Universidade do Minho
Centro de Física

20th Symposium of the International Colour Vision Society

Abstract Booklet

24th-28th, July 2009
Braga (Portugal)

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Preface

Dear Colleagues,

It is with great pleasure that the University of Minho acts as host to the 20TH SYMPOSIUM OF THE INTERNATIONAL COLOUR VISION SOCIETY. By tradition, these meetings have enjoyed a special ambiance, blending science, culture, and stimulating discussion. We hope that this symposium continues and reinforces what has become a wonderful tradition.

The symposium has attracted senior scientists who have helped define the scientific direction of the field, but also many junior scientists and students who bring fresh enthusiasm and insight into the pleasures and diversions of research into colour vision.

The social and cultural programme will unfold in the landscapes of the Minho region and Douro valley, facilitating informal interaction between sessions and contributing to the congenial atmosphere.

We thank everyone that helped in the preparation of the symposium, in particular, our sponsors, the symposium organizers, and the ICVS officers. We wish all participants a stimulating and productive meeting and a delightful stay in Braga.

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Programme

FRIDAY, 24TH JULY

8:30-9:00 Wellcome Desk Open.

9:00-12:45 Directors' Commitee Meeting.

12:45-14:00 Directors' Lunch.

14:00-14:30 Opening of the Symposium.

Session 1

Abnormal colour vision

Moderator: **Dora Ventura.**

14:30-14:45 ***Identification of slight anomalous trichromatism with the Ishihara and American Optical Company (Hardy, Rand and Rittler) pseudoisochromatic plates***. J. Birch. ..... [**ACV1**]

14:45-15:00 ***Fluctuations in contrast sensitivity and color vision of Lebers hereditary optic neuropathy carriers***. D.F. Ventura, M. Barboni, M.F. Costa, A.L.A. Moura, M. Gualtieri, A.G.F. Oliveira, F. Sadun, A. M. DeNegri, A.Berezovsky, S.R. Salomão, V. Carelli, A.A. Sadun. ..... [**ACV2**]

15:00-15:15 ***Variability in chromatic sensitivity in normal colour vision and in congenital deficiency***. J.L. Barbur, M. Rodríguez-Carmona, J.A. Harlow. ..... [**ACV3**]

15:15-15:30 ***Psychophysical testing of peripheral color vision after low level alcohol consumption***. B.V. Nagy, I. Paniti, G. Németh, Gy. Ábrahám. ..... [**ACV4**]

15:30-16:00 **Coffe break.**

16:00-16:15 ***Differences in loss of chromatic sensitivity in various diseases of the visual pathways***. F.G. Rauscher, G.T. Plant, J.L. Barbur. ..... [**ACV5**]

16:15-16:30 ***Acquired colour vision loss in subjects with ARMD***. M. O'Neill-Biba, M. Rodríguez-Carmona, F.G. Rauscher, J.E. Wolf, J.L. Barbur. ..... [**ACV6**]

16:30-16:45 ***Dissecting the acquired component from congenital loss of chromatic sensitivity in the clinical setting***. B.H. Ridha, G.T. Plant, M. Rodríguez-Carmona, M. O'Neill, J.L. Barbur. ..... [**ACV7**]

16:45-17:00 ***Association between color vision loss and risk genotype for vascular proliferation in type 2 diabetics***. M. Gualtieri, D.M.O. Bonci, M. Neitz, J. Neitz, A.L.A. Moura, F.M. Damico, D.F. Ventura. ..... [ACV8]

Verriest Medal Lecture

17:00-18:00 ***Adventures in Mammalian Color Vision***. Gerald H. Jacobs. ..... [VML]

19:00-22:00 **Reception at the Museum Nogueira da Silva**

SATURDAY, 25TH JULY

8:30-9:00 Wellcome Desk Open.

Symposium 1

Temporal aspects of color vision

Moderator: **Andrew Stockman.**

9:00-9:30 ***Color is slow; color contrast is fast***. A.G. Shapiro. (Invited speaker). ..... [TACV1]

9:30-9:45 ***Why is colour perception slow?***. A. Stockman, H. Smithson, C. Ripamonti. ... [TACV2]

9:45-10:00 ***Color shifts induced by time-varying chromatic context: linear and nonlinear neural mechanisms***. S.K. Shevell,A. D'Antona, J.H. Christiansen. ..... [TACV3]

10:00-10:15 ***Perception of temporally-varying color depends on both monocular and binocular neural mechanisms***. A. D'Antona, J.H. Christiansen, S.K. Shevell. ..... [TACV4]

10:15-10:30 ***Temporal characteristics of the short-wavelength-sensitive cones and their associated pathways***. R.J. Lee, J.D. Mollon, Q. Zaidi, H.E. Smithson. ..... [TACV5]

10:30-10:45 ***S-cone excitation ratios for reaction times to blue-yellow suprathreshold changes at isoluminance***. J.M. Medina, J.A. Díaz. ..... [TACV6]

10:45-11:15 **Coffe break.**

Session 2

Vision in low light levels

Moderator: **Steve Buck.**

11:15-11:30 ***Rods do not signal blueness at mesopic light levels***. R.C. Baraas, L.A. Hagen, M. Neitz, J. Neitz. . . . . [VLLL1]

11:30-11:45 ***Limits of colour vision in dim light***. A. Kelber. . . . . [VLLL2]

11:45-12:00 ***Darkening $\neq$ dimming: hue shifts under objective vs. subjective decrease in colour illuminance***. G.V. Paramei, D.L. Bimler, C.A. Izmailov. . . . . [VLLL3]

12:00-12:15 ***Rod influence on appearance of desaturated hues***. S.L. Buck, C. Cunningham, R. J. DeWenter, R. Levens, A. Nguyen, C. Wurden. . . . . [VLLL4]

Invited speaker

12:15-12:45 ***Vision and the practice of making art***. B.R. Conway. . . . . [CONW]

12:45-14:00 **Lunch in the University.**

Session 3

Colour vision and aging

Moderator: **Sophie Wuerger.**

14:00-14:15 ***Selective absorption of short-wavelength light in the eye: effects of pre-receptoral filters and aging on chromatic sensitivity***. E. Konstantakopoulou, J.L. Barbur. . [CVA1]

14:15-14:30 ***Age-related contrast discrimination differences in ON and OFF pathways***. S.L. Elliot, J.S. Werner. . . . . [CVA2]

14:30-14:45 ***Colour-opponent mechanisms are not affected by sensitivity changes across the life span***. S. Wuerger, F. Chenyang, K. Xiao, D. Karatzas. . . . . [CVA3]

Session 4

Colour constancy

Moderator: **Sérgio M.C. Nascimento.**

14:45-15:00 ***Categorical colour naming of surfaces in natural scenes under different illuminations***. K. Amano, D.H. Foster. . . . . [CC1]

15:00-15:15 ***Working memory predicts individual differences in successive color constancy***. E.C. Allen, S.L. Beilock, S.K. Shevell. ..... [CC2]

15:15-15:30 ***Colour constancy in memory and the role of image integrality***. V.C. Sun, L.Y. Chu, R. Wei. ..... [CC3]

15:30-16:00 **Coffe break.**

16:00-17:00 **Posters**

Historical talk

17:00-18:00 ***Lagerlunda***. J.D. Mollon, R. Cavonius. ..... [LAG]

SUNDAY, 26TH JULY

8:30-9:00 Wellcome Desk Open.

Symposium 2

Colour vision and the statistics of natural scenes

Moderator: **David Foster.**

9:00-9:30 ***Can we understand colour processing in the visual system from the statistics of natural scenes?***. T. Wachtler, T.W. Lee, E. Doi, T.D. Albright, T.J. Sejnowski. (Invited speaker)..... [CVSNS1]

9:30-9:45 ***Adaptation to natural color environments assessed by adapting images to observers***. M.A. Webster, I. Juricevic, K. McDermott, S.M. Webster. ..... [CVSNS2]

9:45-10:00 ***The contribution of color to detecting edges in natural scenes***. T. Hansen, K. R. Gegenfurtner. ..... [CVSNS3]

10:00-10:15 ***Color is not an efficient carrier of information in natural images***. M.M. Del Viva, G. Punzi, S.K. Shevell. ..... [CVSNS4]

10:15-10:30 ***Modelling human discrimination of suprathreshold chromatic changes in natural scenes using a visual-cortex model***. D.J. Tolhurst, T. Troscianko, P.G. Lovell, I.D. Gilchrist, M. To. ..... [CVSNS5]

10:30-10:45 ***Using colour as a label in natural scenes***. D.H. Foster, I. Marín-Franch, K. Amano, S.M.C. Nascimento. ..... [CVSNS6]

10:45-11:15 **Coffe break.**

Session 5

S-cone function

Moderator: **Rigmor Baraas.**

11:15-11:30 ***Contribution of melanopsin-expressing retinal ganglion cells to pupillary control pathway studied with a receptor-silent substitution technique***. S.I. Tsujimura, K. Ukai, A. Nuruki, K. Yunokuchi. . . . . [**SF1**]

11:30-11:45 ***The effect of controlled photopigments excitations on pupil aperture***. F. Viénot, S. Bailacq, J. Le Rohellec. . . . . [**SF2**]

11:45-12:00 ***S-cone pathway contribution to depth perception***. M.F. Costa, S.M.C.F. Moreira, D.F. Ventura. . . . . [**SF3**]

12:00-12:15 ***Hue perception is mediated by pathways in which S cone signals are combined with M vs L at the first synapse in the retina***. J. Neitz, K. Mancuso, T.B. Connor, M.C. Mauck, J. Kuchenbecker, M. Wagner-Schuman, A. Salzwedel, M. Neitz. . . . . [**SF4**]

Sunday excursion

12:15-22:00 **Douro cruise, visit to port wine farm and dinner**

MONDAY, 27TH JULY

8:30-9:00 Wellcome Desk Open.

Symposium 3

Genetics and pigments

Moderator: **James K. Bowmaker.**

9:00-9:30 ***Evolution and spectral tuning of vertebrate visual pigments***. D.M. Hunt. (Invited speaker). . . . . [**GP1**]

9:30-9:45 ***Tuning cichlid fish visual sensitivities using differential gene expression and coding sequence evolution***. K.L. Carleton, C. M. Hofmann, K. E. O'Quin, N. J. Marshall, T.W. Cronin, O. Seehausen. . . . . [**GP2**]

9:45-10:00 ***The molecular genetics of color and polarization vision in stomatopod crustaceans***. T.W. Cronin, M.L. Porter, M. Bok, P.R. Robinson. . . . . [**GP3**]

10:00-10:15 ***Signals in light of visual perception: a study of opsin evolution in New World warblers***. N. Bloch, T. Price. . . . . [GP4]

10:15-10:30 ***Epigenetic control of expression of the human L- and M- pigment genes***. S.S. Deeb, D. Bisset, L. Fu. . . . . [GP5]

10:30-10:45 ***Evolutionary origin of high frequency deleterious mutations in the human cone opsins and their role in the most common eye disorders***. M. Neitz, J. Carroll, K.L. Gunther, J. Neitz. . . . . [GP6]

10:45-11:15 **Coffe break.**

Session 6

Colour mechanisms

Moderator: **Ken Knoblauch.**

11:15-11:30 ***Costs and benefits of higher-order color mechanisms***. Q. Zaidi. . . . . [CM1]

11:30-11:45 ***Adaptation of higher order colour mechanisms***. R.J. Lee, J.D. Mollon, Q. Zaidi, H.E. Smithson. . . . . [CM2]

11:45-12:00 ***A performance measure that tracks the yellow-blue line***. M.V. Danilova, J.D. Mollon. . . . . [CM3]

12:00-12:15 ***Do color naming functions predict unique hue loci?***. V.J. Volbrecht, L.S. Baker, A.R. Trujillo, J.L. Nerger. . . . . [CM4]

Invited speaker

12:15-12:45 ***Evolutionary photonics: natural designs for manipulating the flow of light and colour***. P. Vukusic. . . . . [VUK]

12:45-14:00 **Packed lunch in the University.**

Session 7

Peripheral chromatic mechanisms

Moderator: **Barry Lee.**

14:00-14:15 ***Waveguide contribution to the spectral sensitivity of human cones***. M. Vorobyev, L. Fischer, A. Zvyagin, T. Plakhotnik. . . . . [PCM1]

14:15-14:30 ***Distribution and topography of the ganglion cells and displaced amacrine cells in the howler monkey retina (Alouatta caraya)***. L.M. Athaide, J.A.P.C. Muniz, B.D. Gomes, B.L. Finlay, L.C.L. Silveira. . . . . [**PCM2**]

14:30-14:45 ***ERG signals driven by magno- and parvocellular pathways. Variable chromatic and luminance stimulus contents***. J. Kremers, A.R. Rodrigues, L.C.L. Silveira, M. da Silva Filho, G. Pangeni. . . . . [**PCM3**]

14:45-15:00 ***A new view of receptive field structure of midget ganglion cells***. B.B. Lee, H. Sun, D. Cao. . . . . [**PCM4**]

15:00-15:15 ***L- and M-cone input to human ERGs as a function of retinal eccentricity***. N.K. Challa, D. J. McKeefry, N.R.A. Parry, J. Kremers, I.J. Murray, A. Panorgias. . . . . [**PCM5**]

15:15-15:30 ***Contribution from M and P pathways to the contrast sensitivity of pattern transient VEP components***. L.C.L. Silveira, G.S. Souza, B.D. Gomes, E.M.C.B. Lacerda, C.A. Saito, M. da Silva Filho. . . . . [**PCM6**]

15:30-16:00 **Coffe break.**

Session 8

Red-green deficiencies

Moderator: **Keiji Uchikawa.**

16:00-16:15 ***Quantitative assessment of commercial filter 'aids' for red-green colour defectives***. J.D. Moreland, S. Westland, V. Cheung, S.J. Dain. . . . . [**RGD1**]

16:15-16:30 ***Unilateral colour vision defects and the dimensions of dichromat experience***. J. Broackes. . . . . [**RGD2**]

16:30-16:45 ***Red-green dichromats' Basic Colour term use: confusion lines and red-green residual activity***. J. Lillo, H. Moreira, L. Alvaro, I. Davies. . . . . [**RGD3**]

16:45-17:00 ***Categorical color mechanisms of dichromats revealed by color naming and color memory***. K. Uchikawa, H. Nishita. . . . . [**RGD4**]

17:00-18:00 **Posters.**

18:00-18:30 **Business meeting.**

20:00-22:00 **Banquet.**

TUESDAY, 28TH JULY

8:30-9:00 Wellcome Desk Open.

Symposium 4

Seeing coloured "stuff": surfaces, textures, patterns and materials

Moderator: **Qasim Zaidi.**

9:00-9:30 ***Simulating the appearance of natural materials***. H.W. Jensen. (Invited speaker). [**SCSS1**]

9:30-9:45 ***What is the purpose of color for living beings?. A theory of color organization***. B. Pinna, J.S. Werner. . . . . [**SCSS2**]

9:45-10:00 ***Material hue vs. lighting hue***. R. Tokunaga, A.D. Logvinenko. . . . . [**SCSS3**]

10:00-10:15 ***What kinds of contours bound the reach of filled-in color?***. C. Feitosa-Santana, A. D'Antona, S.K. Shevell. . . . . [**SCSS4**]

10:15-10:30 ***Image reconstruction in a color mosaic with random arrangement of chromatic samples***. D. Alleysson, B.C. de Lavarène. . . . . [**SCSS5**]

10:30-10:45 ***The effects of chromatic heterogeneity and spatial blocking on Glass Pattern detectability***. K. Knoblauch, E. Mahler, M. Dojat. . . . . [**SCSS6**]

10:45-11:15 **Coffe break.**

Session 9

Effects of colour and luminance contrast

Moderator: **Baingio Pinna.**

11:15-11:30 ***Colour and luminance contrast in depth perception***. M. Ozolinsh, I. Martín, M.C.Puell. . . . . [**ECLC1**]

11:30-11:45 ***Feature misbinding of color and motion increases with degree of shared shapes***. Y. Sun, S.K. Shevell. . . . . [**ECLC2**]

11:45-12:00 ***The contribution of human cortical area V3A to the perception of chromatic motion: an rTMS study***. D.J. McKeefry, M.P. Burton, A.B. Morland. . . . . [**ECLC3**]

12:00-12:15 ***Effect of colour discrimination on spatial contrast sensitivity***. L.A. Hagen, R.C. Baraas. . . . . [**ECLC4**]

12:15-12:30 ***Perceptual memory for intermittent, color rivalrous images***. P. Kang, S.K. Shevell. . . . . [**ECLC5**]

12:30-12:45 ***Object substitution masking in localization and color discrimination tasks***. S. Mereu, M. Casagrande. . . . . [**ECLC6**]

12:45-13:00 **Closing of the meeting.**

Poster Sessions

16:00-17:00 Saturday 25th, July.
17:00-18:00 Monday 27th, July.

