast); i.e., pairs of 45 deg (magenta) and 225 deg (lime) vs. 135 deg (cyan) and 315 deg (orange) in hue angle, when the scale of two axes were equated by the multiples of discrimination threshold. These two check patterns stimulate L-M axis and S-axis mechanisms at the same extent. Considering the spatio-temporal resolution of fMRI, it is difficult to resolve evoked responses from the two stimuli, only when colours are coded by the combinations of the cone-opponent responses. The result of classification analysis on blood-oxygenation-level dependent (BOLD) signal pattern by fMRI experiment was successful, which supports the presence of hue-selective mechanisms, in addition to the mechanisms that selectively respond to cone-opponent axes. The classification among the four colours was also successful, and selective adaptation to diagonal colour was also observed. These results may support the presence of hue-selective mechanisms in human brain.

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Abstract Nº: 3 **Saturday and Monday:** 15:00 – 17:00

Domain of metamers exciting melanopsin

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Besides being a colour stimulus, light entering the eye may be captured by ipRGCs that elicit a signal controlling pupil aperture (Dacey et al., 2005; Mure et al., 2009). In this paper, we examine to which extent metamers address ipRGCs differently. The theoretical approach consists of examining the efficiency of black metamers to elicit a melanopsin signal in ipRGCs. Considering that any stimulus can be described as composed of two components – a fundamental colour stimulus and a metameric black (Wyszecki, 1958; Cohen & Kappauf, 1982), a black metamer basis is built and the corresponding melanopsin signal is calculated. Two black metamer bases are calculated, one derived from discretisation of a full spectrum white illuminant into narrow spectral bands, and the other using a limited set of colour LEDs. The rationale of the experiment is to adjust the spectral power distribution of metamer white LED illuminations to excite melanopsin at a maximum or at a minimum. The white target colour is that of a typical commercial white LED specified by its colour temperature, and metamer illuminations are produced by adjusting the intensity of seven colour LEDs. The melanopsin response is not directly measured but the pupil aperture, which is assumed to be under ipRGCs control at photopic levels, is recorded (Viénot, Bailacq, Le Rohellec, 2010), following a sudden change of illumination.

Saturday and Monday: 15:00 – 17:00 **Abstract Nº:** 4

Pseudo-isochromatic plates for measuring the ability to discriminate colours

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We have developed new pseudo-isochromatic plates to measure the ability to discriminate colours. The plates may also be used to determine whether the tested person has proatanomalous or deuteranomalous colour vision. We have developed 3 series of test plates. In all the 3 series, plates are arranged in order of increasing difficulty. Plates show one Landolt-C each, in 8 diffferent positions. The first plate has the lowest level of difficulty; anomalous trichomats are able to distinguish the symbol but dichromats are not. In the next 14 plates, the Landolt C symbol gradually fades into the background, up to a colour difference of $\Delta E^*a,b=2.0$ in the case of the last plate. In the first (R/G) series, a red Landolt C is shown in front of a green background. This series serves the purpose of establishing the severity of colour vision deficiency. In the second (P) series, colours are located on the protan confusion line whereas in the third (D) series, on the deutan confusion line. Those performing well in the P series but poorly in the D series suffer from deuteranomaly whereas those performing in the opposite way, that is well in the D series and poorly in the P series, from protanomaly. The plates were printed by a calibrated colour printer; then bound in a book. When using the book, the test person is able to see only one plate at a time, in front of a white background. Continuous white adaptation is provided by the white background and the white page next to the one with the plate. These pseudo-isochromatic plates were used to test 100 persons with colour vision deficiency. Our results showed a 95% efficiency in separating protans and deutans, as verified by anomaloscopy.

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Abstract Nº: 5 **Saturday and Monday:** 15:00 – 17:00

Sex colored the world of ancient insects: What the spectral sensitivities of damselfly photoreceptors tell us!

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Adult odonates (damselflies and dragonflies) occur in a variety of colors. In the blue-tailed damselfly (*Ischnura elegans*) young males are bright green and turn blue later. Immature females show a red or purple coloration, whereas mature females either mimic the blue color of the males or are camouflaged by an inconspicuous olive-green or brown. Males must find a mature mate, and behavioral experiments have shown that they are able to distinguish between the different female color morphs (e.g. van Gossum *et al.*, Evol. Ecol., 25, 2011). Even though sexual signaling is regarded a strong driving force for the evolution of additional spectral sensitivities, there is little evidence that color vision was shaped by mate detection and recognition. So far a possible co-evolution of receptor sensitivities and communication signals could only be demonstrated in butterflies (e.g. Wakakuwa *et al.*, J. Neurosci., 25, 2005). Odonates are also promising candidates and, as one of the oldest extant insect groups, particularly interesting in comparison to butterflies, which radiated quite recently. To study the basis of color vision in odonates, we determined the spectral sensitivities in the compound eyes of male blue-tailed damselflies. Intracellular recordings show that there are at least three kinds of photoreceptors most sensitive to UV, green and red wavelengths. Apart from the typical beta-peak in the UV, green receptors generally have a pronounced secondary peak in the blue spectral range indicating the expression of two opsins per receptor. Taken together, the data available for two dragonfly species (Meinertzhagen *et al.*, J. Comp. Physiol. A, 151, 1983; Yang *et al.*, J. Comp. Physiol. A., 169, 1991) and our own results on damselflies suggest that the last common ancestor of odonates in the Permian already had a sophisticated color vision system based on sensitivities from the UV to the red spectral range.

Saturday and Monday: 15:00 – 17:00 **Abstract N°:** 6

Investigating colour vision in a marine mammal, the harbour seal – a cognitive approach

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Unlike their terrestrial relatives, both, pinnipeds and cetaceans, are M-cone monochromats. Although monochromacy seems to exclude colour vision, an investigation in the Bering Sea spotted seal (Wartzok and McCormick, Vis. Res., 18, 1978) demonstrated the contrary. Other studies in marine mammals seem to prove colour vision as well (Busch and Dücker, Zool. Anz., 219, 1986; Griebel and Schmid; Vis. Res. 1992, Mar Freshw Behav Phy , 35, 1999), but the methods used in these studies raise the question whether perception of brightness contrasts between the colours accounted for their positive results. In our study with the harbour seal, we eliminated any possibility to use brightness as a secondary cue by ensuring a constant state of adaptation throughout the experiments and by matching the colours in their subjective brightness. We furthermore chose a new approach for testing the perception of colour. We trained a harbour seal to form an abstract concept of same/different and showed that he was able to generalise this concept across stimulus dimensions. In the current tests we are using this capability for testing the perception of colour contrasts between two stimuli that are otherwise identical. If the subject perceives the colours, then it will judge both stimuli to be different, otherwise it will respond that they are the same. Other than in the common discrimination task, this cognitive approach ensures that negative results cannot be interpreted as a failure in learning the task. Instead it will doubtlessly prove or disprove colour vision in a marine mammal.