Verriest Medal Winner 2009

Prof. Gerald H. Jacobs, Ph.D

The International Colour Vision Society (ICVS) is pleased to announce that the 2009 Verriest Medal will be awarded to Gerald H. Jacobs at the 20th Symposium of the Society to take place at the University of Minho, Braga, Portugal (July 24-28th, 2009). This award was established in 1991 in memory of the founding member of the Society, Dr. Guy Verriest, and honors outstanding contributions in the field of color vision.

Over the last 45 years, Professor Jacobs has authored more than 200 papers related to color vision. His discoveries have provided a basis for understanding the underpinnings of human color vision within the larger context of the evolution of the mammalian visual system. Professor Jacobs is a member of the Neuroscience Research Institute and the Department of Psychology at the University of California in Santa Barbara, where he has taken an interdisciplinary approach to characterizing the nature and distribution of the cone photopigments within and across mammalian species and understanding how variations in photoreceptor complement relate to differences in color vision capacity. Widely recognized as a leader among his generation of vision scientists, Professor Jacobs has been an inspiring mentor for generations of scientists who have shared his passion for understanding the diversity color vision in our world.

Abstracts-Oral Sessions

Friday, 24th July

Identification of slight anomalous trichromatism with the Ishihara and American Optical Company (Hardy, Rand and Rittler) pseudoisochromatic plates

ACV1

J. Birch[1]

[1]*Henry Wellcome Research Laboratories, Optometry Department, City University, London EC1V OHB.*

Pseudoisochromatic tests are widely used to identify abnormal red-green colour vision. Screening efficiency depends on design parameters and pass/fail criteria. The aim of this review is to document the number of errors made on the 16 Transformation and Vanishing screening designs of the 38 plate Ishihara test and on the America Optical Company (Hardy, Rand and Rittler) test by people with slight colour deficiency. All the HRR plates have Vanishing designs. Results obtained by 486 male anomalous trichromats, identified with the Nagel anomaloscope, were abstracted from files held in a Colour Vision Advisory Clinic. A total of 66 subjects (13.6%) made 8 errors or less on the Ishihara test. These included 61 of 416 deuteranomalous trichromats (15%), mean anomaloscope matching range 6.5 scale units, and 5 of 70 protanomalous trichromats (7%), mean anomaloscope matching range 5 scale units. Twenty five subjects (5.3%) made 5 errors or less. Eight deuteranomalous trichromats made fewer than 3 errors and may not have been identified as colour deficient. A total of 23 subjects (4.7%) made no error on the HRR screening plates and 12 subjects failed to see one figure which is allowed to people with normal colour vision. As a result 35 subjects (7%) would not have been identified as colour deficient (2 protanomalous and 33 deuteranomalous trichromats). Three errors is the recommended fail criterion for the AO HRR and the Richmond 2002 HRR because this gives 100% specificity. Fourteen percent of subjects, including 20% of deuteranomalous trichromats, would have passed using this criterion. These data show that identifying abnormal colour vision is test specific and that fail criterion based on a specific number of errors can influence the estimated prevalence of red-green colour deficiency in population studies and compromise understanding of genotype / phenotype relationships.

ACV2 Fluctuations in contrast sensitivity and color vision of Leber's hereditary optic neuropathy carriers

D.F. Ventura[1], M.T. Barboni[1], M.F. Costa[1], A.L.A. Moura[1], M. Gualtieri[1], A.G.F. Oliveira[1], F. Sadun[2], A.M. DeNegri[3], A. Berezovsky[4], S.R. Salomão[4], V. Carelli[5], A.A. Sadun[6]

[1]*Dept. of Experimental Psychology, University of São Paulo, São Paulo, Brazil.*

[2]*Ospedale S. Giovanni Evangelista, Tivoli, Italy.*

[3]*Azienda Ospedaliera S. Camillo-Forlanini, Rome, Italy.*

[4]*Federal University of São Paulo, São Paulo, Brazil.*

[5]*University of Bologna, Bologna, Italy.*

[6]*Keck School of Medicine, University of Southern California, Los Angeles, CA.*

LHON is caused by a mitochondrial DNA mutation that leads to sudden irreversible loss of central vision. Visual alterations may be present in asymptomatic carriers. We report a longitudinal study measuring color vision and contrast sensitivity (CS) in LHON carriers. Methods. Forty four LHON carriers were tested yearly (2003-2008) and their thresholds were compared to norms. Color discrimination was assessed along the protan, deutan and tritan axes with the Cambridge Color Test (CCT). Luminance CS was measured with a checkerboard stimulus at two spatial frequencies (0.5 and 4.5 cpd), presented at 33 and 1500 ms. Results. Color discrimination was impaired in 47% of the carriers in 2003: 39% in the protan axis, 37% in the deutan and 14%, in the tritan. Over successive years, thresholds changed in 25/44 subjects, improving to normality in 25%, becoming abnormal in 16% and fluctuating from normal to abnormal in 16%. Spearman correlations of protan thresholds, compared year by year, and the same for deutan and tritan, were close to zero in 7 of 12 comparisons. For CS, in the comparison over successive years, thresholds changed in 52% of subjects, having improved to normality in 25%, became abnormal in 11% and fluctuated between normal and abnormal in 17%. Spearman correlation coefficients for CS thresholds were close to zero in the comparison between the three successive years for all measurement conditions. Conclusion. There are large fluctuations of visual performance in over half of the LHON carriers, possibly caused by changes due to environmental stresses. We believe that these changes could be associated with structural compensations (nerve fiber layer swelling and microangiopathy). If the compensatory structural changes are inadequate or environmental stresses excessive, the LHON carrier may develop the severe optic neuropathy associated with LHON affected patients.

Support: FAPESP, CNPq, IFOND

Variability in chromatic sensitivity in normal colour vision and in congenital deficiency

ACV3

J.L. Barbur[1], M. Rodríguez-Carmona[1], J.A. Harlow[1]

[1]*Applied Vision Research Centre, The Henry Wellcome Laboratories for Vision Sciences, City University, London UK.*

We examined the inherent variability in chromatic sensitivity in relation to Rayleigh matches (under dark field conditions) and measurements of red/green (RG) colour thresholds in normal and colour deficients, when adapted to daylight (D65). The existence of variant L and M cone pigment genes within normal trichromats and the consequent variation in peak wavelength separation remains largely undetected both in Rayleigh match parameters and in colour detection thresholds. The Nagel anomaloscope matches were modeled to predict how the wavelength of peak sensitivity and optical density of cones and the noise amplitude in the RG channel affect the midpoint and the matching range (Barbur, Rodriguez-Carmona, *et al*., 2008: *Vis.Neurosci.* 25 (3):507-516). The model predicts well the variability in Nagel parameters observed in normal trichromats and also in colour deficients. The predictions include the observed lack of correlation between match midpoint and matching range in normal subjects, the normal matching range values measured in many deuteranomalous and protanomalous observers and the normal match midpoint and range observed in some subjects with chromatic sensitivity typical of minimal deuteranomaly. The size of the matching range shows no correlation with the subject's light-adapted, RG thresholds. In order to account for these findings we modeled RG chromatic sensitivity thresholds using two sources of noise. The model assumes that the first source of noise is subject-specific and related to the relative numbers of L and M cones in the retina. This we label as cone photoreceptor signal amplification noise which limits chromatic sensitivity under dark field conditions (typical of anomaloscope matches). The second source of noise, the "neural" noise is assumed to be the same for all subjects and limits chromatic sensitivity when the retina is light adapted. These findings suggest that different factors affect the subject's chromatic sensitivity in the two conditions and explain why the anomaloscope matching range fails to predict the subject's chromatic sensitivity under more natural conditions of light adaptation.

Supported by the Civil Aviation Authority (UK), grant number 474/SRG/R.

ACV4 Psychophysical testing of peripheral color vision after low level alcohol consumption

B.V. Nagy[1], I. Paniti[1], G. Németh[1], Gy. Ábrahám[1]

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Alcohol consumption is a major hazard in driving accidents. This is one reason why several effects of alcohol on human perception and reaction have been investigated and reported. However there is one factor which scientific literature does not agree upon. This is the effect of low level alcohol consumption on the peripheral vision. Former psychophysical tests have shown reduction in achromatic flickering pattern recognition towards the periphery after low level alcohol consumption (Moskowitz, 1976) while other studies didn't confirm the significance of this (Quintyn, 1995). Moreover the application of chromatic targets is generally neglected. Our research, supported by the National Police of Hungary was aimed to measure the effect of alcohol consumption on the human peripheral vision with chromatic stimuli commonly used in traffic signals. We have built a flat perimetry based test equipment using a software controlled DLP projector. The field of view of ten subjects with normal color vision were tested monocularly with three different color stimuli at seven viewing angles in five different low level alcohol consumption states checked by a calibrated alcohol probe. Effects of stimulus size, luminance and target speed were also measured and considered in the setup. The test results have shown decrease in the FOV at the maximum alcohol consumption level (0.205 mg/l) compared to the sober state. However higher significance in the differences were only found at viewing angles less than 60^o at red ($p<0.05$), green ($p<0.05$) and yellow ($p<0.1$) stimuli. Differences at viewing angles above 60^o could not be considered significant. Based on the test results we can conclude that alcohol consumption has significant effect on specific areas of peripheral color vision. Therefore beside alcohol's known effects on human performance (ie. reaction time, loss of concentration, etc.) the change in the FOV also shall be considered while driving.

Differences in loss of chromatic sensitivity in various diseases of the visual pathways

ACV5

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Chromatic sensitivity was measured at the fovea and in each of the four quadrants (6 deg) in 59 patients with specific diseases of the visual pathways. The CAD test was used to measure yellow/blue (YB) and red/green (RG) colour detection thresholds. Results were analysed separately for each location tested and compared against age matched normal data. Pregeniculate conditions cause symmetric loss in chromatic sensitivity in either one or both channels. Glaucoma and hypertension tend to cause symmetric YB loss for early glaucomatous damage and greater RG loss at later stages of the disease. Chromatic loss often precedes visual field loss and it may well be the case that measurement of peripheral chromatic discrimination may predict future glaucomatous damage. Optic nerve and chiasmal lesions exhibited symmetric loss to the RG channel with some additional loss of YB sensitivity in some patients. Postgeniculate lesions can cause either symmetric or asymmetric loss depending on the location and extent of the lesion. In patients presenting with 'occipital' or 'occipital and cortical damage' (striate or extra-striate lesions) colour vision was either completely damaged or asymmetrically affected. On the other hand, patients with radiation damage, i.e. prestriate loss, presented with symmetric damage (mainly RG). Cortical cases show symmetrical loss if an earlier pathway is damaged at the same time; only localised cortical damage caused asymmetric loss. Colour specific losses were found to be location specific. Asymmetric colour loss affecting one single colour category differs from general knowledge in the literature where colour vision can be affected in certain conditions, but a symmetric overall loss is usually reported. These observations suggest that selective damage to V1 and early extrastriate visual areas that exhibit good topographic representation of the visual field can cause hue specific losses which implies independent coding of hue specific signals in these areas.

ACV6 Acquired colour vision loss in subjects with ARMD

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ARMD is a slow, degenerative disease that produces gradual structural changes in the retina causing deterioration of vision and blindness. It is caused by changes in the metabolic state of the retina, resulting in non-inflammatory damage to retinal structures. These changes occur gradually over time and often cause measurable loss of visual performance well before structural changes can be detected reliably using current fundus imaging methods. The aim of this study was to examine the extent to which changes in chromatic and rapid flicker sensitivity can be used to screen for ARMD and to quantify these changes in varying stages of the disease. Asymptomatic subjects and ARMD patients with varying degrees of retinopathy were examined. Chromatic sensitivity was assessed under photopic and high mesopic lighting using the Colour Assessment and Diagnosis (CAD) test *(1)*.We measured both red/green (RG) and yellow/blue (YB) chromatic sensitivity. Similar data measured in 330 normal trichromats provide the statistical limits for RG and YB chromatic sensitivity that define the normal range *(2)*. Achromatic high contrast acuity and flicker sensitivity were also assessed. The results reveal significant loss of RG and YB chromatic sensitivity which in the case of ARMD affects both central and peripheral retina and is not localised to the site of retinopathy (the statistical significance of these changes varies from subject to subject with p values < 0.001). Results also reveal a positive correlation between the degree of retinopathy and increased loss of chromatic sensitivity. Significant loss of rapid flicker sensitivity ($p < 0.01$) was also observed in all subjects diagnosed with ARMD. Preliminary results suggest that the loss of chromatic and flicker sensitivity precedes structural changes in the retina as revealed in conventional fundus imaging. These findings suggest that changes in chromatic and rapid flicker sensitivity can provide sensitive indicators of early retinal changes that lead to retinopathy.

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(2). Rodriguez-Carmona M, Harlow AJ, Walker G, Barbur JL. The Variability of Normal Trichromatic Vision and the Establishment of the 'Normal' Range. *Proceedings of 10th Congress of the International Colour Association*, Granada (Granada, 2005) 2005; 979-982.

Dissecting the acquired component from congenital loss of chromatic sensitivity in the clinical setting

ACV7

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Congenital colour anomaly (Daltonism) affects $\sim$ 8% of men. The most common type is red-green deficiency. Optic nerve or retinal disease can cause either transient or permanent loss of chromatic sensitivity. Daltonism is difficult to assess clinically when acquired deficiency is also present. Pseudo-isochromatic tests (e.g., the Ishihara plates) are the most common clinical tools for assessing colour vision deficiencies. In the case of the Ishihara the first plate and the following 16 pseudo-isochromatic plates are routinely used, while the anomalous colour plates are rarely used. In this study we examine the use of the anomalous test plates in patients with Daltonism when acquired loss of chromatic sensitivity is also involved. Ten patients with Daltonism developed asymmetric optic nerve or retinal disease (optic neuritis, non-arteritic ischaemic optic neuropathy, maculopathy with cone dysfunction). In each patient, there was asymmetry in the ability to read the anomalous colour plates: 2-4/4 in the unaffected or less affected eye; 0-2/4 in the more affected eye. Although relatively crude and qualitative, the anomalous test plates can be used efficiently in a clinical setting to screen for acquired and often asymmetric disease over and above congenital colour anomaly. A number of patients have been examined further using the Colour Assessment and Diagnosis (CAD) test (*Proc.R.Soc.Lond.B*. 258 (1353):327-334). The results show that the selection of appropriate parameters for the CAD test reveal the presence of acquired loss of chromatic sensitivity in patients with Daltonism. The technique exploits the differences in the pattern of loss observed in congenital and acquired deficiencies and the dependence of chromatic sensitivity loss on stimulus size and location in the visual field.

ACV8 Association between color vision loss and risk genotype for vascular proliferation in type 2 diabetics

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Color vision is affected in diabetics, in many cases prior to diabetic retinopathy. The mechanisms for this loss and their relation to development of retinopathy remain unclear. Risk for the development of diabetic retinopathy has been associated to genetic markers for the expression of erythropoietin (EPO), with higher risk linked to the homozygous TT genotype and lower risk to the GG genotype. Here, we investigate the relationship between the EPO expression genotypes and color discrimination in type 2 diabetics without retinopathy. Discrimination thresholds along the protan, deutan and tritan axes, as well a MacAdam ellipse at CIE coordinates u' = 0.1977 v'= 0.4689 were measured in 21 patients, using the Cambridge Colour Test (Cambridge Research Systems, Ltd). The EPO markers were identified by direct sequencing from blood sample DNA. Eight patients were homozygous for the risk genotype TT, 4 had the protective genotype GG, and 9 patients were heterozygote. The color vision outcome from the patients TT TG patients was consistently worse than for the GG genotype in all the parameters measured. Mean protan, deutan and tritan thresholds ($u'v'$ $*10^4$) were 88$\pm$13, 111$\pm$21 and 152$\pm$21 for TT carriers; 125$\pm$17, 122$\pm$29 and 253$\pm$31 for TG carriers and 64$\pm$4, 53$\pm$13 and 109$\pm$13 for GG carriers. Our results suggest association between genetic markers for retinal vascular proliferation and pre-retinopathic color vision loss. The association between losses of a highly sensitive functional parameter and risk genotypes may provide valuable information for early detection and clinical management of patients more susceptible to diabetic visual damage.