Abstract Nº: 7 **Saturday and Monday:** 15:00 – 17:00

Weighing quality attributes

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Understanding how observers perceive image quality is complex, largely because of the subjectivity but also from the dimensionality of the task. A considerable amount of work has been done on finding a way to assess perceived quality of a printed document without observers. These methods usually focus on one quality attribute at a time. However, when an observer views a document, he most likely judges the quality with consideration to all attributes simultaneously, or a subset of relative attributes depending on the document type and the differences between the reproductions. With a focus on different printing options, this study has investigated the difference in perceived quality between printing options and how the most relevant quality attributes may relate to one another. A set of observers have been asked to compare the quality of reproductions that have been printed with different workflows. The principle components have been determined and used to understand the relationships that may exist between the different quality attributes. A set of image characteristics have also been selected to help summarize the amount of each attribute a given document may have.

Saturday and Monday: 15:00 – 17:00 **Abstract Nº:** 8

Relative frequency of metamerism correlates negatively with entropy of colours in natural scenes

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Metamerism has several interpretations, but one of the most important is that it is the effect whereby a pair of surfaces that are indiscriminable under one light are discriminable under another. In natural scenes, the relative frequency of metameric pairs of surfaces, expressed as a proportion of all pairs of surfaces, varies systematically, with higher relative frequencies found in vegetated scenes (Foster, J. Opt Soc. Am. A, 23, 2006). Since the relative frequency depends on the particular spectral reflecting properties of the surfaces in a scene, their frequency of occurrence, the spectrum of the illuminants, and the spectral sensitivities of the receptors of the eye, it might seem unlikely that a single colour property of a scene under a given illuminant could account for much of this dependence. But one such property, the differential entropy, captures some important features of the distributions of colours. To test the relevance of this property, the frequency of metamerism was estimated for each of 50 hyperspectral images of natural scenes, classified as predominantly vegetated or predominantly nonvegetated, illuminated by two extreme daylights with correlated colour temperatures (CCTs) of 4000 K and 25000 K. The Shannon differential entropy was estimated from the tristimulus coordinates of each of the scenes under a fixed daylight with CCT 4000 K. The dependence of log relative frequency of metamerism on differential entropy had a Pearson product-moment correlation coefficient of -0.82 both for predominantly vegetated and for predominantly nonvegetated scenes. When differential entropy was instead estimated for daylights with CCTs 25000 K and 6500 K, the correlation coefficients were little altered, ranging from -0.83 to -0.81. Of necessity, the frequency of metamerism across pairs of arbitrary daylights depends on more than the distribution of colours under a particular daylight, but differential entropy is a surprisingly good predictor.

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Abstract Nº: 9 **Saturday and Monday:** 15:00 – 17:00

Influence of correlated color temperature of a light source on colour discrimination capability of observers

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Experimental evidence indicates a preference in correlated colour temperature of light sources for daily living activities (Oi et al. Proc. 26th session of CIE, 2, 2007) or viewing artistic paintings (Pinto et al., J. Opt. Soc. Am. A, 25, 2008). There are also data relating the capability of observers to make judgments on colour difference with the spectral power distribution of light source used (Viénot et al., Proc. AIC colour'05, 2005). The present work describes a visual colour discrimination experiment whose results corroborate the existence of a relation between the correlated colour temperature of a light source and the colour discrimination capabilities of the observers. The visual experiment consisted of a test of colour discrimination in which the observer must indicate whether each of the 20 pairs of chromatic samples is perceived to be different in a pair or not. There are two types of items; those of equal samples that have identical reflectance curves, so that they do not present this source of variability in the responses due to the change either of reflectance or of illuminant, and those of different reflectance curves, in which the colour differences can vary with a change in light source. To minimize this effect, the sample pairs chosen were of very similar spectral reflectance since they were all based on the samples of the NCS album prepared with a limited number of pigments. When, furthermore, one uses a RGBA LED-light source whose spectrum consists of four peaks that are regulated with different intensities to achieve different colour temperatures and luminances, one can minimize the effect of different light source spectra. The analysis of the data for the pairs of different samples showed no significant differences for the case of three distinct values of the luminance, but appreciable and statistically significant (ANOVA $p<0.05$) differences for the case of different correlated colour temperatures.

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Saturday and Monday: 15:00 – 17:00 **Abstract N°:** 10

Foveal colour discrimination is enhanced in the vicinity of the caerulean line

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The boundary between reddish and greenish hues runs obliquely in the MacLeod-Boynton diagram and corresponds approximately to the 'caerulean line', the locus of mixtures of skylight and sunlight. We find that chromaticity discrimination is enhanced for stimuli that straddle this boundary. Observers were asked to discriminate the two halves of a circular 2° field divided vertically by a thin line and presented for 150 ms on a background metameric to Illuminant D65. The task was a spatial forced-choice: the observer indicated which half-field was the greener. Each half-field was independently jittered in luminance to ensure that discrimination was based only on chromaticity. To choose our stimuli, we rescaled the vertical axis of the MacLeod-Boynton diagram so that a line passing through unique yellow (576 nm) and the metamer of Illuminant D65 had a slope of $-45°$. We then selected a series of lines that intersected this line at 90°, and we measured discrimination along these +45° lines. In a given block of trials, the test chromaticities were always equidistant from a given point on the test line but their separation was increased or decreased according to the subject's performance. In different blocks, we probed different positions along the test line. Thresholds were expressed in terms of the factor by which L/(L+M) was changed. In interleaved phenomenological measurements we established the point on each +45° line that appeared neither reddish nor greenish. Discrimination thresholds exhibited a marked minimum close to the transition between reddish and greenish hues. A control experiment showed that this remained the case when the observer needed only to identify the odd one out of four quadrants. Our results cannot easily be explained in terms of two independent chromatic channels that correspond to the axes of the MacLeod-Boynton diagram.

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Abstract N°: 11 **Saturday and Monday:** 15:00 – 17:00

Colour in cartography for colour-blindness people

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Maps enable visual access to spatial information, but they are often unreadable by a person with colour vision deficiency (CVD). It would be useful for this group of people (approx. 8% of men) to improve their accessibility to map. However, aesthetic aspects should not be neglected: who would like to read or to buy an "ugly" map? This study was based on a questionnaire (duration of 1h 30min), undertaken by 50 CVD people. The questions concerned cartography (reading information from the map, access time) and aesthetics (preference of one map style over another). The results were analysed with respect to two axes. The first, not examined here, concerns the topographic improvement (improving legibility by the smallest change in original colours). The second axis is concerned with the attractiveness of the map, so that it is both legible and pleasant for a CVD person. The results of the test showed that a map should have the following properties: accessibility, i.e. the legend placed as close as possible to the map; clarity, i.e. avoiding putting a colour by class of object and preferring symbolic wefts of the same colour; pleasantness, i.e., choosing appropriate tints (according to the test, deutans like green maps) and exploiting simultaneous contrast (they see well yellow roads on a green background). The test results also reveal that it is necessary to improve confidence in usage. Many CVD people do not use maps fearing they may commit errors. A more accessible and clearer map will improve confidence and will be appreciated for its aesthetics.

Saturday and Monday: 15:00 – 17:00 **Abstract Nº:** 12

Hypoxia, color vision deficiencies and saturated blood oxygen

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Pilots in the United States are allowed to fly at altitudes up to 12,500 ft (3800 m) without supplemental oxygen. Previous research has shown that the color vision of individuals with normal color vision (NCV) can be mildly affected near this altitude, but there is little information available related to the color discrimination of individuals with congenital red-green color vision defects (DCV) in this environment. Chromatic thresholds were measured using the Cambridge Color Test (CCT), Color Assessment and Diagnosis (CAD) test, and Cone Specific Contrast Test (CSCT) relative to a gray background. Thresholds were also measured relative to a yellowish background using the CCT. Fourteen NCV and 17 DCV individuals participated. A hypobaric altitude chamber was used to simulate ground and 12,400 ft (3780 m) pressure equivalents. Although there was an expected difference ($p<0.05$) between the two groups with respect to the red-green chromatic thresholds, there were no significant altitude effects for any of the tests or backgrounds. Because the results may have been confounded by variability in adapting to the altitude, the relative change in chromatic thresholds was examined as a function of saturated blood oxygen (SaO_2). No significant association was found between thresholds measured using the CSCT, the CCT, or the CAD red-green thresholds and SaO_2. However, there was a significant relative decrease in the CAD blue-yellow threshold at 12,400 ft (3780 m) as SaO_2 decreased, irrespective of the color vision status. The negative findings on this study are similar to previous reports which reported no change, or subtle changes, in color vision at this altitude for photopic vision. The lower CAD blue-yellow thresholds with decreased SaO_2 was a counter intuitive finding, but it appears to related to a rotation of the discrimination ellipse towards a scotopic error axis due to mild hypoxia in some individuals.

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Abstract Nº: 13 **Saturday and Monday:** 15:00 – 17:00

Scaling suprathreshold stimulus in chromatic threshold units: is it an appropriate metric?

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Previous works (McKeefry et al., IOVS, 44: 2267-76, 2003; Zele et al., Vis. Res. 47:608-611, 2007; Vassilev et al., Vis. Res., 49: 524-29, 2009) still discuss the best way to scale a stimulus to provide an indication of its perceptual strength. Scaling suprathreshold stimuli in multiples of threshold has been used for the purpose of comparing suprathreshold performance for stimuli modulated along different dimensions. However, Zele et al. (2007) suggest that expressing suprathreshold data in threshold units can produce outcomes artificially biased in favour of the mechanism with poorer sensitivity. While McKeefry et al. (2003) showed that, if the stimulus is modulated on cardinal axes, the differences in reaction times are reduced when scaling is based on detection threshold. An alternative scaling metric is contrast, where stimulus is characterized by their physical properties, like Weber or Michelson contrast. Vassilev et al. (2009) said that the Weber contrast offers a more appropriate metric to specify suprathreshold stimuli. In order to add some piece of evidence to this discussion we modified the reaction time model proposed by O'Donell et al (Vis. Neurosc. 27: 119-129, 2010) replacing the Weber chromatic contrast – RMS_i – by a multiple of chromatic threshold (RMS_i/RMS_{it}). The results seem to be contradictory since this new analysis shows that colour along chromatic direction equal to 90° appears as the most informative. Moreover, this model shows an inconsistent trend of the shared contrast gain which grows as the size decreases. Scaling suprathreshold stimuli in multiples of each observer's colour detection threshold seems not to be appropriate, favouring the chromatic direction with lower sensitivity and smallest size of the stimuli. Threshold sensitivity and reaction time are related to different features of the internal response generated by the visual stimulus. So, the Weber contrast offers a more appropriate metric for specifying superthreshold stimuli.

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Saturday and Monday: 15:00 – 17:00 **Abstract Nº:** 14

Is there rod intrusion in male marmosets?

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Under poor light conditions, dichromatic humans seem to be able to perform like trichromats, while monochromats would achieve dichromacy. Some evidence supports the idea that rods and cones may interact in order to enhance color perception. In marmosets, in which a visual polymorphism obligates males to be dichromats, rods were shown to be active under human photopic levels. Taken that into account, it is feasible to imagine that, under a wide range of natural situations, rod intrusion could occur in marmosets, allowing dichromatic males to improve their color discrimination. Our study was conducted in order to investigate the effect that low, intermediate and high light levels, which naturally occur in tropical forests, would have on the foraging abilities of male marmosets. Light intensities were measured from dawn to dusk at three different forest locations: forest shade, small gap, big gap. Based on these measurements, 14 male marmosets (Callithrix jacchus) were subjected to foraging tasks in 1×2×2 m enclosures under low, intermediate and high sunlight levels. During experimentation, small cubes (1×1×1 cm), made out of foam rubber and colored in four shades of green, were spread on the enclosure's floor. On top of these background elements, small cubes (1×1×1 cm), made out of cake frosting and colored in two shades of blue, green and orange, were scattered. Individually, each male was observed during four sessions of 5 minutes while it foraged for the colored food on the green background. Under high light levels, as expected, and also under low light levels, males did well on blue target detection, while performed poorly on green and orange food detection. Under intermediate light levels, detection of blue and orange targets did not differ, while green targets remained undetected. These results can be interpreted as behavioral evidence that rod intrusion may occur in marmosets under natural situations.