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Adventures in mammalian color vision

VML

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The past half century has witnessed remarkable progress in our understanding of the nature of color vision. This change reflects the development of many new technical tools as well as novel ways of thinking about old problems, but it also has been significantly aided by an expansion of the focus of attention from a handful of select species to include many others. I will draw on a few such examples to provide a retrospective on this aspect of the story.

Saturday, 25th July

Color is slow; color contrast is fast

TACV1

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The visual response to chromatic modulation is often thought to be slow: typically, chromatic modulation thresholds at 10 Hz are about eight times higher than thresholds at 1 Hz. However, a number of studies have shown that the visual system can adapt perfectly well to fast chromatic contrast (>10 Hz) and that neurons in area V1 can respond to fast chromatic contrast modulation. To account for these (and other) findings, Shapiro (2008, *Journal of Vision* 8/1/8, 1-18) proposed a model that explicitly incorporates separate color and color contrast pathways. At an intuitive level, the model recognizes an observer's ability to perceive both the color of a patch and the color contrast of the patch relative to the surrounding field. In this presentation, I will give further demonstrations that support the existence of a separate rectified color contrast pathway; I will show that some classic temporal sensitivity measurements can be reinterpreted within the dual pathway framework; and I will discuss the dual pathway model in light of some recent physiological findings (Liu and Wandell, 2005, *Journal of Neuroscience*, 25, 3459-3468; Johnson, Hawken and Shapley, 2008, *Journal of Neuroscience*, 28, 8096-8106) that indicate at least two separable color responses at the level of the cortex. An important question is whether these separable color responses originate at the cortical level (the slow "color" response being derived from the fast color-contrast response) or whether the two responses originate in the retina, as might be suggested by a rectified chromatic response in the M ganglion cells (Lee and Sun, 2009, *Journal of Vision*, 9/2/15, 1-18).

TACV2 Why is colour perception slow?

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It is well known that chromatic perception is "slow". For instance, chromatic flicker produced by the alternation of coloured lights fades to achromatic as their alternation rate is increased. Chromatic mechanisms have a characteristically lowpass temporal frequency response (one that falls monotonically with frequency) with a poor response to higher temporal frequencies compared with the luminance mechanism, which has a characteristically bandpass response (one that peaks in sensitivity at an intermediate frequency). The greater chromatic sensitivity loss with increasing frequency is generally assumed to reflect greater temporal integration within chromatic mechanisms. However, the loss might be consistent with a limit in the rate at which chromatic mechanisms can signal changes in hue. That is, chromatic mechanisms might be "slew-rate-limited". Seemingly consistent with this view are the results of series of experiments in which observers were presented with M- and L-cone-isolating sawtooth stimuli that could be either rapid-on (slowly-off) or rapid-off (slowly-on). Between about 6 and 13-Hz rapid-on-L-cone and rapid-off-M-cone sawtooth stimuli appear greener, while rapid-off-L-cone and rapid-on-M-cone sawtooth stimuli appear redder, even though they have the same mean chromaticities. These changes can be explained by supposing that slew-rate-limited chromatic mechanisms can track the slowly changing part of the sawtooth better than the quickly changing part-with the result that their mean output is always skewed in the direction of the slow change. More formal measurements of the detection of the coloured offset as a function of sawtooth modulation depth and as a function of sawtooth slope yield experimental data with which we can test the slew-rate model. The predictions of the slew-rate model are complex. In its simplest from, the model predicts a *bandpass* chromatic response with a precipitous loss of high frequency sensitivity, which is inconsistent with the lowpass characteristics of chromatic mechanisms.

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Color shifts induced by time-varying chromatic context: linear and nonlinear neural mechanisms

TACV3

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In natural viewing, an object often is seen against a chromatic background that varies in space and time. Spatially complex backgrounds have been studied extensively since the 'Mondrian' experiment of McCann, McKee & Taylor (1976); temporally varying backgrounds, however, have received much less attention, despite the intriguing and now classical report that a temporally varying chromatic surround at a relatively low frequency (∼4 Hz) is seen to fluctuate in color itself but does not induce temporally varying color changes within a central test field (DeValois, Webster, DeValois, & Lingelbach, 1986). The standard explanation is a cortical linear temporal filter that attenuates the chromatic inducing signal above 4 Hz. Experiments reviewed here require revising this account to include a nonlinear neural response and two linear temporal filters, one prior to and another following the nonlinear mechanism. The first linear filter is within pathways that maintain nearly independent l=L/(L+M) and s=S/(L+M) responses; the second linear filter acts on a higher-order chromatic representation that combines l and s responses. Experimental evidence includes (i) for a surround at temporal frequency f well above 4 Hz, a steady induced color shift that differs from the induced shift with a steady surround at the temporally-averaged surround chromaticity; (ii) for a surround modulated simultaneously at two temporal frequencies f_1 and f_2 both above 4 Hz, induced temporal variation within the central-test color at (iii) perceived temporal frequency $|f_1 - f_2|$; (iv) for a 6 Hz chromatic surround that varies simultaneously along both l and s, a steady induced color shift that is altered by changing the relative phase of l and s stimulation (that is, simultaneous chromatic surround modulation from $+l$ to $-l$ and $+s$ to $-s$, with $+l$ coincident with $+s$ compared to $+l$ coincident with $-s$).

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TACV4 Perception of temporally-varying color depends on both monocular and binocular neural mechanisms

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The perceived color of light in one region of visual space depends on light in surrounding regions. Perception of a central light that varies in chromaticity over time is strongly affected by a temporally-varying chromaticity in the surround. Both monocular and binocular neural processes are shown here to mediate the percept of the central temporally-varying light. METHODS: Observers viewed a central test stimulus (1 deg diameter) with the l chromaticity of Macleod-Boynton space varying over time. This stimulus had a surround (6 deg diameter) that also varied in l chromaticity at the same temporal frequency. Center and surround were separated by a thin dark gap (0.2 deg) and were either presented to the same eye (monocular condition) or to opposite eyes (dichoptic condition) at the same frequency (3.125, 6.25, or 9.375 Hz). Relative phase between center and surround was varied. Observers adjusted the modulation depth of a separate temporally-varying field to match the perceived modulation depth in the central test area. RESULTS & CONCLUSIONS: In both the monocular and dichoptic conditions, the perceived modulation depth of the central light depended on the relative phase of the surround; this could be modeled as a linear combination of center and surround modulation. At the lowest temporal frequency, 3.125 Hz, the surround's influence was virtually the same for monocular and dichoptic conditions, suggesting at this temporal frequency that the surround influence was mediated by only a binocular neural mechanism. At the two higher frequencies, the surround's influence was greater for the monocular condition than the dichoptic condition, and this difference increased with temporal frequency. These results are consistent with a linear combination of responses from two separate neural mechanisms that mediate the influence of the surround, one binocular and dominant at lower temporal frequencies (<4Hz) and one monocular and predominant at higher temporal frequencies (6-10Hz).

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Temporal characteristics of the short-wavelength-sensitive cones and their associated pathways

TACV5

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Many morphologically and functionally distinct retinal ganglion and LGN cell types have been characterised, several of which have opponent cone inputs and so may carry chromatic information. Of interest are the asymmetries in LGN cells carrying S-cone signals: S+ signals are opposed by (L+M), whereas L+ signals are opposed by (S+M), giving -S+L-M (Tailby *et al*., 2008, *J. Neuroscience*). The traditional model of opponent colour processing, however, assumes that chromatic information is transmitted to the brain in just two independent pathways: one encoding [L-M] cone responses, and the other encoding [S-(L+M)] responses. We challenge the predictions of this model in a psychophysical task. Simultaneous sinusoidal modulations of L-M and S-(L+M) result in procession around an elliptical locus in the MacLeod-Boynton chromaticity diagram, with eccentricity dependent on the relative phase of the modulations. Under conditions in which the visited hues fall on a circular locus at 10Hz, observers can discriminate clockwise and counterclockwise processions, which implies that the loci are distorted by neural delays prior to the site of combination of the component modulations (Stromeyer *et al*., 1991, *Vis. Res.*). Indeed, there is independent evidence that S-cone signals arrive at a central site some milliseconds after L-M signals. Introducing a physical delay renders clockwise and counterclockwise processions indiscriminable. Conversely, when we use component modulations intermediate to the cardinal mechanisms we find no physical delays at which discrimination is impossible. Our results support the classical model in which chromatic information is carried to a central site by only two independent mechanisms. Comparing our data to simulations suggests that -S+L-M signals do not provide an additional dimension that supports discrimination of hue loci. We estimate a delay in the S-cone pathway of 12ms relative to L-M opponent modulations, but cannot say exactly where this delay arises.

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TACV6 S-cone excitation ratios for reaction times to blue-yellow suprathreshold changes at isoluminance

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Reaction time (RT) can be defined as the latency from the onset of a test stimulus until the execution of a motor response. In colour vision, the measurement of RT as a function of suprathreshold contrast increments and decrements has provided valuable information on the neural conduction time through different pathways from retina to cortex (Díaz, Jiménez del Barco, Jiménez & Hita, 2001, *Color Research & Application*, 26, 223-233; McKeefry, Parry & Murray, 2003, *Investigative Ophthalmology & Visual Science*, 44, 2267-2276). Although previous studies have examined alternative metrics to scale achromatic increments and decrements in both fovea and periphery (Zele, Cao & Pokorny, 2007, *Vision Research*, 47, 608-611; Vassilev, Murzac, Zlatkova & Anderson, 2009, *Vision Research*, 49, 524-529), the existence of an appropriate metric at isoluminance is an open issue. Here we examined RT for blue and yellow changes at isoluminance as a function of the Weber contrast, multiples of the detection threshold and the S-cone excitation ratio between the test stimulus and the background. Isolation of the blue-yellow mechanism was done by heterochromatic flicker photometry. Equiluminance was established by an achromatic (x=0.332, y=0.333) and chromatic (x=0.442, y=0.290) reference stimuli. Stimuli were presented at fovea. They were selected in the CIE-1931 chromaticity diagram along two different blue-yellow confusion lines, each one having a different luminance value (15 cd/m^2 and 12 cd/m^2). The hue-substitution method was used to measure RT at isoluminance in four normal observers (two of them for each confusion line). Mean RTs as a function of different metrics were fitted using Piéron-type functions. Our results show that S-cone increments and decrements at isoluminance equate better when using the S-cone excitation ratio. We propose a RT model that combines this metric with the notion of information processing and threshold units.

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Rods do not signal blueness at mesopic light levels

VLLL1

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It has long been assumed that rods elicit the sensation of blue at low levels of luminance. (e.g. Trezona, 1970, *Vision Research*, 10, 317-332). Here three observers (24, 34 and 36 yr), all of whom were heterozygous for a novel S-opsin mutation (I190T), were tested with the Cambridge Colour Test (Regan *et al*., 1994, *Vision Research*, 34, 1279-1299) at different levels of retinal illuminance. Their results were compared with those of a group of healthy normal trichromatic females (all younger than 40 yr). The trivector test, which measures sensitivity along the protan, deutan and tritan confusion axes, was presented on a calibrated CRT monitor controlled by a computer graphics system. The vector length was extended to maximum achievable for the monitor along the tritan axis (0.1650 units in CIE *u'*, *v'* space). Observers were tested monocularly with their preferred eye. They viewed the monitor through an artificial pupil of 2.8 mm from a distance of 3.1 m, where the gap in the Landolt-C subtended 1 deg. Cone-plateau thresholds were obtained after bleaching with a tungsten-halogen lamp covered by a large diffuser (33 000 Td) for 1 min, followed by a 4 min waiting period before testing for 3 min. Dark-adapted thresholds were obtained after dark adaptation for 30 minutes. Thresholds were measured at least twice at two different retinal illuminance ranges: 16-118 Td and 1.6-12 Td. The lowest illuminance level was obtained by adding a 1.0 ND filter in front of the eye. The performance of observers with the I190T mutation was significantly different from that of normal trichromats along the tritan vector at all conditions tested: they behaved as mild tritans at 16-118 Td, but as tritanopes at 1.6-12 Td, for both cone-plateau and dark-adapted conditions. The results imply that S-cones, and not rods, are responsible for signalling blueness at low mesopic light levels.

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VLLL2 Limits of colour vision in dim light

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Humans and most vertebrates loose colour vision when night falls and rely on colour-blind rod vision in dim light. We have shown that nocturnal animals with three different eye designs can use colour vision in very dim light: nocturnal hawkmoths that possess superposition compound eyes learn to associate flower colours with a food reward at starlight levels (Kelber *et al*. 2002, *Nature* 419:922). Nocturnal carpenter bees with apposition compound eyes learn the colour of landmarks at the nest entrance (Somanathan *et al*. 2008, *Curr Biol* 18:R996). This is surprising because apposition eyes are not very light-sensitive, and spatial and/or temporal summation are needed to achieve colour vision in starlight. Finally, nocturnal geckos use colour in dim light (Roth & Kelber 2004, *Proc R Soc Lond B* S6:S485). All of these animals rely on one set of photoreceptors for vision. We have now tested the limit of colour vision in the horse, a mammal with an arrhythmic life style that possess both rods and cones in the retina. Horses have large eyes and thus potentially highly sensitive vision but it turned out that they loose colour vision at about the same light intensity as humans do (Roth *et al*. 2008, *PLoS One* 3:e3711). Anatomical and optical studies show that a single cone in the horse retina is just about as sensitive as a human cone. Thus, the similar absolute sensitivities of horse and human colour vision can be explained on the single cone level. Obviously, horse eyes are adapted to highly resolved rod vision in dim light. The relationship between optical sensitivity and colour vision sensitivity in geckos, hawkmoths, bees and horses will be compared. Which selective pressures set the threshold of colour vision in different animals still remains an open question.

Darkening $\neq$ dimming: hue shifts under objective vs. subjective decrease in colour illuminance VLLL3

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Objectively reducing the luminance of colour stimuli ('darkening') results in a hue shift, the Bezold-Brücke effect (e.g. Boynton and Gordon, 1965, *Journal of the Optical Society of America* 55, 78-86); this is accompanied by a shift in saturation (Bimler and Paramei, 2005, *Journal of the Optical Society of America A*, 22, 2120-2136). When colour stimuli are dimmed by adaptation to light rather than to dark (Jacobs and Gaylord, 1967, *Vision Research*, 7, 645-653), hue also varies, but it is not clear how far this parallel extends between 'darkening' and 'dimming' by adaptation change. Notably, the change to light adaptation may increase the saturation of hues by removing rod intrusion (Buck, Knight and Bechtold, 2000, *Vision Research*, 40, 3333-3344). This study presents a common framework for comparing outcomes of darkening vs. dimming. Data were obtained by applying the colour-naming method to monochromatic lights. The data allow the stimuli to be located in a spatial map where two dimensions stand for colour-opponent systems, whereas the changes in hue are reflected by angular displacements. We found that the pattern of hue shifts differs between the darkening and dimming conditions. Rather than a Bezold-Brücke effect, change in adaptation reveals an Abney effect: that is, the key influence on hue comes not from subjective stimulus intensity but from saturation. It follows that whatever non-linearity in the visual system allows colour dilution with white light to exert the Abney effect on hue, it is also invoked by adaptation changes. We compare the hue shift caused by 'dimming' to that produced by spatial luminance contrast (Bimler, Paramei and Izmailov, 2009, *Journal of the Optical Society of America A*, 29, 163-172).

VLLL4 Rod influence on appearance of desaturated hues

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Studies using maximally saturated, narrow-band spectral lights reveal three rod influences on hue perception: red bias at short wavelengths, blue bias at middle wavelengths, and green bias at long wavelengths). Studies using less saturated lights have shown only some of these effects. Here, we assessed rod influence on R/G and B/Y opponent-hue dimensions at chromaticities extending from the spectrum locus toward white. A staircase procedure measured observers' null points for R/G (unique blue and unique yellow) and B/Y (unique green). Stimuli were 5°-diameter discs centered 7° from fixation in temporal visual field. Rod influence was inferred from differences in null points measured under dark-adapted (maximizes rod influence) and cone-plateau (minimizes rod influence) conditions for stimuli presented at 0 to 1.4 log photopic trolands (CIE 10°). R/G and B/Y null points were determined for both spectral lights and mixtures of pairs of monochromatic lights that spanned the chromaticity diagram. Consistent with prior studies, along the spectrum locus, rods shifted all three unique hues to longer wavelengths: by up to 50 nm for unique green (blue bias), 10 nm for unique blue (red bias), and 9 nm for unique yellow (green bias). All three rod hue biases were also found for desaturated lights, extending toward white for distances that varied among observers. Some observers showed rod effects for stimuli of as little as ∼25% excitation purity, the least saturated we have tested so far. These results show that all three rod hue biases can alter the appearance of a wide range of desaturated hues like those found in the natural world, not just spectral hues of the laboratory.