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Abstract Nº: 15 **Saturday and Monday:** 15:00 – 17:00

Brightness contrast and brightness assimilation in photopic and mesopic adaptations

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The brightness of a visual scene region is influenced by the luminances of adjacent regions. This phenomenon is known as brightness induction and includes both brightness contrast and assimilation effects. The different nature of rod and cone pathways could affect this induction. We analyzed the effect of light adaptation in the perception of grey patches embedded in three foveal stimuli configurations. A Simultaneous Brightness Contrast display (SBC) and two brightness assimilation stimuli — a White's display (W) and a Brightness Illusory Contour configuration (BIC) (Barrionuevo et al., J. Vis, 9(8), 2009) — were evaluated. Using a forced choice method with constant stimuli, we measured the luminance of a grey patch over the black stripe (W and BIC) or over the black square (SBC) that had been matched in brightness to a grey patch with constant luminance (Lr) over the white region (stripe or square). Two adaptation conditions were evaluated: photopic (Lr=76 cd/m^2) and mesopic (Lr=0.076 cd/m^2). The mesopic condition was achieved using neutral density filters. Three subjects (AV $\geq$ 1, without historic illnesses) were tested. In the SBC configuration, the induction was significantly higher under the photopic condition than the mesopic. However in W and BIC, the induction was significantly higher under the mesopic condition compared to the photopic condition. In the mesopic range, the low light levels arriving to the surround photoreceptors reduce both the cone lateral inhibition and the rod intrusion on the test perception, thus the induction in the brightness contrast is reduced. The opposite effects found in the assimilation cases (W and BIC) show the participation of post-retinal mechanisms, independent to the light adaptation. These results suggest that brightness contrast and brightness assimilation have different processing in the visual system.

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Saturday and Monday: 15:00 – 17:00 **Abstract Nº:** 16

The role of specular reflections present in labial teeth and gingiva images as visual cue for texture and sharpness perception

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Reasonable investigation has been applied in the past to discover the dependence of specular reflections on the perception of shape. It was found that mechanisms in the human visual system are capable of recovering shape information from specularities (Fleming *et al.*, Journal of Vision 4, 798-820, 2004). Throughout work related to gingival inflammation assessment from photographic images at the University of Granada (Eckhard *et al.*, Proceedings of the Interim Meeting AIC 2011, in progress, 2011), it was discovered that specular reflections might also provide a visual cue for texture and sharpness perception. In the latter work, a special image acquisition technique that aims in minimizing specular reflections on labial teeth and gingiva using polarization filters was developed and evaluated. For direct visual comparison, images from several individuals were captured successively, first without specular reflection reduction in the acquisition process and afterwards including the latter. Apart from proving the applicability of the acquisition method for the task of specular reflection reduction in labial teeth and gingiva images, visual evaluation by expert and non-expert observers revealed a perceived decrease in image sharpness and texture for images with reduced specularities. To investigate this aspect, an experiment was conducted to prove the occurrence of the effect for different light sources and different cameras in the acquisition process. By placing a printed patch with varying frequency line patterns on subjects teeth during image acquisition, it can be shown that the perceived decrease in image sharpness and texture loss are not related to the modifications in the image acquisition set-up. Moreover, a perceptual experiment provided evidence for this effect to be perceptual in nature. Future work will be devoted towards investigating the occurrence of this effect for other objects or image scenes with naturally occurring large amounts of specularities.

Abstract Nº: 17 **Saturday and Monday:** 15:00 – 17:00

Chromatic opponency as an unsharping mechanism

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Colour vision is often analysed as a trade-off between spatial and chromatic sensitivity (e.g. Manning, J. R., Brainard, D. H. Visual Neuroscience. 26, 2009): the retina can only contain a certain number of receptors. One may either have a large number of the same type of photoreceptor (high spatial resolution at a single focal wavelength) or one may have multiple types of photoreceptor (lowering the spatial resolution, increasing the spectral resolution). However, in scattering media, such as turbid water, the optical transmission function is wavelength dependent: There is a blurring of the transmitted image, which is (as a rule of thumb) greater a shorter wavelengths. I will make the argument that this can be exploited to enhance edge detection – muddying the water between spatial and spectral sampling. There are physiological reasons to believe this takes place. Whilst for many fish, movement and luminance sensors are colour blind, this is not true for all fish. Opponency has been found in the movement detection cells of the optic tectum (Z. Gačić et al. Arch. Biol. Sci., Belgrade, 61 (1), 2009) and opponent mechanisms have implicated in optomotor response experiments. Using a model of scattering in the diffusion limit, and correcting for receptor noise, (Vorobyev M, Osorio D. Proc Biol Sci. 265(1394), 1998) it can be seen that an opponent signal can be used to filter out low frequency image components. This process is called 'unsharping' in photography and creates an illusion of sharpness in images. The biological version of this process can be used to make sure responses are sensitive to edges, and, to some degree correct for the increased blurring of objects with distance.

Acknowledgements: BBSRC

POSTERS

Saturday and Monday: 15:00 – 17:00 **Abstract N^o:** 18

Psychophysical and physiological responses to gratings with luminance and chromatic components of different spatial frequencies

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Gratings containing luminance and chromatic components of different spatial frequencies have seldom been used to study segregation of signals in luminance and chromatic pathways (Lee *et al.* J. Physiol. 589, 2011), although such compound stimuli are encountered in the natural environment. We report here psychophysical detection and discrimination thresholds to compound gratings that consist of luminance and chromatic components with the latter either half or double the spatial frequency of the former. These results were compared with spatial frequency tuning curves to simple luminance and chromatic gratings. Sensitivities to the compound gratings follow the envelope of the contrast sensitivity functions of the luminance and chromatic components, after scaling for spatial frequency and chromatic contrast. Discrimination sensitivity of compound gratings from either chromatic or luminance simple gratings was limited by the detection threshold for the luminance or chromatic component that is present in the compound stimulus but not in the simple grating. This would not be expected if chromatic and luminance information were multiplexed in a single afferent pathway. Multiplexing predicts that performance on a discrimination task should follow similar profiles across grating comparison conditions. However, the discrimination thresholds measured imply contributions from independent mechanisms. Equivalent data were obtained for S cone modulation. Comparative physiology data was obtained from macaque ganglion cells; responses to luminance and chromatic components of the compound gratings were strongly segregated in the magnocellular and parvocellular pathways at all spatial frequencies. Together, this data supports the segregation of luminance and chromatic information in complex patterns in luminance and chromatic channels, with the magnocellular and parvocellular pathways serving as the corresponding physiological substreams, at least near threshold.