Vision and the practice of making art

CONW

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Visual Art can be viewed as a natural experiment in which the mechanisms employed by the visual system for encoding scenes are reflected in the process, practice and product of the artist. In this lecture, I will explore some of the strategies that artists use in the execution of 2-dimensional graphic work (paintings and drawings) with an emphasis on representations of color, and will attempt to draw connections between these strategies and the neural mechanisms they expose.

CVA1 Selective absorption of short-wavelength light in the eye: effects of pre-receptoral filters and aging on chromatic sensitivity

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Inter-subject variations in yellow-blue (YB) chromatic sensitivity have often been attributed to differences in pre-receptoral spectral absorption of light and the effects ageing has on these filters. The two main filters of blue light in the eye are Macular Pigment (MP) and the crystalline lens. The absorption of blue light by the MP and the crystalline lens was measured and related to the subject's chromatic sensitivity at both 26 and 2.6 cd/m^2. Red-green (RG) and YB chromatic detection thresholds were measured at the fovea for both young and older subjects using the Colour Assessment and Diagnosis (CAD) test. A new Macula Assessment Profile (MAP) test was used to measure the spatial profile of the Macular Pigment Optical Density (MPOD) in each subject investigated (Kvansakul, Rodriguez-Carmona, *et al*., 2006: *Ophthalmic* & *Physiological Optics* 26:362-371). The MAP test employs a new implementation of the flicker-cancellation technique that also allows us to estimate the blue light absorption of the lens and the subjects' overall sensitivity to rapid flicker. Preliminary results suggest that absorption of blue light by the MP does not significantly affect YB chromatic sensitivity. Increased absorption by the crystalline lens correlates well with age and also shows some correlation with decreased YB sensitivity. The worsening of YB chromatic sensitivity at the lower light level investigated and the increased inter-subject variability may well reflect changes in the retina due to ageing effects that also correlate with increased blue light absorption by the lens.

Age-related contrast discrimination differences in ON and OFF pathways

CVA2

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Both optical and neural factors are known to contribute to age-related changes in human spatial vision. With optical factors controlled, Shinomori and Werner have found age-related changes in temporal ON- and OFF-pathways measured with luminance and S-cone modulation. Here we used psychophysical methods developed in the Pokorny-Smith lab to evaluate age-related changes in putative ON and OFF pathways for 10 younger (mean age 22 years) and 10 older (mean age 74 years) observers. Contrast discrimination thresholds were measured using the pedestal-delta-pedestal paradigm, thought to reveal the contrast gain signature of the magnocellular pathway. Observers pre-adapted to a uniform field plus a pedestal four-square array. In the brief trial period (35 ms), the four-square array was incremented or decremented in luminance by a small amount (< 0.1 log units) from the pedestal, with one square presented at a higher or lower retinal illuminance. Trials followed a double-random alternating staircase, with thresholds measured in the 1) increment and 2) decrement directions. Using a four-alternative forced choice procedure, the observer's task was to choose the unique square. Stimuli were presented in Maxwellian view, and heterochromatic flicker photometry was used to equate the illuminance for each observer. Thresholds obtained in the two staircases revealed differential discrimination functions, suggesting discriminations were mediated by the ON and OFF pathways, respectively. The contrast gain slopes obtained with a fitted equation are consistent with previous reports for young observers. Older observers showed a significant change in the contrast gain slope for both increment ($p < 0.001$) and decrement ($p = 0.05$) thresholds, but the change was substantially greater in the putative ON pathway (57% vs. 27% increase in the fitted values). Differences suggest that both ON and OFF pathways undergo age-related sensitivity loss, but the contrast gain signature is altered to a greater degree in the ON pathway.

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CVA3 Colour-opponent mechanisms are not affected by sensitivity changes across the life span

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Purpose. The purpose of this study was to assess in a large sample of colour-normal observers of a wide age group (n=185; age range: 18-75) whether sensitivity changes across the life span are associated with corresponding changes in the colour-opponent mechanisms that mediate hue perception. We therefore obtained the following data in the same set of observers: the sensitivity along the protan, deutan and tritan line, the settings for the four unique hues from which the characteristics of the colour-opponent mechanisms can be derived, and neutral grey settings. Results. We find a significant decrease in chromatic sensitivity with increasing age, in particular along the tritan line. When we predict the relative cone weights (L:M; L:S) of the colour-opponent mechanisms from the chromatic (protan, deutan, tritan) thresholds, we find a pronounced dependency on age for the L:S ratio. The observed relative cone weights (associated with a particular hue), on the other hand, are rather constant throughout the life span. Conclusion. The weighting of the cone inputs by the colour-opponent mechanisms (red-green; yellow-blue) appears to change with age. Such an adaptive weighting is useful to maintain colour constancy throughout the life span in the presence of known changes in the ocular media and retinal sensitivity losses.

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Categorical colour naming of surfaces in natural scenes under different illuminations CC1

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Colour naming quantifies colour appearance more directly than colour matching because it requires absolute rather than relative judgements, but it has the disadvantage that a single name may encompass many discriminable colours. This problem is circumvented here by tracking the centroids (foci) of colour categories. Images of natural scenes under daylights of correlated colour temperature either 6500 K or 25000 K were generated on a colour monitor from a set of hyperspectral data to allow the accurate control of illuminant and reflectance spectra. Each scene contained a test surface, a sphere, whose spectral reflectance coincided with that of a sample drawn from approximately 430 Munsell reflectances grouped into eight colour categories, namely, red, green, blue, yellow, pink, purple, brown, and orange (cf. Sturges and Whitfield, 1995, *Color Research and Application*, 20, 364-376). Each category comprised approximately 60 spectra, but with empirically determined foci the nominal boundaries were not critical. Only one category was tested in each experimental session. Observers, viewing each image for 1 s, named the colour of the test surface by pressing one of nine computer keys corresponding to the eight categorical colour names plus neutral. Focal colours were estimated from the peaks of the smoothed distributions of observers' responses in the CIE 1976 (*u'*, *v'*) space, chosen for ease of comparison with previous reports. To quantify the effect of a change of illuminant, a focal-colour constancy index was calculated with perfect constancy corresponding to 1 and perfect inconstancy to 0. Focal-colour constancy varied with both test surface and scene, but, overall, performance approached that with traditional measures of constancy, with some indices as high as 0.9, obtained with a purple surface. Extending previous findings, these results suggest that for some surfaces, categorical colour perception is sufficiently robust to anchor relative judgements of surface colour in natural images.

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CC2 Working memory predicts individual differences in successive color constancy

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Color constancy is imperfect and shows rather large individual differences. This study tested whether individual differences in working memory (the ability to hold information in mind during distraction) are related to differences in color memory and/or color constancy. High- and low-working-memory participants were identified using the Aospan and Arspan tasks (Unsworth, Heitz, Schrock, & Engle, 2005). Participants studied a test color for one minute for later recall (paradigm modeled after Jin & Shevell, 1996). In the uniform background condition, the test color was surrounded by a uniform achromatic background that reflected all wavelengths nonselectively; in the complex background condition, the achromatic background had eight different colored sectors embedded within it. These conditions manipulated context: a complex background typically improves color constancy. During the study phase, each participant saw the (simulated) Munsell papers under one illuminant (A or C). After the study phase, participants generated random numbers for two minutes in the dark, to prohibit verbal rehearsal of the test color. A second display was then presented that had either the same illuminant used during training or the other illuminant. Participants set the color of a test patch to appear like the color they had studied (a memory match). The paradigm allowed measurement of both color memory (no illuminant change between training and test) and color constancy (illuminant change between training and test). Better color constancy was found for high- than low-working-memory participants for both background conditions. Better color memory was found for high- than low-working-memory participants only for the complex background condition. This suggests that working memory is involved in the establishment, maintenance and/or retrieval of a color-constant neural representation, not just in simple color memory for a chromaticity always viewed under the same illuminant. This study provides the first account for individual differences in successive color constancy.

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Colour constancy in memory and the role of image integrality CC3

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Colour constancy is a relative stability of the perceived colour appearance despite illumination changes. Jin and Shevell (1996) (Jin, E. W., & Shevell, S. K. (1996). Color memory and color constancy. *J Opt Soc Am A*, 13(10), 1981-1991.) described colour constancy phenomena observed in colour memory matching tasks, where the test colour patches displayed with surround of colour patches showed good constancy in recall tasks after viewing the test colour for several minutes. In the present study, we first replicated Jin and Shevell (1996) experiments, and then applied the test-recall tasks with surrounds composed of real scene images. During the experiments, the test/recall patches were displayed with one of the following five surround conditions: 1) a dark surround. 2) a uniform grey surround. 3) a surround composed of colour patches. 4) a real scenic image surround. 5) a randomly cut-and-rearranged scenic image surround. The rationale for the additional two conditions was to test whether the image integrality can affect colour memory, as it did for object recognition (Biederman, I., Glass, A. L., & Stacy, E. W., Jr. (1973). Searching for objects in real-world scenes. *J Exp Psychol*, 97(1), 22-27.). The results show that good colour constancy in memory always comes into effect for all surrounds except the dark surround. However, the extent of constancy still varies with different surround conditions.

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LAG Lagerlunda

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Histories of tests for colour vision deficiency often mention a fatal railway accident that occurred on the single-track trunk line from Malmö to Stockholm on the night of 14-15th November, 1875. The scene of the accident was the estate of Baron Lagerfelt in Östergötland, but the critical events of the night were played out at Linköping (the normal passing place for the northbound and southbound expresses) - and at Bankeberg (a small station to which the passing was reassigned at a few minutes notice). First to arrive at Bankeberg, the northbound express slowed almost to a halt, but then inexplicably accelerated forwards towards the Lagerlunda estate, despite signals from the stationmaster, Uno Björkelund, and a lineman, Oskar Johansson. Under the regulations then in force (*Tjenstgörings-Reglemente vid Statens Jernvägar*, 1874), the night signals were: *Stop*: a red lantern light or any light moved up and down; Caution: a green light, or any light slowly moved from left to right; *All-clear*: a white light swung in a circle. Soon after the accident, the ophthalmologist Frithiof Holmgren suggested that the driver of the northbound, Andersson, or his oiler, Larsson, had been colour blind. Neither survived to be tested. Using the manuscript records of Björkelund's trial and other archival materials, we have re-examined the role of colour blindness in the Lagerlunda incident. The accident definitely cannot be attributed to colour blindness alone: as with many railway accidents, a conjunction of several human errors and system weaknesses was required before the collision became possible. Yet it is a matter of record that the Lagerlunda accident attracted world-wide concern and had a central role in the introduction of colour vision testing in European railways. But to persuade the management of the Swedish State Railways, Holmgren used a dramatic *coup de theatre* and not a little subterfuge.

Sunday, 26th July

Can we understand colour processing in the visual system from the statistics of natural scenes? CVSNS1

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The notion that neural processing is adapted to the sensory environment has been a successful basis for explaining coding properties of neurons in the visual system. To investigate whether this approach can provide insights into the principles underlying the properties of colour processing, we analyzed natural scenes with respect to the coding of colour. A fundamental requirement for colour vision is the ability to process visual signals in a cone-type specific way. Analyses of cone response estimates to natural scenes show that cone-type selective wiring can be acquired in an unsupervised manner, based solely on the statistics of the cone responses. This finding supports recent theories of the evolution of trichromatic vision in primates. A prominent feature of colour processing is colour opponency. Opponency has been proposed to be a consequence of the overlapping cone spectral sensitivities. However, an analysis of natural images showed that opponency is an efficient way to represent spectral information in natural scenes, independent of the cone spectral sensitivities. This suggests that colour opponency is a consequence of the properties of the visual environment, not primarily of the photoreceptor spectral sensitivities. As a result of opponent processing, colour selectivities in retina and LGN cluster around the orthogonal axes of cone-opponent colour space. In visual cortex, however, colour selectivities are more distributed and not organized around orthogonal colour space axes. Efficient codes for cone responses in natural scenes show a preference for opponency along non-orthogonal axes in colour space, similar to the colour preferences of neurons in the visual cortex. This suggests that the transformation of colour signals from retina to visual cortex achieves a representation that is adapted to the statistics of colour in natural scenes.

CVSNS2 Adaptation to natural color environments assessed by adapting images to observers

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Adaptation can strongly affect color appearance and is thought to be important for optimizing color coding. Yet how color vision might be adapted to specific environments and the consequences of these adjustments remain unclear. We explored the effects of color contrast adaptation in a new way - by adapting images rather than observers to simulate theoretically complete adaptation. This allowed us to probe effects of long-term adaptation over time scales that are difficult to test by adapting observers. The adaptation was modeled as gain changes in the cones and in post-receptoral channels selective for different color-luminance directions. Image sets were sampled from different environments and rendered after adjusting the gains so that the average response within each channel was equal across two environments. This centers contrast responses on the average color for a given environment and scales sensitivity inversely with the range of stimulus contrasts. Changes in color appearance were assessed by determining how hue loci should vary in the same observer under different adaptation states, and provide a measure of the extent to which individual differences in color appearance might be attributable to differences between environments. Visual performance was assessed with a search task for colored targets among neutral distracters, both shown as Gaussian blobs superimposed at random locations across the images. Search times were compared for pairs of original and adapted images and targets that were equivalent except for the simulated changes with adaptation. For natural environments that vary widely in their distributions, pronounced changes in color appearance and search times are readily demonstrated and thus lend support to functional accounts of contrast adaptation. Assessing performance across the range of environments routinely encountered allows us to assess the extent to which adaptation might significantly impact color coding or when performance could be enhanced by pre-adapting images for observers.

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The contribution of color to detecting edges in natural scenes CVSNS3

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In a statistical analysis of over 700 natural scenes from the McGill calibrated color image database (Olmos and Kingdom, 2004, http://tabby.vision.mcgill.ca) we found that luminance and chromatic edges are statistically independent. These results show that chromatic edge contrast is an independent source of information that natural or artificial vision systems can linearly combine with other cues for the proper segmentation of objects (Hansen and Gegenfurtner, 2009, *Visual Neuroscience*). Here we investigate the contribution of color and luminance information to predict human-labeled edges. Edges were detected in three planes of the DKL color space (Lum, L-M, S-(L+M)) and compared to human-labeled edges from the Berkeley segmentation data set. We used a ROC framework for a threshold-independent comparison of edge detector responses (provided by the Sobel operator) to ground truth (given by the human marked edges). The average improvement as quantified by the difference between the areas under the ROC curves for pure luminance and luminance/chromatic edges was small. The improvement was only 2.7% if both L-M and S-(L+M) edges were used in addition to the luminance edges, 2.1% for simulated dichromats lacking an L-M channel, and 2.2% for simulated dichromats lacking an S-(L+M) channel. Interesting, the same improvement for chromatic information (2.5%) occurred if the ROC analysis was based on human-labeled edges in gray-scale images. Probably, observers use high-level knowledge to correctly mark edges even in the absence of a luminance contrast. While the average advantage of the additional chromatic channels was small, for some images a considerably higher improvement of up to 11% occurred. For few images the performance decreased. Overall, color was advantageous in 74% of the 100 images we evaluated. We interpret our results such that color information is on average beneficial for the detection of edges and can be highly useful and even crucial in special scenes.

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CVSNS4 Color is not an efficient carrier of information in natural images

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The visual system summarizes complex scenes to extract meaningful features (Barlow, 1959; Marr 1976) by using image primitives (edges, bars), encoded physiologically by specific configuration of receptive fields (Hubel & Wiesel, 1962). We recently proposed a pattern-filtering approach, based on the principle of most efficient information coding under real-world physical limitations (Punzi & Del Viva VSS-2006). The model was a good predictor of an early stage of visual analysis. The model, applied to black and white images, predicts from very general principles the structure of visual filters that closely resemble well-known receptive fields, and identifies salient features, such as edges and lines. A comparison of model performance to that of human observers found that human sensitivity closely follows the model predictions (Del Viva & Punzi VSS-2006). Here, the model was applied to a set of colored natural images in order to consider the role of color in the initial stages of image processing and edge detection. Again, the model identified salient features in these more complex, realistic images with both color and luminance information. The model predicts, however, that color information is used in a very different way from luminance information. The results showed that equiluminant patterns are far from being efficient coders of information: they are either too common (uniform colored regions) or too rare and therefore are discarded by our approach. The results showed also that luminance information alone gives an efficient, compact summary of visual images.

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Modelling human discrimination of suprathreshold chromatic changes in natural scenes using a visual-cortex model

CVSNS5

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We are investigating how observers rate the magnitudes of spatiochromatic changes in images of natural scenes: e.g., changes in object position, shape or colour, and combinations of these. We rotate hue or change saturation of the whole image or of objects within it in an HSL space, reflecting discrimination or recognition tasks that observers meet in everyday life. The observers' task is to rate the perceived difference between images presented sequentially. We ask how well observers' ratings are predicted by modelling Gabor-like receptive fields whose linear and non-linear properties and interactions are based closely on human grating psychophysics and visual-cortex neurophysiology. The first stage of the model splits each full-colour image into 3 colour planes; then the images are compared plane by plane, calculating the responses of nonlinear modelled simple cells selective to orientation and spatial frequency. The choice of the three planes is problematic, but we have had most success with a "Luminance" and two colour-opponent Boynton/MacLeod planes; the model is less predictive of human performance when we split as cone-based LMS planes or as machine-based RGB planes. When the three channels are matched for the sensitivity to luminance and isoluminant RG or BY gratings (from Mullen & Kingdom, 2002, *Vis.Neurosci.*, 19, 109), the three channels contribute roughly equal weight to the predictions. The model output is a single number that estimates how big a difference observers would perceive between image pairs. The model works as well for colour changes as for shape/size changes, even with peripherally-viewed stimuli where the RG system is very much less sensitive. Some kinds of image change, for example blur, texture and object disappearance (but not chromatic ones), are badly predicted by the cortex-based model. This may point to limitations of low-level models in accounting for globally-perceived image characteristics.

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CVSNS6 Using colour as a label in natural scenes

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Trichromatic sampling by the eye and variations in illumination both limit the effectiveness of colour as a label for identifying the elements of a scene. The aim of this work was to quantify these physical limits for an ideal observer who uses colour signals to represent each point in an image. Simulations were based on 50 hyperspectral images of natural scenes under various daylight illuminants with correlated colour temperatures 4000 K, 6500 K, and 25000 K. Estimates were made of the information, in the sense of Shannon, available from each scene under different illuminants and the information retrieved with optimum, linear, cone-opponent processing. For the largest illuminant difference, between 25000 K and 4000 K, the information available was 17 bits, equivalent to an average of 1.4×10^5 distinct identifiable points per scene. The maximum information retrievable with optimum cone-opponent coding was ca. 15.5 bits, equivalent to an average of 4.5×10^4 distinct identifiable points per scene, although estimates were obtained by extrapolation. Even without taking into account receptoral and postreceptoral noise, these estimates were much smaller than the estimated average number of discriminable colours, ca. 2.7×10^5, available in single images of natural scenes (Linhares, *et al*., *J. Opt. Soc. Am. A*, 2008, 25, 2918-2924). This difference suggests a possible physical basis for the observation that colour naming is coarser than colour discrimination.

Contribution of melanopsin-expressing retinal ganglion cells to pupillary control pathway studied with a receptor-silent substitution technique

SF1

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It is widely accepted that the constriction and dilation of the pupils is evoked by changes in the ambient luminance, suggesting that retinal cone pathways contribute to the pupillary control mechanism. Recently, several studies have shown that retinal ganglion cells containing the photopigment melanopsin, which are intrinsically photosensitive in primates, project to the pupillary control centre in the pretectum. The aim of this study was to investigate how signals driven by melanopsin-expressing retinal ganglion cells (mRGCs) contribute to the pupillary control mechanism. We designed and built a novel multi-primary stimulation system to independently stimulate mRGCs from the other photoreceptors using a receptor-silent substitution technique. The stimulation system consists of an optical diffuser and an integrating sphere. We calculated excitations of the mRGCs and the other photoreceptors on a test field. In the mRGC condition we changed an excitation of mRGCs alone without changing the colour and the luminance on a test field. In the luminance condition we changed luminance of the test field alone without changing the colour and the excitation of mRGCs. The mRGC excitation and the luminance for test field varied 3.3 times in each condition. The test field was presented for 10 minutes and the pupillary diameter was recorded for 2 seconds and repeated with an interval of 30 seconds during test field presentations. In mRGC condition, when pupil diameter was compared across the five excitation levels each observer showed highly significant differences in pupil diameter across mRGC excitation. The pupil diameter decreases as mRGC excitation increases. Although the colour and luminance of test field were constant, the remarkable decrease of pupil diameter was found. In luminance condition the pupil diameter decreases as luminance of test field increases. These results indicate that the mRGC signals contribute greatly to the pupillary control mechanism as well as luminance signals.

SF2 The effect of controlled photopigments excitations on pupil aperture

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Several studies have shown that the pupil aperture responds to the spectrum of light. The underlying mechanism is subject to discussion. Five photopigments are present in the retina: L-cone, M-cone, S-cone and rod pigments, and the melanopsin recently identified in the body and dendrites of a few ganglion cells. The intrinsically photosensitive retinal ganglion cells (ipRGCs) are good candidates for controlling the tonic pupil aperture but their spectral sensitivity is close to rods and S-cones which are other candidates. Our study aims at identifying the stimulus for the pupil response when the luminance is maintained and the spectrum of light changes. A light booth was equipped with five types of coloured light emitting diodes (LEDs): Blue, Cyan, Green, Orange and Red. The intensity of each LED type could be adjusted to control the light spectrum. Pairs of illuminations were prepared ensuring the exclusive change of excitation of one receptor type and silent substitution for others. Because the range of the possible controlled changes of excitation was narrow, we also prepared pairs of illuminations ensuring silent substitution for luminance rather than for L-cones and M-cones independently. Photographs of the observer's eyes were taken following one minute of adaptation to each illumination. The observer could view freely the illuminated field of view (150 degrees) until he was instructed to fixate a single target letter just above the camera when the photograph was taken. The pupil diameter and the iris diameter were measured on the digital pictures. Preliminary results show that, at constant luminance, a change of pupil size is obtained with isolated melanopsin excitation, isolated S-cone excitation or isolated rod excitation but a clear pattern has not emerged yet.

S-cone pathway contribution to depth perception SF3

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One of the central tasks of the visual system is to derive the third dimension in the visual scene from the two dimensional images that fall on the retinal surface. To accomplish this several mechanisms have evolved, the two most central of which are stereopsis and motion parallax. Stereoscopic depth perception utilizes the disparity cues between the images that fall on the retina of the left and right eyes. The purpose of this study was to determine what role the S-cone channel plays in the processing of stereopsis. Thirteen subjects aging from 17-24 (20 $\pm$ 1,4 years; 8 females) with 20/20 best corrected visual acuity were tested for uncrossed (distal) binocular disparity using the Frisby stereo test (Clement Clarke International Ltd, London, UK). Stereoacuity was measured with the best corrected binocular vision and using a band pass blue filter (Schott BG25) to isolate the S-cone responses. A four alternative forced-choice procedure was used and the stereoacuity was measured using a staircase procedure. The viewing distance started at 1 meter presenting plate 1 (4.027mm), following a correct response we presented plate 2 (2.013mm) and plate 3 (0.67mm). If the subject was able to see the stereo target in plate 3 we increased the viewing distance in steps of 10 cm until the first wrong response occurred. For the next 3 reversals the steps were reduced to 5 cm. Blue filter stereoacuity was higher for all subjects. The mean stereoacuity without blue filter was 5.4 sec of arc ($\pm$ 2.4) and under blue filter condition it was 14.8 ($\pm$ 8.5). This difference had a statistical significance (U= 4,00; p= .024, Mann-Whitney U test). Our results show that the S-cone input contributes to depth perception but the stereoacuity measured for this retinal pathway is significantly lower than under the three cone inputs of normal vision. This low participation of the S-cone system in this spatial vision task may be related to the low density of S cones in the retina, and to the greater light diffraction in the blue condition, causing image blur.

SF4 Hue perception is mediated by pathways in which S cone signals are combined with M vs L at the first synapse in the retina

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S cones contribute to all four hue percepts assayed psychophysically. However, textbook 'red-green' opponent cells have no S cone input. To account for this discrepancy, a two-stage model has been proposed in which color signals are recombined in the cortex. However, an alternative is that the most frequently recorded parvocellular L vs M cells are not responsible for hue perception. Instead, hue percepts could rely on a small subset of ganglion cells in which S signals are combined with opposing L and M inputs via horizontal cells providing the substrate for S-cone input to both red/green and blue/yellow hue at the first synapse. We tested this hypothesis by taking advantage of the fact that S-cone inputs to blue-cone bipolar cells can be blocked by intravitreal injections of L-AP4 in animals or mutations to the gene encoding mGluR6 in humans. We, thus, studied S-cone signals introduced to the visual pathways via horizontal cells in isolation in rodents and monkeys and in a human subject with mGluR6 mutations. S cone signals were examined using S-cone isolating stimuli at the bipolar level using the light-adapted, long-flash ERG and at higher levels using ultrahigh field strength fMRI and psychophysics. Robust S-cone signals were detected at all levels of the visual pathway from bipolar cells to perception under conditions that block S-cone input to blue-cone bipolar cells but leave S-cone pathways via horizontal cells intact. We conclude that S-cones have access to the L/M pathway via horizontal cell connections such that signals from all three cone types are combined in the retina, at the first synapse. S-cones input to either L or M cones, which, in turn, output to either ON or OFF bipolar cells, producing four combinations corresponding to circuits for red, green, blue and yellow.

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Evolution and spectral tuning of vertebrate visual pigments GP1

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Adaptations of the visual system have occurred throughout vertebrate evolution and frequently involve changes in the frequency of the different photoreceptor classes in the retina combined with changes in the spectral sensitivity of the visual pigments that they contain. These adaptations particularly affect the different cone classes. The driving forces behind these changes are generally either the quantity or quality of environmental light or the demands of a particular visual task. Examples that will be discussed will be taken from our recent studies and will include (1) the loss of cone classes and shifts in spectral sensitivity found in nocturnal, fossorial and deep-water species, and (2) the multiple occurrences of loss of UV-sensitivity in vertebrate evolution.

GP2 Tuning cichlid fish visual sensitivities using differential gene expression and coding sequence evolution

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Cichlid fishes are highly speciose with over 1500 species in the Great Lakes of Africa. During their recent evolution, these fishes have rapidly diverged in morphology and color pattern. We have found that their visual systems are also highly diverse with some of the largest known differences in visual sensitivities amongst closely related species. This diversity is a result of cichlids having seven unique cone opsin genes. Because these genes are sensitive from the ultraviolet to the red ends of the spectrum, and because species differ in which sets of these genes they express, visual sensitivities can show large shifts between species. Cichlids can also more finely tune visual pigments through alterations in opsin amino acid sequence. By comparing the visual sensitivities of more than 50 species from Lake Malawi and 8 species from Lake Victoria, we have determined that ecology plays an important role in shaping these sensitivities. This includes factors such as foraging and photic environment with variation occurring over small geographic scales. We will discuss our progress to determine the genetic mechanisms which control cichlid visual sensitivities as well as their role in driving cichlid diversification.

The molecular genetics of color and polarization vision in stomatopod crustaceans

GP3

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Stomatopod crustaceans have the most complex assemblage of visual receptor classes known; retinas of many species are thought to express up to 16 different visual pigments. We investigated subsets of expressed opsin genes in retinas of seven stomatopod species representing a broad taxonomic range (five families, three superfamilies) using degenerate primers targeting crustacean middle-wavelength-sensitive (MWS) opsins, and further examined three of these species with primers targeting putative ultraviolet-sensitive (UVS) opsins. Physiological studies suggest that stomatopods contain up to six photoreceptor classes with middle-wavelength sensitivity and six additional classes with ultraviolet sensitivity. Thus, we expected that the primers utilized would isolate up to six different opsin gene copies of each spectral class per species. In the MWS class, a total of 79 unique retinal opsin transcripts were isolated, representing six to fifteen different transcripts in each species. Minimally, this characterized sequence diversity requires four to ten opsin copies in the genome of each species. These MWS opsin transcripts form six distinct phylogenetic clades, grouping with other characterized crustacean opsins and sister to insect middle-wavelength types. Intra- and interspecific clusters of highly similar transcripts suggest that there has been rampant, recent opsin gene duplication in the stomatopods, together with ancient gene duplication events within the stem crustacean lineage. Using evolutionary trace analysis, 10 amino acid sites located in two distinct regions of MWS opsin polypeptides were identified as functionally divergent. These two clusters of sites indicate that stomatopod MWS opsins have diverged both with respect to spectral tuning and to signal transduction interactions. Interestingly, our preliminary results suggest that the UVS opsins are actually less diverse than expected, with as few as two distinct opsin transcripts expressed in a retina. Specialization for spectral diversity has apparently taken different evolutionary routes in the MWS and UVS opsin classes of these crustaceans.

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GP4 Signals in light of visual perception: a study of opsin evolution in New World warblers

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Animal signals are thought to evolve in response to environmental pressures (e.g. predation) and selection for intraspecific communication. However, the sensory system and its role in signal evolution has been much more difficult to study. In the case of visual communication, the sensory system has been largely studied without considering signals or the ecological setting. Consequently, we do not understand the evolutionary relationships between these components. Here, we propose to assess how opsins, and thus color vision, vary in relation to color visual signals, using the New World warblers as a model system. These species vary greatly in their colors and their ecology has been well studied, making them an ideal system to study the role visual perception plays in signal evolution. We will evaluate differences in color vision among species from opsin sequences and from relative opsin abundances. We have amplified complete coding sequences for all five opsin genes in more than 15 New World warblers, and found substantial non-synonymous variation in all cone opsins, but none in the rhodopsin. Interestingly, close to 80% of the observed substitutions are in, or adjacent to the binding pocket, and therefore, have the potential to alter the opsins' spectral sensitivity. However, we are still unable to verify that the observed variation indeed translates into differences in the opsins' spectral sensitivity. We will obtain this information by expressing the different opsins in vitro. Additionally, we found considerable variation in relative opsin abundances among New World warbler species. Contrary to our expectations from cone photoreceptor abundance, we found the SWS1 (UVS) opsin to be the most abundant in all studied species. Understanding the observed variation in the opsins of New World warblers will shed some light into avian color vision and its role in the evolution of plumage coloration.

Epigenetic control of expression of the human L- and M-pigment genes

GP5

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Differential DNA methylation is an essential epigenetic signal for gene regulation without changing the DNA sequence. Epigenetic signals include methylation of cytosine bases at CpG sites in DNA resulting in reduction of gene expression. DNA methylation has been shown to play important roles in cell differentiation, genomic imprinting, X chromosome inactivation, and genome stability. We compared the CpG methylation patterns of the promoter of the L-pigment gene (OPN1LW) plus an upstream DNase 1 hypersensitive (DHS) site between the human retinoblastoma cell line WERI, which expresses the L and M pigment genes when treated with thyroid hormone (T3), and lymphoblastoid cell lines that do not express these genes. DNA was isolated from these cells and then treated with bisulfite to convert the unmethylated cytosines (Cs) to thymines (Ts). The targeted regions were PCR-amplified, cloned and sequenced to determine the position and ratio of methylated to unmethylated Cs at each site in at least 35 clones of each cell line. The great majority of the 14 CpGs located within the proximal 200 bp of the promoter, plus 20 bp of the 5'-untranslated region were unmethylated in WERI cells whether or not treated with T3, but almost totally methylated in the lymphoblastoid cell line. Three of the CpGs located just upstream of the 200 bp of the promoter were methylated in both WERI and lymphoblastoid cells. Significant differential methylation was also observed within the DHS region located about 6 kb upstream of OPN1LW gene. This DHS region contains a highly conserved sequence "insulator" motif that has been shown to regulate gene expression. In conclusion, methylation patterns contribute to epigenetic regulation of expression of the L- and M-pigment genes and potentially to differentiation of L and M cones and determination of the retinal L:M cone ratio.