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Abstract N^o: 19 **Saturday and Monday:** 15:00 – 17:00

Color shifts from perceptual organization mediated by motion

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Perceptual organization plays an important role in color appearance (e.g., Wollschläger & Anderson, 2009; Xian & Shevell, 2004). We studied whether the color appearance of a stationary test was altered by segmenting it from a background put in motion. Shifts in color appearance were compared following chromatic adaptation for two background conditions, one stationary, the other moving. The background was a red, fan-shaped segment of a 30-150' annulus. The background rotated pendularly (to the left and right by 25°, completing 1/2 cycle/sec) around a fixation point located 90' below the 30'-wide test. By this, the background appeared to "slide" behind the test, but also maintained constant stimulation within a 90' area of the background that included the test. Therefore, retinal adaptation near the edges of the test was the same whether the background was stationary or moving. The effect of adaptation on color appearance was measured using a red-green hue cancellation technique. For each experiment, observers completed 3 conditions: test superimposed on no, a stationary, or a moving background. Five levels of test-field luminance were used per condition (4-20% above the background luminance). Various background chromaticities and luminances were tested in different experiments. Results from 4 observers revealed individual differences related to the magnitude of color shifts with a stationary background. Two observers showed strong color shifts with a stationary background, but weaker shifts with a moving background, consistent with a difference in only the additive effect of a background on color appearance. Two additional observers showed no difference between the stationary and moving background, but also showed weaker color shifts in the stationary condition. These results suggest that perceptual organization mediated by motion can alter color appearance, but actual shifts may depend on individual differences in overall magnitude of chromatic adaptation.

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Saturday and Monday: 15:00 – 17:00 **Abstract Nº:** 20

What cone excitation ratios do and do not tell us about colour constancy

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Colours of objects and their backgrounds can be described in terms of some transformation of the signal generated by the long-wavelength (L), medium-wavelength (M) and short-wavelength (S) cones. An influential observation is that cone excitation ratios remain constant under different illuminations, often described as von Kries adaptation. Here we test the extent to which the von Kries rule is compatible with the stability of perceived colour. We used an asymmetric colour matching paradigm, testing the chromaticity (CIE1976 u'v' space) and luminance shifts, both induced by different test illuminants, compared with viewing under a reference illuminant (C). Data for standard illuminant A (orangey-reddish) and for a pre-defined illuminant S (sky blue) are presented. Preliminary studies used real Munsell chips under illuminants with continuous spectra. Subsequently, we tested stimuli based on computer-simulated Munsell samples, presented for either 1 sec, 60 sec or dichoptically. We show that when constancy is moderate, failures of the von Kries rule may be attributed to data scatter. However, when colour constancy is almost complete, the cone contrasts cease to be linear functions. The departures from linearity are substantial particularly for L/M cones and depend on their relative excitation. Luminance changes introduce nonlinearities. Consequently, lightness constancy is incompatible with the von Kries rule. For extreme shifts in test illuminant, e.g. from S to A, a substantial failure of von Kries rule for all cones occurs, despite quite good colour constancy. Under some conditions there is complete dissociation between von Kries adaptation and the stability of perceived colours under different illuminants. This indicates that mechanisms other than cone contrast must underlie colour constancy, as expected from neurophysiological studies (Zeki 1983; Wild et al. Nature 313, 133, 1985).

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Abstract N^o: 21 **Saturday and Monday:** 15:00 – 17:00

Visual pathways do not age

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In 1997, Pokorny & Smith (Pokorny et al., J. Opt. Soc. Am. A, 14, 1997) developed a psychophysical method to preferentially stimulate either the parvocellular (P) or the magnocellular (M) pathways. This method provides a powerful tool to study potential visual impairments of visual pathways. Their stimuli were based on the luminance contrast gain differences between the two pathways and the mode of presentation of stimuli changes depending on the channel, M or P, to preferentially stimulate. This rules out controversial results found when P and M are stimulated following their color and/or spatial-temporal sensitivities. In this study, we tested whether normal ageing has an effect on M and P pathways. We used the described method to measure contrast thresholds in two populations differing in age ($\approx$27 vs $\approx$60 year old). As expected, we found that both M and P contrast thresholds increase with age but we did not find any difference between the two pathways efficiency measured as the slope of contrasts vs. threshold curve. These results are in agreement with Wuerger's results (Wuerger et al., Ophthalmic Physiol. Opt., 30, 2010) but are non consistent with Elliot's ones (Elliot et al. J. Vis, 10, 2010). This inconsistency may be due to (1) the lower mean age of our elderly population (60 vs 70), (2) our use, to produce the stimuli, of a VSG card 2.5 (Cambridge Research Systems) with a more accurate control of luminance as compared to the Elliot's study. To investigate further, we will perform fMRI experiments using the same protocol. Adaptation of the protocol to fMRI and some primary results were presented.

Acknowledgements: Authors would thank Cluster HVN, Région Rhones-Alpes for funding support on fMRI. A.D. thanks Seitz Phototecnik A.G. (Zurich) for their financial support.

Saturday and Monday: 15:00 – 17:00 **Abstract Nº:** 22

Scattered light in the eye and its effects on visual acuity, contrast sensitivity and colour vision

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Forward light scatter in the eye reduces retinal image contrast, particularly in the presence of sources of bright light. The resulting effect on colour vision is less well understood. Although shorter wavelengths are likely to be scattered more, previous findings suggest that chromatic detection thresholds are unaffected by normal levels of forward light scatter, although detectable changes in suprathreshold coloured stimuli may occur (Barbur, Colour Vision Deficiencies XIII, 28, 1997). Age-related structural changes in the cornea, iris and the lens can significantly alter the amount and angular distribution of forward scatter, making the effects of increased scatter in older eyes difficult to quantify. To avoid such problems we investigated the effect that 'fogging' filters have on several aspects of visual performance in a group of young subjects. A new method was developed to measure the light scattering characteristics of fogging filters. A flicker cancellation technique was modified to measure the scatter function of the eye for red, green and blue light. Appropriate filters were selected to approximately double the levels of scattered light of the average normal young observer. Visual acuity and contrast sensitivity were measured using the Contrast Acuity Assessment (CAA) test and chromatic sensitivity was measured using the Colour Assessment and Diagnosis (CAD) test. Doubling the amount of forward light scatter did not significantly affect visual acuity, but significantly reduced contrast sensitivity. The filter caused small but significant increases in both red/green and yellow/blue thresholds. In conclusion, in the absence of other factors, doubling the typical amount of forward light scatter in the eye causes a significant worsening of achromatic contrast sensitivity, with negligible effect on visual acuity and a small, but significant effect on colour detection thresholds. The effect of large levels of scattered light on the chromatic appearance of saturated colour stimuli remains to be examined.

Acknowledgements: We acknowledge the support of the EPSRC towards work on glare in lighting installations.