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GP6 Evolutionary origin of high frequency deleterious mutations in the human cone opsins and their role in the most common eye disorders

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More than 99.9% of species that have existed in the 3 billion years of life on earth have become extinct. Organisms and organs, seemingly magnificently suited for their purpose, are not so as a result of careful planning, but rather as the consequence of serendipitous genetic changes that may be adaptive in the short-term, but in the face of a continuously changing environment, will ultimately prove to be evolutionary wrong moves with the predictable endgame being extinction. We tested the idea that human X-chromosome opsin genes bear the unmistakable hallmark of evolution-chance genetic changes that initially proved adaptive but have since been countered by environmental changes, in this case, relaxation of selection against color vision defects, that have placed the L and M cone opsins on an irretrievable path to self-destruction. We sequenced 76 OPN1LW genes and 102 OPN1MW genes from Caucasian males, all of whom had normal color vision as demonstrated by performance on color vision tests. The genes encoded nineteen different amino acid sequence variants of L opsin and nine variants of M opsin. The nearly perfect association between vision loss and non-synonymous amino acid changes in the other two human visual pigments, rhodopsin and the S cone opsin, predicts by analogy that most of the amino acid sequence variation in L and M cone opsins will cause vision disorders. We tested for an association between OPN1LW haplotypes and AMD and found a clear association. We also found OPN1LW, and alleles to be a major genetic factor underlying simple myopia. We conclude that common sequence variants of L opsin are associated with two of the most prevalent human vision disorders, age-related macular degeneration (AMD) and myopia and conclude that degenerative mutations of the opsin genes contribute to most common eye disorders that plague modern humans.

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Costs and benefits of higher-order color mechanisms CM1

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Psychophysics and electrophysiology agree that from striate cortex to posterior infero-temporal cortex, the three color signals transmitted by the retina are processed by neurons whose preferred stimuli are distributed widely in hue directions, and whose tuning progressively narrows in color space. Previous studies have concentrated on evidence for these higher-order mechanisms, this study analyzes the computational costs and benefits of expanding the neural dimensions of color signals. For decoding spatially-uniform colors, higher-order mechanisms provide a small temporal advantage but some accuracy problems. Optimal decoding schemes, interval or population based, effectively involve narrow color tuning, which could be achieved by spike-coincidence detectors. A decision stage using vector sums leads to systematic mean biases in decoding, depending on the distribution of preferred directions, whereas using the peak of the population response leads to larger estimation variability. In mid-level vision tasks involving spatio-temporal color variations, higher-order mechanisms provide many advantages over three cardinal mechanisms and their six rectified versions. Higher-order mechanisms enable adaptation levels to be separated for different color-contrast directions, thus enhancing sensitivity to novel stimuli. Similarly, higher-order mechanisms improve segmentation of variegated color images, and discrimination of colored textures, by separating non-cardinal variations from their orthogonal counterparts. If color induction were confined to cardinal mechanisms, the differences in their contrast-responses would lead to disturbing changes in object hues. Finally search in color-clutter is more efficient when conducted through mechanisms tuned to many different color directions. Observers can recognize objects and scenes extremely rapidly, which suggests that feed-forward neural transformations achieve efficient object representations. Higher-order mechanisms increase the number of neural dimensions in which objects and scenes can be represented across viewing and lighting conditions. We are examining whether representations for individual objects form simple surfaces in high-dimensional color spaces, thus enabling simpler linear decision rules for rapid object and scene classification.

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CM2 Adaptation of higher order colour mechanisms

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Krauskopf, Williams and Heeley (1982, *Vis. Res.*) used adaptation to sinusoidal modulation along lines in the isoluminant plane of DKL colour space to reveal two cardinal colour mechanisms that exhibit independence - thresholds in one cardinal direction are not elevated following adaptation in the other. All intermediate adaptation directions produced generalised threshold elevation for all test directions. Krauskopf, Williams, Mandler & Brown (1986, *Vis. Res.*) later showed that intermediate adaptation directions influenced thresholds in a way not predicted by adaptation of only two colour mechanisms, a result that they suggest could be explained by additional desensitization in higher order colour mechanisms that are maximally sensitive in non-cardinal directions. We set out to test explicitly whether it is possible to differentially elevate thresholds with adaptation stimuli that are matched in the modulation presented to early colour mechanisms. A stimulus that is modulated in time around a circular locus in the isoluminant plane of colour space provides sinusoidal modulation to each of the cone classes, and to both cardinal mechanisms. The time-averaged level and the amplitudes of these signals are the same for clockwise (CW) and counterclockwise (CCW) modulations, as is the locus of hues presented. However, at modulation frequencies of around 10 Hz, the modulating stimuli appear different depending on whether the sense of procession is CW or CCW, consistent with a delay in the S-cone pathways that transforms the hue circle modulations to differently oriented elliptical loci at a central site (Stromeyer *et al.*, 1991, *Vis. Res.*; Lee *et al.*, 2009, ICVS). We measured chromatic discrimination thresholds along eight chromatic directions, before and after adaptation to hue circle stimuli. The pattern of threshold elevations was different following adaptation to CW or CCW modulations. By exploiting neural delays we have been able to isolate differential adaptation of higher order colour mechanisms.

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A performance measure that tracks the yellow-blue line CM3

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In our phenomenological experience of colours, a special status attaches to a line that runs across colour space from ∼576 nm to ∼476 nm. It is the line that runs from unique yellow to unique blue: colours to one side of the line are predominantly reddish and colours to the other side are greenish. The exact position of this line depends on the observer's adaptive state, and under some experimental conditions, the line may be curved. Few performance measures are known that correlate with this yellow-blue line. In the MacLeod-Boynton (1979) chromaticity diagram, the line is oblique, and does not correspond to either of the two 'cardinal axes'. Measuring colour discrimination by two-alternative spatial forced-choice in the parafovea, we have found that there is deep furrow of reduced thresholds that runs across colour space close to the yellow-blue line. The experimental conditions were similar to those we have used to study discrimination in the parafovea as a function of spatial separation (Danilova and Mollon, 2006, *Vision Research*, 46, 823-836). The adapting field had a chromaticity metameric to equal-energy white. The discriminanda were two patches falling on an imaginary circle of diameter 5 deg, centred on the fixation point. They were separated by a gap of 3.7 deg, and their centre point could occur at random at any point on the imaginary circle. The discriminanda were independently jittered in luminance. We worked in an analogue of MacLeod-Boynton space scaled so that the yellow-blue (576-476-nm) line was at -45 deg. In each experimental session, measurements were made for several referent stimuli located along a line that was orthogonal to the yellow-blue line. This was repeated at different points along the yellow-blue line. Each set of measurements showed a minimum, and the minima plotted out a locus close to, and parallel to, the yellow-blue line.

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CM4 Do color naming functions predict unique hue loci?

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Unique green and unique yellow loci were determined indirectly via color-naming functions and directly using a forced-choice, double-random staircase procedure for four observers. In both procedures, a 2.5^o stimulus was used that filled perceptive fields for blue, green, yellow and red; all measurements were made at 10^o temporal retinal eccentricity. Color-naming functions were obtained for monochromatic stimuli (480-620 nm, 20 nm) at 4 min intervals following a bleaching (5500K) stimulus. Unique hue loci obtained with the staircase procedure were measured 4-9 min post-bleach and after 28 min dark adaptation. The unique hue values at these two measurement points were compared to the 8 min and 28 min post-bleach values derived from the color-naming functions. These time points were selected to permit comparison of hue loci determined without rod contribution and with rod contribution. In general, the unique green loci measured with the staircase procedure were substantially shorter than those derived from color-naming functions, ranging from 3 to 19 nm with the time period associated with the cone plateau and 21 to 37 nm with the time period associated with the rod plateau. The unique green loci derived from the color-naming functions showed a shift from shorter to longer wavelengths with time post-bleach while there was a minimal shift between the two unique green loci measured in the staircase procedure. The differences in unique yellow loci between the two methods were much smaller than those for unique green, but showed a similar pattern. Thus, the hue loci derived from the color-naming functions were different from those obtained with the direct method, though the direction of shift was maintained from the bleach to the no-bleach conditions. These differences between methods may reflect the different criteria used to determine unique hue loci or perhaps, and more interesting, the different procedures reflect mediation at different points in the visual pathway.

Evolutionary photonics: natural designs for manipulating the flow of light and colour

VUK

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The study of structural colour in brightly coloured animals is an exciting interdisciplinary area of research[1]. Complex photonic bandgap (PBG) structures (which prevent the propagation of a band of wavelengths through them - causing strong coloured reflections) in Colepotera[2] and Lepidoptera[3] suggest broad innovation in nature's use of materials and its manipulation of light. In certain butterflies, ultra-long-range visibility of up to one half-mile is attributed to photonic structures that are formed by discrete multilayers of cuticle and air[3]. This contrasts, in other butterfly species, to photonic structures designed more for crypsis and which not only produce strong polarisation effects but can also create colour stimulus synthesis using highly adapted structures[4]. Optical systems also exist that employ remarkable 2D and 3D photonic crystals of cuticle to produce partial PBGs, with the effect that bright colour is reflected, or fluorescence emission is inhibited[5], over specific angle ranges. From the perspective of modern optical technology, these structures indicate a significant evolutionary step, since in principle, these 2D and 3D periodicities are potentially able to manipulate the flow of light in all directions. This lecture will present an overview of this emerging field of study, as well as several of the exciting recent discoveries that reflect nature's optical design ingenuity, and the technological applications to which they are currently being applied.

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PCM1 Waveguide contribution to the spectral sensitivity of human cones

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The spectral sensitivities of human cones have been previously modeled using geometric optics. However, because the outer segment diameter of human cones is comparable to the wavelength of light, waveguide rather than geometric optics must be used to model the spectral sensitivity. To find the dependence of light absorption on wavelength in cone outer segments, we numerically solved Maxwell equations. Cones were arranged in a periodic triangular array. Each individual cone consisted of inner and outer segment with constant refractive indexes and of an ellipsoid - a region where refractive index varied gradually from inner to outer segment. Inner segment and ellipsoid had real refractive index. Outer segment had complex refractive index whose imaginary component corresponded to the absorption by visual pigment. To model the wavelength dependence of the absorption, we used Govardovskii's templates of the visual pigment extinction coefficient. Using our numerical solution, we derived an analytical description of the distribution of electromagnetic field. The electromagnetic field can be described as a superposition of three modes with an appreciable amount of energy travelling between outer segments. Because light is not absorbed between outer segments, the effect of self-screening is less pronounced than that expected on the basis of geometric optics considerations. The shape of the spectral sensitivity derived from our numerical and analytical calculations agrees with the psychophysically determined shape better than that predicted on the basis of geometric optics. Our calculations show that waveguide contribution can account for small, but significant discrepancy between psychophysically determined cone spectral sensitivity and the estimates of this sensitivity based on geometric optics.

Distribution and topography of the ganglion cells and displaced amacrine cells in the howler monkey retina (Alouatta caraya) PCM2

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Differently from all other Platyrrhini, males and females howler monkeys are regular trichromats. Previous studies have shown that the howler monkey has a well developed fovea and a very high cone density in the foveola (Franco *et al*., 2000; Finlay *et al*., 2008). In the present work, the density distributions of ganglion cells (GC) and displaced amacrine cells (DAC) were determined in three retinas from different Alouatta caraya. The animals were deeply anesthetized and perfused transcardially. The eyes were removed and the retinas were prepared as whole, flat-mounts, and stained with cresyl violet using the method of Nissl. The criteria to distinguish GC from DAC were refined by inspecting a collection of capuchin monkey retinas retrogradely labeled after horseradish peroxidase or biocytin deposits in the optic nerve and couterstained with cresyl violet (Silveira *et al*., 1989; Yamada *et al*., 1996). GC density peaks at 0.5 mm from the fovea, reaching 50,000 / mm^2. In comparison with the capuchin monkey retina, the howler monkey retina has a lower peripheral GC density which compensates for an increased foveal packing. The increased central GC number means that the increased cone density in this primate could be available for increased acuity measured behaviorally. The GC density decreases towards the retinal periphery at approximately the same rate along all meridians, but is 1.2-1.8 times higher in the nasal periphery when compared to the temporal region at the same eccentricities. The DAC have a shallow density gradient, their peak density in the central region was about 1,500-2,000 / mm^2. The means and standard deviations for the retinal area and total numbers of cells (n = 3) were: 679 $\pm$ 37mm^2; 1,120,299 $\pm$ 76,581 GC and 553,447 $\pm$ 81,000 DAC. The GC density distribution in the howler monkey retina is consistent with that of diurnal Anthropoidea.

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PCM3 ERG signals driven by magno- and parvocellular pathways. Variable chromatic and luminance stimulus contents

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PURPOSE: The scientific and clinical value of the ERG may profit greatly if their signals can be correlated with activity in the different retino-geniculate pathways. We have recently published data that suggested that the flicker ERG is determined by the magnocellular activity at high temporal frequency and by parvocellular activity at 12 Hz (Kremers and Link, *J. Vision*, 2008). Here, we provide independent data that support this proposal and exclude alternative explanations. METHODS: ERGs to stimuli, in which red and green LEDs were modulated in counter-phase, were measured. The modulation depth in the two LEDs was varied so that the luminance content was changed but the chromaticity was constant. The measurements were repeated at different temporal frequencies between 4 and 36 Hz. The experiment was performed in normal trichromats and in a deuteranope. In a control experiment, the same luminance and chromatic stimuli were presented in the absence of rod and S-cone stimulation (achieved by silent substitution with additional modulation in orange and blue LEDs). RESULTS: At 36 Hz, the response amplitudes and phases followed the luminance content in the stimulus. At 12 Hz, the response amplitudes and phases were constant and thus are determined by the chromaticity in the stimulus. The responses measured in the deuteranope were mainly determined by the luminance content at all temporal frequencies. The control experiment yielded similar results as the main experiment. CONCLUSIONS: The flicker responses at high temporal frequencies (above about 30 Hz) are driven by the magnocellular pathway. At 12 Hz, the responses are driven by the parvocellular pathway. These data exclude an explanation on the basis of a rod- and/or S-cone driven response intrusion. Because the flicker ERG is mainly driven by bipolar cell activity, the data suggest that diffuse and midget bipolar cells already display luminance and chromatic sensitivities respectively.

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A new view of receptive field structure of midget ganglion cells PCM4

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The receptive field centers of midget ganglion cells of the parvocellular pathway are assumed to derive from a single cone. The input to the surround is controversial; cone-specific or mixed-cone surround models have been suggested. In a new approach we measure spatial frequency (SF) tuning curves to luminance, red-green chromatic, or L- and M-cone isolating gratings. Predictions for the tuning curves for this grating set are different for the two models. Which model can predict responses for all four conditions? Both fail dramatically. With L- or M-cone isolating gratings, for most cells the slope of the SF tuning curve is too shallow to be predicted by a single Gaussian mechanism. An inverse cosine transform of the SF curves gives spatial structure for M- and L-cone receptive fields. For both (irrespective of center type) there was a sharp central peak (giving responses to high SFs) set in broad, shallow flanks (to give the shallow slope). We could describe the data satisfactorily with a dual opponent-mechanism model, a local, opponent receptive field added to a much wider opponent mechanism. However, some other cells showed more complex behavior, but with spatial phase properties again consistent with a dual opponent mechanism. These results indicate receptive field structures for midget ganglion cells are more complex than expected from pure or mixed cone surround models. We suggest the small-scale opponent field is derived from outer retinal connectivity, in some cells at least with mixed surrounds. The broader opponent mechanism might arise from amacrine cell networks in inner retina. It is possible that the broad-field opponent mechanism serves to amplify in the PC pathway the |M-L| opponent signal, which is known to be weak in natural scenes. Lastly, the extensive spatial summation observed with psychophysical detection of red-green perturbations may have in part a retinal substrate.

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PCM5 L- and M-cone input to human ERGs as a function of retinal eccentricity

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Physiological studies have led to conflicting views regarding the nature of L- and M-cone input to ganglion cell receptive fields in the central compared to the peripheral retina. Some provide evidence in favour of a cone selective pattern of cone inputs, whilst others support a more random pattern of input. In order to investigate the nature of L- and M-cone input to ganglion cells we recorded ERGs from human subjects at temporal rates of 12Hz and 30Hz. These frequencies isolate the activity of cone-opponent and non-opponent post-receptoral mechanisms, respectively (Kremers and Link, 2008, *Journal of Vision* 8(15):11, 1-14). ERGs were obtained from these flickering stimuli with one of the following configurations: (1) Circular stimuli of different angular subtense which increased in 100 steps up to 70-deg diameter. (2) Annuli with 70-deg outer diameter but gradually ablated from the centre in 100 steps. L- and M-cone isolating responses were obtained from five colour normal subjects using a DTL fibre electrode. Cone contrasts were equalized for each stimulus condition. Fourier analysis of the ERGs was used to measure the magnitude of the first harmonic of the response. The ratio of the L- and M-cone responses was found to be close to unity for 12Hz stimulation in both the central and peripheral retina. In addition, phase differences were close to 180^o. For 30Hz stimulation the L- and M-cone ratio was found to vary between 4:1 and 10:1 across observers, with smaller phase differences between the L- and M-cone responses. These results suggest that for ERGs which reflect the activity of the L-M cone-opponent mechanism, a constant 1:1 input ratio exists between L- and M-cones as a function of retinal eccentricity. This result points to the maintenance of cone selective input in the peripheral human retina in chromatic vision.

Contribution from M and P pathways to the contrast sensitivity of pattern transient VEP components

PCM6

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Contrast sensitivity of visual evoked potential (VEP) components was estimated using 2 cycles/degree sinewave gratings presented either as 1 Hz pattern reversal or 300 ms onset / 700 ms offset. Twelve young healthy subjects were studied. All subjects had visual acuity normal or corrected to 20/20 and were monocularly tested through the eye with the lowest dioptric error. Eight subjects participated in the two stimulation protocols. All experiments were performed according to the tenets of the Declaration of Helsinki and the Brazilian Norms for Ethics in Research (Resolution 196/96, Health National Council of Brazil). We studied the P100 and N135 components of pattern reversal VEP as well as the C1 and C2 components of the onset / offset VEP. Double slope straight lines were fitted to data representing P100 amplitudes as a function of log stimulus contrast, whilst N135, C1, and C2 amplitudes as functions of log stimulus contrast were fitted by single straight lines. Contrast thresholds were estimated by finding contrast values at zero amplitude for each VEP component. Contrast sensitivity values were estimated by taken the inverses of contrast thresholds. Contrast sensitivity estimated from P100 at low contrasts, N135, and C2 were similar ($P > 0.05$) and higher than those obtained from P100 at high contrasts and C1 ($P < 0.01$) which were also similar to each other ($P > 0.05$) (one-way ANOVA; Bonferroni test for post hoc comparisons). It is suggested that the M pathway contributes to P100 at low contrasts, as well as to N135 and C2 at all contrast levels, whilst the P pathway contributes to P100 at high contrasts and C1 at all contrast levels. A simple model for the M and P contribution to the VEP contrast sensitivity is proposed by adding logarithmic functions with different thresholds for each pathway.

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RGD1 Quantitative assessment of commercial filter 'aids' for red-green colour defectives

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We assess the effect of commercial filter 'aids', which are claimed to improve the colour discrimination of red-green colour defectives, using colour spacing of the Farnsworth-Munsell D15 test and of standard red, yellow and green traffic signals (EN 1836:2005) in protanomalous and deuteranomalous colour vision. The spectral transmittance of 42 'aids' (5 manufacturers) is measured. Chromaticities are computed by convolving these spectra with the cone fundamentals (De Marco, Pokorny and Smith, 1992, *Journal of the Optical Society of America A*, 9, 1465-76) and either the D15 spectral reflectance factors and spectral power distribution (SPD) of CIE Illuminant C or the SPDs of traffic signals. Chromaticities are presented in an analogue of a cone excitation diagram (MacLeod and Boynton, 1979, *Journal of the Optical Society of America*, 69, 1183-6). Standard deviations of chromaticities, parallel to the L/(L+M) axis of that diagram, are used to compute 'enhancement' factors E (ratio of filtered to non-filtered standard deviations) related to the relative excitation of long (L) and medium (M) wavelength sensitive cones. Account is taken of the diagram's non-uniformity. Luminous transmittances are computed for all 'aids'. Plots of luminous transmittances against E factors depict both the safety and utility characteristics for each 'aid'. Values of E for traffic signals with most 'aids' are less than unity, rendering them useless and some 11 to 15 of those (for deuteranomals and protanomals respectively) are dangerous: failing the EN standard with less than 8% luminous transmittance. A few 'aids' have expansive E factors but these are small (1.09 to 1.16 for deuteranomals and protanomals respectively) for signal lights and somewhat larger for the D15 test (1.24 to 1.29). Analyses, replicated for 19 'aids' of one manufacturer using 657 Munsell colours within the D15 locus, yield E factors within 1% of those found for the D15 test itself.

Unilateral colour vision defects and the dimensions of dichromat experience

RGD2

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One of the main pillars of support for the common view, that protanopes and deuteranopes see yellow and blue and not red and green, has been the reports of unilateral cases. Judd 1948 might seem almost definitive evidence – examining the 10 most promising reports from a ∼90 year period. Reexamination of the reports reveals a very different picture. Starting with the 3 putative cases of unilateral dichromacy: in one of them, perceptions of red and green are clearly reported; in another, perceptions of green; and in the third, the experimental methods are such that they might almost have been designed – if there had been any residual red-green perception – to fail to reveal it. von Kries's (1918) case of unilateral deuteranomaly seems to have a reduced perception of green and yellow, not of green and red. Most interesting is Nagel (1905) – reporting a case of supposedly deuteranopic fovea with near-normal periphery; but it is doubtful that, with the fovea, the man saw only yellow and blue; and Nagel himself gives reason (1905, 1908) for thinking that deuteranopes in general (and himself in particular) actually have sensations of red and some 'remnant' of green. As for the acquired cases: the defects are so fundamentally different from the loss of one cone type that it is completely obscure whether they can be a guide to the latter. The later reports (Graham *et al*. 1961, etc.; MacLeod & Lennie 1976; and the tritanopia in Alpern, Kitahara & Krantz 1983) prove no help to the yellow-and-blue view either. But the problems are not merely of detail: in view of the larger evidence, especially about residual red-green discrimination in dichromats, there are more general morals to draw about the experimental techniques and general theoretical stance that have guided studies of dichromacy.

RGD3 Red-green dichromats' Basic Colour term use: confusion lines and red-green residual activity

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Colour Basic Color Terms (hereafter BCTs) use by dichromats and common observers was compared. For this comparison, two visual search tasks were used. Prototype task required pointing out the best exemplar of a BCT. Mapping task required pointing out all the stimuli that could be included in a BCT. A 102-stimuli set was used for both searching tasks. This set accurately represented all BCTs. Dichromats obtained good results in the prototype searching task, especially for primary BCTs (red, green, yellow, blue, white and black). They predominantly selected stimuli included in the target BCT. More errors appeared in the mapping task. Frequently, these errors were stimuli that were similar in lightness and confusion line to some stimuli included in the target BCT. In any case, the number of errors was less than could be expected in "true dichromats", and evidence was obtained of Red-Green (R-G) mechanism residual activity: Error probability was reduced when the distance between a target stimulus and the target BCT prototype (on the same confusion line) was increased. The relevance of our results is discussed in relation with the ergonomic utility of some devices. Such devices are used to attempt to emulate dichromats' vision assuming they have no R-G mechanism activity.

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Categorical color mechanisms of dichromats revealed by color naming and color memory

RGD4

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Dichromats lack one of the cones so that they cannot discriminate colors on a confusion line. Red, green and yellow, for example, should not be discriminated by protanope and deuteranope. However they can actually use these color names in their everyday lives. Some previous studies suggested that several possible mechanisms, such as anomalous cone pigments, a nonlinear parallel chromatic channel or luminance cue, were responsible for this color naming ability of dichromats. We reported that protanopes and deuteranopes could perform trichromat-like color naming in normal observing conditions, but in restricted observing conditions, such as strong chromatic adaptation, small field, short duration and equal luminance, they showed some confusion in color naming along the red-green direction (Uchikawa, 2008, *Asia-Pacific Conference on Vision* Abstract 26). In the present paper we report a further investigation on color categorization mechanism of dichromats using a memory color-matching method. In an experiment we used the OSA color scales simulated on a CRT as stimuli. A test color, randomly selected from the 100 test-color set, was presented for 5sec, then after 30sec the observer started color matching by his memory. He changed colors on the CRT using the 3 variables of L, j and g of the OSA color space until he could choose one of the 1406 colors, which matched to the test color in his memory. He repeated this memory color-matching procedure for all 100-test colors. The categorical color naming experiment was also carried out for 424 OSA color samples with the Berlin and Kay's 11 basic color names. The results showed that color samples selected by color memory were restricted in the categorical color-naming regions for trichromats, but this tendency was not clearly shown for dichromats. This suggests that dichromats do not have categorical color perception based on a neural mechanism, but they use color appearance cues to show trichromat-like color categories.

Tuesday, 28th July

Simulating the appearance of natural materials

SCSS1

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Why is the sky blue?. Why is grass green?. What determines the color of human skin?. Questions such as these are increasingly important in the development of the next generation algorithms for appearance modeling in computer graphics. In this talk, I will describe some of our recent work in simulating the appearance of materials such as human skin, hair, milk, and ice. Our algorithms simulate the scattering of light within materials and are capable of efficiently handling both variation due to texture and due to layers within the materials. I will also present new research for predicting the appearance of materials based on their molecular structure in order to answer the question: “what will it look like if I mix these molecules together”?

SCSS2 What is the purpose of color for living beings?. A theory of color organization

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Phylogenetic and paleontological evidence indicates that in the animal kingdom the ability to perceive colors evolved independently several times and has existed for at least half a billion years. The color system is also considered newer and independent from a luminance system. This implies a high evolutionary neural investment and suggests that color vision has some fundamental and specialized functions providing biological advantages. What are these advantages? What is the purpose of color for living beings? Why are fruits usually narrow band? How is color organized in flowers? Why are animals so colorful? What are the adaptive and perceptual meanings of polychromatism?. To answer these questions, we studied psychophysically new conditions of the watercolor illusion related to color filling-in; that is, the process of whole completion due to color that creates the uniqueness and distinctiveness of the visual objects. We studied conditions where color filling-in is satisfied and conditions where it is violated. This suggests that, next to the filling-in process, there is a chromatic parcelling-out process of separation, division and breaking of a whole object into unconnected and ungrouped elements. This process destroys the amodal completion of color (Pinna, 2008) that creates the uniqueness and distinctiveness of the object. Our data suggest several principles of color filling-in and parcelling out that can be subsumed within a more general theory of color organization. This theory explains (i) how to creates a hierarchical structure within the same object, then favoring the emergence of several components (e.g., the central region of a flower) on the whole object, (ii) how a chromatic part-whole organization emerges, and (iii) how colors create a hierarchy of perceptual meanings that in biology can be related to higher adaptive fitness. This happens with organisms, like plants, whose aim is to be seen, but also with organisms whose aim is to be concealed.

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Material hue vs. lighting hue

SCSS3

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Observers can easily differetiate between a pigmented stain and the white surface that it lies on. The same applies for a colour shadow cast on the same surface. Although the difference between these two kinds of colour appearance (referred to as material and lighting hues) is self-evident even for inexperienced observers, it has not been captured by any colour appearance model so far. Using multidimensional scaling (MDS) we have obtained experimental evidence for the dissociation of these two types of hue in the human colour vision. The stimulus display consisted of 2 identical sets of Munsell papers (5R4/14, 5YR7/12, 5Y8/12, 5G6/10, 10BG5/8, 5PB5/12 and 10P5/12) illuminated independently by yellow, neutral, and blue lights. The CIE 1976 *u'v'*-coordinates of lights were (0.199, 0.530), (0.174, 0.476), and (0.183, 0.210). Dissimilarities between all the 210 paper/light pairs were evaluated by ranking for five trichromatic observers. As a standard pair, the paper 5Y8/12 lit by the yellow light and the paper 5PB5/12 lit by the blue light were presented all the time during the experiment indicating the rank 100. In the MDS output configuration, the papers lit by the same light made a closed configuration retaining the same order as the Munsell book. The paper configurations for the yellow and blue lights were shifted parallel to each other along an orthogonal direction with that for the neutral light located in between. The direction of the shift is interpreted as the yellow-blue lighting dimension. The average shift between the yellow and blue lights along this dimension was 27.5% of its standard pair, between the blue and neutral lights 25.2, and between the yellow and neutral lights 9.4. The corresponding shifts in the *u'v'*-coordinates were 70, 56, and 16% respectively. We argue that the yellow-blue lighting dimension cannot be reduced to that of the reflected light.

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SCSS4 What kinds of contours bound the reach of filled-in color?

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Introduction: Filling-in occurs when a visual feature located in one region of visual space is perceived in a nearby region where it is not actually present. In the case of color, a classical example of filling-in is the Boynton Illusion, in which an achromatic area between a black squiggly contour and a yellow region is filled-in by the yellow. In this case, the squiggly line serves as a luminance contour that bounds the area filled-in by color. Purpose: The present study investigated whether color filling-in is bounded also by illusory contours. Methods: This study evaluated different kinds of contours: real (different forms of a luminance-contrast edge) and illusory (Kanizsa square from solid pacmen, Kanizsa square from "bull's eye" pacmen, horizontally phase-shifted vertical lines). For all stimuli, a yellow square (defined solely by an S-cone from its achromatic background) was presented within one type of contour. In one condition (a control), the yellow square physically abutted the contour. In two other conditions, the yellow square was not touching the contour: in one condition it was approximately 4 min from the contour and in another condition about 6 min. Stimuli were presented for 8 seconds. The subject indicated via a button press whether the yellow appeared to be touching the contour (thus a filled-in color). The proportion of times that filling-in occurred and the response time of filling-in were measured. Results & Conclusion: Filling-in occurred for both real and illusory contours. Thus illusory contours without luminance contrast, as well as contours defined by local luminance contrast, are capable of constraining filled-in color.

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Image reconstruction in a color mosaic with random arrangement of chromatic samples

SCSS5

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Recent high resolution imaging of the retina (Roorda *et al*., 1999) shows that the mosaic of cones follows a random arrangement. Moreover, arrangement and proportion of cones differs largely from individual to individual. These finding renew the understanding of color vision because most of the models of color vision ignore the mosaic sampling. Here we propose a simulation of mosaic sampling applied on color image. From the simulation, we can infer the processing needs for retrieving spatial and chromatic information without ambiguity from the mosaic. We show that with linear processing it is possible to recover spatial and chromatic information from a mosaic of chromatic samples arranged randomly. We also show that low frequency component of achromatic information could serve for contour discrimination, which enables improving the interpolation of chromatic information. As an analogy to the mosaic of cones, it may be possible that in the cortex, the low frequency achromatic spatial information of the magnocellular pathway helps the reconstruction of chromatic information coming from the parvocellular information.

Roorda and Williams, *Nature*, 1999.

SCSS6 The effects of chromatic heterogeneity and spatial blocking on Glass Pattern detectability

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Glass Patterns (GPs) are composed of a field of locally-oriented pairs of dots (dipoles) distributed along a global flow. The perception of this flow is thought to require two stages: i) extraction of local orientation of individual dipoles at an early cortical stage, such as V1, ii) followed by extraction of the global flow at a higher cortical level, such as V4. We have previously shown using fMRI that a ventral region along the fusiform gyrus is differentially activated in the comparison of concentrically with randomly oriented dipoles, independently of whether the dipoles are specified by achromatic or chromatic contrasts. This was also true if the dipoles were different colors (cross-dipole, multi-chromatic) but not if the elements of the dipoles were different colors (within dipole, multi-chromatic), suggesting that early stage neural channels mediating local orientation detection have narrow chromatic bandwidths. Two hypotheses are possible for the second stage: i) orientation pooling independent of color; or ii) probability summation across chromatically narrowband, orientation channels. We tested these by measuring the threshold for detecting GPs as a function of the coherence of the dipole orientations. Coherence thresholds were obtained for 8 observers for 8 (uni-chromatic) color directions in an equiluminant plane and for two cross-dipole, multi-chromatic conditions: i) dipole chromaticity randomly distributed in space; ii) dipole chromaticity constrained within spatial blocks of the image. Using a criterion-free measure of sensitivity, we found that coherence thresholds for either of the multi-chromatic conditions did not differ significantly from the uni-chromatic conditions. These results support a second stage model in which the local orientations are pooled independently of color.