Abstract N°: 23 **Saturday and Monday:** 15:00 – 17:00

A pseudo three-dimensional stimulus influences asymmetrically to chromatic- and luminance-contrast effects by a background colour

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It is well known that surrounding colours can influence colour appearance of a given field and the field is perceived as a different colour. This phenomenon includes both the effect of the luminance contrast and the effect of the chromatic contrast. In the previous research on background effect (Shinomori et al., 20th Sympo. Int. Colour Vis. Soc., 2009), three-dimensional layout of a central stimulus had less colour contrast effect than two-dimensional layout of the central stimulus. Additionally, in our previous research (Inamoto et al., Asia-Pacific Conf. on Vis., 2010), the influence of a background colour to a perceived colour of a stimulus was less, when the central stimulus was under a sinusoidal luminance modulation, compared to the case that the central stimulus was homogeneous (under a constant luminance). In the experiment, subjects reported that the central stimuli under the sinusoidal luminance modulation were perceived as three-dimensional. Thus, we made the hypothesis that a three-dimensional impression of the central stimulus in two-dimension is one of factors to decrease background's contrast effects. In this paper, in order to investigate this hypothesis, we made the two-dimensional (flat) stimulus in which luminance distribution causes pseudo three-dimensional perception, and the control stimuli that has almost identical luminance distribution to it but causes two-dimensional perception. We compared the chromatic- and luminance-contrast effects by a background colour on the pseudo three-dimensional stimulus and the control stimuli. Results indicate that the effect of luminance contrasts on the pseudo three-dimensional stimulus and the control stimuli (two-dimensional) were almost comparable. On the contrary, the effect of chromatic contrasts on the pseudo three-dimensional stimuli decreased as compared with the two-dimensional stimuli. These results suggest that a three-dimensional impression of the central stimulus decreases chromatic contrast effect, but has no influence on luminance contrast effect.

Acknowledgements: JSPS KAKENHI 20300081

Saturday and Monday: 15:00 – 17:00 **Abstract Nº:** 24

Melanopsin driven pupillary light response is partially preserved in Leber's Hereditary Optic Neuropathy (LHON) patients

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The massive retinal ganglion cell loss in LHON causes a central scotoma and dyschromatopsia. Melanopsin expressing retinal ganglion cells (mRGCs) were recently reported to be relatively spared (La Morgia et al, Brain, 2010; Kawasaki et al, Clin Exp Ophthal, 2010). To assess their functional integrity we evaluated pupillary light responses (PLR) driven by the mRGCs in patients with LHON. Participants were 12 LHON patients (9 males; 47.8±14.1 yrs) and 12 healthy subjects (3 males; 38.7±15.9 yrs). The PLR was measured with an eye tracker (Arrington) and stimuli were controlled with a Ganzfeld (Roland). All subjects were dark adaptated for 10 minutes and PLRs were measured monocularly, to 1s, 250 cd/m^2 flashes (Park et al, ARVO, 2010). Blue (470 nm) and red (670 nm) flashes were presented at 1 m intervals. The transient PLR was analyzed by measuring peak amplitude and latency; the median amplitude at 4-6 s after the flash offset was analyzed to estimate the sustained melanopsin response (mR)(Park et al, ARVO, 2010). The mR was present in all controls and in 9/12 patients, subdivided into mR LHON and non-mR LHON groups. No difference was found for the transient PLR latencies among groups. Peak amplitude did not differ between controls and mR LHON, but the non-mR LHON group differed from both ($p<0{,}05$). The mR amplitude was larger for blue than for red stimuli, consistent with a sustained response driven by mRGCs. This response differed among all groups ($p< 0{,}05$) for the blue stimulus, showing greater pupil constriction in the control than in the two LHON groups. The melanopsin-driven PLR is present in LHON patients; although it is diminished in part of the patients, it is normal in others, suggesting that mRGCs are partially spared, consistent with histological findings previously described (La Morgia et al, Brain, 2010).

Acknowledgements: IFOND, FAPESP, CAPES, CNPq, Instituto de Olhos de Colatina, UNIFESP

Abstract Nº: 25 **Saturday and Monday:** 15:00 – 17:00

Cone contrast does not predict peripheral colour matching

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Shifts in colour perception are seen when parafoveal and peripheral targets are compared. In general, the hue of the peripheral stimulus is perceived distorted and less saturated. There are, however, four hues that remain invariant and it is found that three of these are correlated with unique red, blue and yellow (Parry et al. 2006). Unique green is an exception and does not correlate with any invariant hue. Here we investigate these observations in terms of cone excitation ratios or cone contrast. Thirty eight observers (26±8 years, mean±1S.D.) performed an asymmetric colour matching experiment. A parafoveal spot (1° diameter, 1° eccentricity) was presented simultaneously for 380ms with a peripheral spot (3° diameter, 18° eccentricity). The observers matched these stimuli by adjusting the chromatic axis and purity of the peripheral target. Three observers performed a 4 alternative forced choice (4AFC) naming experiment to determine unique hues. Unique hues were defined as the central maxima of the resultant four colour naming functions. Despite obtaining a match between parafoveal and peripheral stimuli, the peripheral L- and M-cone contrasts do not match the parafoveal L- and M-cone contrast. S-cone contrast calculations indicate good correspondence between parafoveal and peripheral stimuli. The peripheral RMS cone contrast matched the parafoveal with a few exceptions and these were particularly apparent in the bluish-green region of the colour space. The results suggest that cone contrast, between matched parafoveal and peripheral stimuli, remains unchanged if the stimuli excite equivalent numbers of cones. If for example the stimuli are spatially separated on the retina and excite different number of cones, a mismatch in cone contrast is observed. The previously reported discrepancy between peripherally invariant and unique green might, therefore, be attributed to reduced numbers of M-cones in the peripheral retina.

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Saturday and Monday: 15:00 – 17:00 **Abstract Nº:** 26

The Knill and Kersten brightness illusion can be accounted for by removing low spatial frequency content

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A number of investigators have proposed that brightness illusions arise because the visual system estimates the surface reflectance of the objects based on knowledge of (or inferences about) the illumination in the scene. Knill and Kersten (1991) created a demonstration that has been used as evidence for this type of theory. In their demonstration, two physically identical shaded squares are contextualized so that they appear either to be the front faces of two cubes or the front surfaces of two cylinders. As part of a pair of cubes, one square appears to be much brighter than the other square, but as part of the cylinders, the squares appear to be of similar shading. The perceived differences occur presumably because the shading on the cylinders is consistent with the illumination of curved objects. Here we examine whether the Knill and Kersten demonstration can be accounted for simply by removing low spatial frequency content from the image. The procedure is as follows: blur the image with a convolution kernel of diameter, d, and then subtract the blurred image from the original image. We compare the gradient profile of the two squares as a function of d. The gradients of the squares are markedly different in the filtered images when the squares form part of the cubes, and are less different when the squares form part of the cylinders. The effect is most pronounced when d equals the size of the squares (250 pixels). A model that does not require the visual system to make inferences about the illumination in the scene can therefore explain the Knill and Kersten display.

Acknowledgements: Supported by NIH grant R15EY021008 to AGS

Abstract Nº: 27 **Saturday and Monday:** 15:00 – 17:00

Feature binding of a continuously changing object

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Consider two patches of light, one presented continuously and smoothly changing in color from red to green over time, and the other briefly pulsed. During the pulse, both patches are physically identical but observers perceive them to be different, with the continuously changing patch ahead of the pulsed one along the color continuum (Sheth, Nijhawan & Shimojo, 2000). Similar results hold for other continuously changing features such as luminance or spatial frequency, but the magnitude of the lead time of the continuously changing patch depends on the particular feature. Color has a longer lead time than luminance or spatial frequency. In previous work, the lead time for each feature was measured separately. Here, two features known to have different lead times, color and orientation, were simultaneously changed together over time. Initially, a bar (2.6° × 0.4°) appeared on one side of a fixation point. The color of the bar changed continuously, either from green to red or red to green. At the same time, the bar rotated continuously about its center, either clockwise or counter-clockwise. The starting color and orientation were randomized on each trial. Exactly halfway through the presentation, a bar was pulsed for 79 msec on the other side of the fixation point. At that instant, the color and orientation of the pulsed bar were physically identical to the continuously changing bar. The observer compared the pulsed bar to the continuously changing one in both color and orientation. The results showed color maintained a longer lead time than orientation, which implies that observers perceived a combination of color and orientation that never was presented to the eye

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Saturday and Monday: 15:00 – 17:00 **Abstract N°:** 28

Color discrimination performance of genetically identified dichromatic macaques

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The analysis of color discrimination performance in dichromatic subjects has played an important role in our understanding of the color vision. Macaque monkey normally has trichromatic color vision nearly identical to that of humans and is thought to be indispensable model animal to study neural mechanisms of human color vision. In this study, we examined the properties of color discrimination behavior of the macaques with dichromatic genotype, presumably protanope (L cone missing) (Onishi *et al.* Nature 1999). Four macaque monkeys (*Macaca fascicularis*), two genetically identified protanope and two trichromats, participated in color vision test. The animals were trained an odd-one out task in which they had to discriminate a target color from two identically colored distractors that systematically differed in L and M cone color space. Color of the target was fixed across trials whereas that of distractors were changed trial by trial. Each color stimulus was composed of various combinations of lights from yellow (560 nm) and red (660 nm) LEDs that were integrated within three boxes horizontally placed at 45 mm intervals, and the light was emitted through 8 mm circular apertures on the black background. The animals responded by pressing one of three buttons, and received reward when the button corresponding to the target was pressed. Both trichromats and dichromats tended to make errors when the target and distractors had the same hue even when they had different luminances. In addition, dichromats showed substantial errors when M cone excitations were the same between the target and distractors. The behaviors of dichromats cannot be simply accounted for by the lack of L cone signals, and the results suggest that these monkeys may use some additional signals to perform fine color discrimination.

Acknowledgements: Cooperative research program of Primate Research Institute.

Abstract Nº: 29 **Saturday and Monday:** 15:00 – 17:00

Male and female differences in color categorization and color discrimination

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Studies regarding the color categorization are focused in anthropological and cognitive areas as the cultural differences of colors and the naming of the colors. The influence of the color discrimination in color categorization is few addressed. We applied the Farnsworth-Munsell (FM100 Hue) color test in 18 naive subjects (10 women, age between 19 and 24 yrs). For color discrimination, the standard arrangement of the caps in order according the color to form a regular color series (matching to sample); for categorization, the caps were randomly presented one-to-one and the task was to categorize the respective color in red, green, yellow or blue. Data were normalized and the comparison in both methods considered the gender. We found a statistical difference between color discrimination and categorization for male ($p = 0.021$). Male and female were different also for naming ($p = 0.014$). A positive correlation was found between discrimination and categorization for male ($r = 0.28$; $p = 0.007$). We conclude that male and female differ in color discrimination and categorization. For male, the color categorization is more related to the color discrimination than female.

Acknowledgements: CNPq, FAPESP

Saturday and Monday: 15:00 – 17:00 **Abstract N^o:** 30

Working memory is related to simultaneous as well as successive color constancy

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Color constancy is imperfect and shows large individual differences. In the case of successive color constancy, these individual differences are related to working memory – the ability to hold information in mind in the face of distraction. Specifically, high-working-memory observers (HighWMs) show better successive color constancy than low-working-memory observers (LowWMs), particularly when there is little contextual information in the scene (Allen *et al.*, JEP: LMC, 2011). The current study tested whether working-memory differences are related also to *simultaneous* color constancy, where successful performance depends on constructing a mental representation that discounts the illuminant, but not maintaining this representation over an extended duration. HighWMs and LowWMs saw a reference and test display simultaneously on a computer screen; the goal for each trial was to make the color of the test patch in the center of the test display appear like the color of the reference patch in the center of the reference display. In half of the trials, the (simulated) illuminant of the test display was the same as that of the reference display, and in the other half it was different. This allowed measurement of both simultaneous color constancy (different illuminants for reference and test displays) and simple color matching accuracy (same illuminants for reference and test displays). Two background conditions (chromatically uniform or complex) were employed across trials to vary the amount of contextual information in view. Overall, HighWMs showed *worse* simultaneous color constancy than LowWMs. This effect was moderated by the amount of contextual information in the scene; LowWMs' performance improved substantially in the complex-background condition, while HighWMs' performance did not differ across background conditions. Importantly, HighWMs and LowWMs did not differ in their simple color matching accuracy. These results and their implications will be discussed in relation to the previous findings for successive color constancy.

Acknowledgements: NIH grant EY-04802 to S.K.S. and an NSF CAREER award to S.L.B.

Abstract Nº: 31 **Saturday and Monday:** 15:00 – 17:00

Evaluation of a vision screener implementation of the HRR color vision plates

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In 2010, Sperian introduced the Titmus V4 stereoscopic vision screener, capable of rapidly testing a variety of dimensions of visual perception. Previous Titmus models used a slide of photographic reproductions of Ishihara plates to assess color vision. New slides are now available featuring plates with six symbols drawn from the fourth edition of the HRR pseudoisochromatic plate test. These slides were produced by a lithographic process using spot color inks individually formulated to produce protan, deutan and tritan confusions when transilluminated by the tester's standardized illuminator. Here, we evaluate the Titmus-based HRR test in comparison to the plate-based HRR, the previously available Ishihara Titmus slide, the Farnsworth-Munsell D-15 Dichotomous Color Blindness Test, and the Dvorine Pseudoisochromatic Plate Test. Test slides containing the six symbols were presented monocularly, with the same symbols arranged differently between the two eyes. Each subject was presented with two different slides with different symbol arrangements on each. Subjects included 27 individuals with red-green deficiencies and 136 with normal color vision as determined by the Nagel anomaloscope. The red-green stimuli showed remarkably high specificity and sensitivity: all normal subjects passed and all color deficient subjects who made errors on other tests failed. The Titmus test thus matched or outperformed the other color vision tests used in the comparisons. The blue-yellow stimuli also showed high sensitivity, though specificity could not be assessed due to absence of subjects with tritan deficiencies in our subject pool. Color vision testing on the Titmus instrument offers several advantages compared to plate or chip-based tests. The spectral quality, light intensity, and viewing distance are all precisely controlled, eliminating those sources of unreliability. Additionally, the HRR slides include stimuli for testing both red-green and blue-yellow color vision and the availability of alternate versions of the slides provides a method to circumvent cheating.

Saturday and Monday: 15:00 – 17:00 **Abstract Nº:** 32

Direction in the colour plane as a factor in chromatic flicker and chromatic motion

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Rapid alternation between two isoluminant hues creates a residual chromatic flicker. With hue pairs chosen to be equally subjectively dissimilar, the flicker is greater for alternation along some directions in colour space (orange / blue) than others (green / purple), suggesting an interaction between the (L-M) and S0 chromatic opponent channels (Bimler, J. Opt. Soc. Am. A 27, 2010). This phenomenon was explored systematically by choosing eight pairs of hues that cross the colour circle (i.e. diametric opposites) and using the method of paired comparisons to scale their flicker-inducing contrast. The motion-inducing contrast of the pairs was measured in the same way, i.e. the chromatic motion observed when a grating, formed from spatial alternation between two hues, drifts across the visual field. Data for border distinctness were also collected to isolate the (L-M) channel. The same 16 hues were grouped into other pairs, more tangential to the colour circle and therefore less dissimilar, which were quantified in the same way for flicker and motion contrast. Both phenomena consistently drew upon both chromatic channels, though in different proportions. Multiplexing of chromatic and temporal variation information along motion-processing pathways is discussed as a possible factor in both phenomena.

Abstract N^o: 33 **Saturday and Monday:** 15:00 – 17:00

Contrast sensitivity of human trichromats to red-green pseudo-isochromatic gratings

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The aim was to examine the variation in spatial properties of colour vision for observers with varying degrees of colour-discrimination ability. A method for measuring pseudo-isochromatic contrast sensitivity at low spatial frequencies on a standard CRT monitor was developed. The stimulus consisted of an array of spatially discrete round spots of varying size and luminance. The spots that made up the background had a single chromaticity. The spots that made up the grating had a chromaticity that was varied along the L- or M-cone axes in the CIE 1931 (x, y) chromaticity diagram with mean chromaticity set to CIE illuminant E. Luminance was set to vary between 32.0 and 48.0 cd/m^2 with average luminance of the grating and background being the same creating luminance noise. This made the grating effectively pseudo-isochromatic. Contrast sensitivities to the pseudo-isochromatic gratings were measured at 12 spatial frequencies from 0.3-3.0 c/deg for field sizes of 7 or 2° to make sure that at least four cycles were visible for each spatial frequency. Test stimuli were generated via a nVidia Quadro FX3500 graphics card and presented on a calibrated 22-inch CRT monitor (ViewSonic P227f, Walnut CA, USA). Observers were classified with a battery of colour-vision tests. Observers were corrected to best logMAR letter acuity and viewed the stimuli monocularly from a distance of 114.6 cm. Results show that both L- and M-cone contrast sensitivity functions are low-pass. The functions indicate that the limiting spatial frequency is, in most cases, around 5-6 c/deg. This is lower than that reported by Mullen (J. Physiol. 359, 381-400, 1985). The latter may be related to either greater complexity of the stimuli or that the acuity of an individual cone type (L or M) is lower than that of the red-green opponent system.

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Saturday and Monday: 15:00 – 17:00 **Abstract Nº:** 34

Is there any rule for the recognition of shadows?

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We see different opacit of shadows in our daily life, but we just recognize them as a shadow. It does not mean that the visual system ignores the visual information from shadows. In the current study, we tested whether there were any relationships between (1) surface reflectance where the shadow was cast, (2) intensity of illumination casting the shadow and (3) opacity of the shadow. The experiment was conducted in a real environment using a trapezoidal prism covered by a black cloth placed on a circular board fitted onto a table. The circular board was covered by a matt paper having a reflectance of either 9.5% or 88.3%, and illuminated by one of three intensities of a neutral illumination. Observers were asked to adjust a luminance of the shadow at (1) most plausible appearance, (2) upper limit of plausible appearance, (3) lower limit of plausible appearance as a shadow in that scene. Results indicate that in two out of four observers, the luminance of the shadow was not simply determined by the luminance contrast between the shadow area and its immediate surrounding's, but by the relationship between the shadow area and the entire scene. A model with an estimating illumination can explain the results.

Acknowledgements: Grant-in-Aid for Young Scientists 22700218, JSPS KAKENHI 20300081

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PROGRAMME

	Friday July 1	Saturday July 2	Sunday July 3	Monday July 4	Tuesday July 5
08.30–09.00	Registration desk open	Registration desk open	Registration desk open	Registration desk open	Registration desk open
09.00–10.45	Directors' committee meeting	Colour vision deficiencies: Neurological & congenital I Invited speaker *Fabriziomaria Gobba*	The Waaler symposium Invited speaker *Joel Pokorny*	Colour in context Invited speaker *Anya Hurlbert*	Ecology of colour vision Invited speaker *Daniel Osorio* 10:30–11:00 Coffee break
10.45–11.15		Coffee break	Coffee break	Coffee break	11.00–12.45 Ecology of colour vision (cont.) Physiological processes of colour vision
11.15–12.15		Colour & cone function Invited speaker *Heidi Hofer*	Colour in the periphery	Colour in context (cont.) Colour mechanisms	
12.15–12.45			Group photo		
12.45–14.00	Directors' lunch	Lunch at the college	Sunday excursion *Cruise on the Oslofjord*	Lunch at the college	ICVS 2011 closes Lunch (not included)
14.00–14.30	Opening of the Symposium	Colour vision deficiencies: Neurological & congenital II		Colour mechanisms (cont.)	
14.30–15.00	Colour vision in ageing				
15.00–15.30		Posters		Posters	
15.30–16.00	Coffee break	Coffee break		Coffee break	
16.00–16.45	Rod-Cone interaction	Posters		Posters	
17.00–18.00	Verriest Medal Lecture *Steven Shevell*	Colour applications		Colour induction & constancy	
18.00–18.30				Business meeting	
19.00–20.00	Reception *Tubaloon, Kongsberg Church Square*	Free evening			
20.00–00.00				Banquet *Silver Melting Hut, Norwegian Mining Museum*	

A piece of native wire silver from Kongsberg’s silver mines.

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