Colour and luminance contrast in depth perception

ECLC1

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Perception of depth is based on different mechanisms and various cues, that help to detect absolute and relative distances between objects and observer. The present report are devoted to studies of depth perception of different colour pair objects - two moving bars of one colour (red, green, blue or yellow) that are placed in front of a display of the same or another colour of various saturation. Two LEDs mounted at ends of PMMA bars illuminate from inside the surface of bars up to luminance 100 cd/m^2. Pshychometric curves are built, and the perception threshold is determined from Lorentz sigmoidal fit. The threshold depends on the luminance level of the background and bars, and on their contrast (either luminance and/or colour). For the case of an uniform background the basic depth perception mechanism is the binocular parallax. The bar relative displacement amplitude (up to 3 cm) causes the image size deviation up to 0.6%, and the monocular cues would contribute in the depth perception. Experiments performed monocularly confirm a negligible contribution of the size effect in the total perception threshold. Comparing the colour contrast and luminance contrast contribution in present conditions the following conclusions can be made. Taking as a reference the isoluminant conditions (same luminance of 40 cd/m^2 of green bars and red background), the depth perception threshold can be halved increasing the bar luminance to 100 cd/m^2. Diminishing the bar luminance toward zero the colour contrast decreases and in opposite, the luminance contrast increases. Within this range the measurements have strong dispersion; however for final monochromatic conditions (large area of red background and dark bars) the detection threshold does not differ significantly from the isoluminant case. Introducing the need of fully stereovision fusion of visual scene - using a textured monochromatic background instead of uniform one leads to small changes in the depth perception threshold, however dispersion of results decreases significantly. Results for red-green and yellow-blue pairs are explained on basis of stimuli induced activity within noisy neural environment.

ECLC2 Feature misbinding of color and motion increases with degree of shared shapes

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Peripheral visual objects may be mistakenly perceived to have a feature of similar central-field objects. Consider red dots moving downward and green dots moving upward in the periphery, and red dots moving upward and green dots moving downward in the central visual field. The percept is often all red dots (in both center and periphery) moving upward and all green dots moving downward (Wu, Kanai & Shimojo, 2004). Here, a working hypothesis was that the likelihood of misbinding a central-field feature to a peripheral object increases with the number of shared visual features among central and peripheral objects. With central and peripheral objects that always share a common collection of features for motion (upward and downward) and color (red and green), as in Wu *et al*. (2004), misbinding should increase in frequency with the degree of shared shapes in central and peripheral fields. In the periphery, the stimuli were always downward moving red squares and upward moving green diamonds. Objects presented in the central visual field had (1) no shapes in common with peripheral objects (e.g., upward moving red circles and downward moving green circles); (2) one shape in common with peripheral objects (e.g., upward moving red squares and downward moving green circles, so squares were in common); or (3) two shapes in common (e.g., upward moving red squares and downward moving green diamonds, so both squares and diamonds were in common). Observers reported the perceived motion direction of the majority of peripheral red objects and green objects. Misbinding was reported in all conditions, with increasing frequency of misbinding from condition (1) to condition (2) to condition (3). The results show that the probability of misbinding color and motion increases with the total number of shared features among central and peripheral objects.

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The contribution of human cortical area V3A to the perception of chromatic motion: an rTMS study

ECLC3

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Area V3A is an important visual region in the human brain for the perception of motion (Tootell *et al*., 1997, *Journal of Neuroscience* 17, 7060-7078). However, little is known about its contribution to the perception of motion when it is defined by colour. In this study V3A was first identified in 5 human participants on both a functional and retinotopic basis using fMRI techniques. V3A, along with other motion responsive areas (V5/MT+, dorsal V3 and V1), was then targeted for disruption by the repetitive transcranial magnetic stimulation (rTMS) whilst the participants performed a delayed speed matching task. The stimuli used for this task included chromatic, isoluminant motion stimuli which activated either the L-M or S-(L+M) cone opponent mechanisms, in addition to stimuli that contained only luminance contrast (L+M). The speed matching tasks were performed for chromatic and luminance stimuli that moved at a speed of either 2 deg/s or 8 deg/s. rTMS to area V3A produced a perceived slowing of all chromatic and luminance stimuli at the slow and fast speeds. Similar deficits were found when rTMS was applied to V5/MT+. In contrast no deficits in performance were found when areas V1 and V3d were targeted by rTMS. These results provide evidence of a causal link between neural activity in human area V3A and the perception of chromatic isoluminant motion. Furthermore, they establish area V3A, alongside V5/MT+, as a key visual area in a cortical network that underpins the analysis of both chromatically- and luminance-defined motion.

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ECLC4 Effect of colour discrimination on spatial contrast sensitivity

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Achromatic contrast sensitivity at low spatial frequencies might be better for observers with balanced L/M-cone ratios, as increased pooling of signals between different types of cones is thought to improve signal-to-noise ratios at these spatial frequencies (Hsu *et al*., 2000, *JOSA A*, 17, 635-640). Here, contrast sensitivity was measured at a range of spatial frequencies for groups of observers with varying degrees of colour-discrimination ability. Eight normal trichromatic males, eight normal trichromatic females, five deuteranomalous trichromatic males, and five female carriers of a deutan colour-vision defect were classified with a battery of colour-vision tests. Spatial contrast sensitivity was tested with horizontally oriented Gabor patches (full-width-at-half-height of 1.0 deg) at ten different spatial frequencies from 1.2 - 31.0 c deg-1. Observers were corrected to best logMAR letter acuity and viewed the stimuli monocularly through a 2.8 mm artificial pupil from a distance of 6 m. Average luminance of the Gabor patch was 35 cd m-2. There were distinct group differences between normal trichromats, carriers and deuteranomalous observers with regards to colour discrimination. There was no difference in contrast sensitivity for high or medium spatial frequencies between the groups. Normal trichromatic females had significantly better sensitivity than deuteranomalous males at the lowest spatial frequencies, with normal males and carriers having marginally better sensitivity than the deuteranomals. The normal trichromatic females were significantly better at 1.2 c deg-1 relative to both groups of males, and at 2.0 c deg-1 relative to deuteranomalous males and carriers of deutan deficiency. The main difference between the four groups of observers is that normal trichromatic females probably have a higher density of M cones than the others, and therefore an L/M-cone ratio that is closer to two (Miyahara *et al*., 1998, *Vision Research*, 38, 601-612), indicating that variations in L/M cone ratios might be the reason for the observed difference at low spatial frequencies.

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Perceptual memory for intermittent, color rivalrous images ECLC5

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When rivalrous stimuli containing luminance contrast are presented continuously to each eye, the percept alternates over time between the two stimuli. This perceptual alternation can be slowed, and even stopped, if the same stimuli are presented intermittently (Leopold *et al*. 2002). A basic question is whether the stabilized percept, which reveals perceptual memory between intermittent presentations, reflects a persisting dominant response from one eye (Chen & He, 2004; Pearson & Clifford, 2004) or persistence of what is consciously seen (the percept). This study examines binocular percepts resulting from rivalrous equiluminant chromatic gratings, which give rise to form rivalry between the two eyes but with the colors from both eyes bound to parts of the dominant form (perceptual misbinding of color to form; Hong & Shevell, 2009). A 2 cpd square-wave vertical grating was presented to one eye and a tooth-shaped vertically oriented grating (top half of grating phase-shifted by one-half cycle relative to bottom half) to the other eye. Stimuli were equiluminant (e.g., purple/white in one eye, green/white in the other eye). Initially, the stimuli were presented for several seconds and then extinguished. Then they were presented for 0.5 sec every 2.5 sec (0.5 sec on, 2 sec off) for 1 minute. In one condition, stimuli were not swapped between eyes and in the other condition stimuli were swapped between eyes after each 0.5 sec presentation. In both conditions, when a binocular, misbound percept (misbinding of color to form) was the last percept seen during the initial viewing period, the misbound percept was stabilized on later 0.5 sec presentations. This shows that static, binocularly rivalrous stimuli establish a perceptual memory during the 2-sec OFF period at the level of the binocularly integrated percept, not at the level of retinotopically specific eye-dominance.

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ECLC6 Object substitution masking in localization and color discrimination tasks

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Object substitution is a visual masking illusion that occurs when the visibility of a stimulus (target) is impaired by a set of surrounding small dots that remain visible after the target disappears (Enns & Di Lollo, 1997). Prior studies have shown that the effect of object substitution is larger in discrimination than in detection tasks (Gellatly et al., 2006) suggesting that, to some extent, the target must have been detectable while the identity was not discernable. There is good evidence that identification of a stimulus relies on its localization; so, one hypothesis is that object substitution impairs identification more than localization visibility. This study aimed to evaluate the effect of object substitution masking along the color dimension in both localization and identification tasks, in order to evaluate whether the object substitution effect occurs prior to or after the stimulus localization. The luminance of red, green and blue stimuli was equated with the grey background in order to prevent observers from localizing or identifying the target based on solely the evaluation of brightness. We used a' (Kunimoto *et al*., 2001) as a measure of awareness to consider both an objective evaluation of visibility and a subjective level of confidence. Results showed that awareness was lower in color identification than in localization, confirming the prediction that identification of a stimulus critically depends on its localization. Furthermore, object substitution equally impaired awareness in the two tasks suggesting that neither the location nor the identity of the target were available to conscious report, even though location was more visible than color when the target was presented alone. Our results seem to contrast with the hypotheses that single feature identification does not depend on localization (e.g. Treisman & Gelade, 1980), and suggest that object substitution occurs before the target has been localized.

Abstracts-Poster Session

Modelling the effect of stimulus space on measured cell responses

P1

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Experiments often treat the choice of color space as secondary because colors can in principle be represented in any color space. But colors defined in non-uniform spaces pose particular challenges. A recent study showed that a population of cells in posterior inferior temporal cortex (PIT) of macaque monkey represented all colors but had prominent peaks at the unique hues. Like previous studies in extrastriate cortex, this study used a stimulus set that had the most vivid equiluminant colors permitted by the monitor, lying on a triangle in CIE space. John Mollon has remarked that cone contrast varies among stimuli within this set, and is highest for the red and blue apices of the triangle. Mollon argues that the population color tuning for PIT would also be observed in the LGN when tested with the triangular stimulus set. Here we model how linear neurons, like in the LGN, and nonlinear neurons typical of extrastriate cortex would respond to the triangular stimulus set. We simulate the responses of three populations of cells: one tuned to cardinal directions like LGN; one with uniform color tuning across color space; and one tuned to unique hues. None of the simulations that assume linearity match the PIT data because they only yield peaks at the apices of the triangle, unlike the measured PIT population that also has peaks at intermediate colors; in particular, the simulated LGN population has only two prominent peaks. Simulations of nonlinear neurons result in less drastic distortions of the population tuning. The nonlinear model population tuned to cardinal directions shows too few responses to the blue and green apices of the triangle compared with the PIT data. The PIT data is most closely matched by simulations of populations of nonlinear neurons tuned either to unique hues or possibly uniformly across color space.

P2 Comparison of the contrast and size response functions of the magno-, parvo- and koniocellular pathways in human visual cortex

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Contrast information is transmitted from the retina to the cortex by three parallel pathways: the magno-, parvo- and koniocellular pathways. The magnocellular pathway is particularly sensitive to fast changing, blurred stimuli even when luminance contrast is low but respond weakly to chromatic isoluminant stimulation. In contrast, the parvo- and koniocellular pathways are very sensitive to high spatial frequency stimuli even with low chromatic contrast. Parvocellular neurons respond preferentially to red-green contrast, while koniocellular neurons respond to blue-yellow contrast. Furthermore, the parvocellular pathway responds mostly to foveal stimulation, while the magno- and koniocellular pathways convey mostly peripheral information. As a result, these different pathways might code stimulus size differently. The aim of this study was to use ERP/EEG recordings to elucidate how the three retino-cortical pathways process contrast and stimulus size. We used stimuli with temporal, spatial and chromatic properties so that each stimulus mainly activated a single retino-cortical pathway. The properties of the stimuli were based on the neuronal properties of each of these pathways, obtained from single cell studies in animal models, and on the chromatic properties of the post-receptoral mechanisms, as determined by psychophysical studies in humans. The stimuli used were phase reversed circular horizontal Gabor patterns. Analysis of the visual ERP responses showed that the three pathways responded to contrast with different and somewhat unexpected dynamics. The responses of the magno- and parvocellular pathways showed saturation with increasing contrast, while the response of the koniocellular pathway was proportional to contrast. For the magno- and koniocellular pathways, increasing stimulus size increased the slopes of the contrast response functions. This does not appear to be the case for the parvocellular pathway where the slopes of the contrast response functions were independent of stimulus size, suggesting that different rules of spatial summation operate for these three pathways in humans.

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Age-related changes in temporal S-cone ON- and OFF-pathways P3

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S-cone sensitivity decreases with age, but the magnitude may depend on temporal parameters. In this study, age-related changes in an S-cone pathway were quantified for chromatic increments and decrements in terms of their impulse response functions (IRF). Thresholds for a series of double pulses, separated by varying interstimulus intervals (20-360 ms), were measured for chromatically modulated stimuli. Isoluminance and the location of tritan lines were determined individually. The stimuli were presented as a Gaussian patch ($\pm$1SD= 2.3 deg) on an equiluminant white background in one of four quadrants around a central fixation cross so that detection could be measured with a four-alternative forced-choice method and interleaved staircases for each ISI. Subjects included ten younger (mean = 23 years) and ten older (mean = 74 years) observers, who were carefully screened to rule out anterior segment, retinal or optic nerve abnormalities. IRFs were calculated from thresholds as a function of ISI using a model that varied four parameters of an exponentially-damped sinewave. As previously reported, IRFs for S-cone increments in excitation were slower than for luminance modulation, but faster than IRFs for S-cone decrements. This is consistent with detection by separate ON- and OFF-S-cone pathways. Additional analyses will describe differences in S-cone IRFs for increments and decrements to compare age-related changes in putative ON- and OFF-pathways.

P4 The intensity threshold of colour vision in two species of parrot

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Birds have advanced colour vision that has inspired to a great amount of research. Still however, only little is known about avian colour vision in dim light. We have used behavioural tests to determine the intensity threshold of colour vision in Bourke's parrot (*Neopsephotus bourkii*) and the budgerigar (*Melopsittacus undulatus*). These are Australian parrots with similar lifestyles and body sizes except for the eyes that are larger in Bourke's parrots. Furthermore, while the budgerigars are diurnal Bourke's parrots are active also before sunrise and after sunset. This suggests that its eyes are large to increase sensitivity. Since the intensity threshold of colour vision is dependent upon the sensitivity of the eyes, our hypothesis was that the Bourke's parrots have colour vision in dimmer light than budgerigars. To test this hypothesis we also performed morphological investigations and calculated the optical sensitivities of the single cones for white light. Surprisingly, Bourke's parrots loose colour vision at higher light intensities (-0.398 log cd/m^2) than budgerigars (-0.925 log cd/m^2). These results cannot be explained by the eyes' optical sensitivities that are almost identical (budgerigar = 0.27 μm^2 sr^{-1}, Bourke's parrot = 0.25 μm^2 sr^{-1}). However, the retina of Bourke's parrot has more (cone to rod ratio =1.2:1) and longer rods (18.5 μm) than the budgerigars (2.1:1, 13.3 μm). These adaptations together with the large eyes might provide the Bourke's parrots with good spatial vision in bright light and, due to pooling of rod signals, a high sensitivity that allows them to be active in dimmer light. As a consequence, the retina of Bourke's parrot contains fewer cones, which implies that budgerigars can pool more cones within each retinal receptive field and thereby acquire stronger colour signals. If so, it might explain the difference in the behavioural results between the parrots.

Opsin divergence and retinal regionalization in the visual system of the cricket (*Gryllus bimaculatus*) P5

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Most adult insects possess two eye types: three ocelli and a pair of compound eyes. The concomitance of different kinds of visual organs in one organism makes insects an interesting model for visual pigment evolution. Whereas the spectral sensitivities of the compound eyes (Briscoe and Chittka, 2001, *Annual Review of Entomology* 46, 471-510) and the ocelli (Mizunami, 1995, *Vision Research* 35(4), 443-452) have been investigated in many insect taxa, studies on the sequence and expression pattern of opsin genes have concentrated on only a few, highly derived, holometabolous insect orders. Spectral sensitivities do not necessarily mirror phylogenetic relationships and, based on the limited molecular data set available so far, general conclusions on the evolution of insect opsins are questionable. We have therefore investigated retinal opsins in the cricket Gryllus bimaculatus, a comparatively primitive, hemimetabolous insect. Combining electrophysiological and molecular methods, we provide evidence for two ocellar photopigments, a green- (λ_{max} = 511 nm) and an ultraviolet (UV)-sensitive one (λ_{max} = 350 nm). In the compound eyes, three spectral classes of photoreceptors with peak absorbances in the green (515 nm), blue (445 nm) and UV (332 nm) range have previously been identified (Zufall *et al*., 1989, *Journal of Comparative Physiology A* 164(5), 597-608). We show that the respective opsins differ from those found in the ocelli. According to the opsin expression pattern, the retina of the compound eyes can be divided into three parts: (1) the so-called dorsal rim area, which is specialized to detect skylight polarization, with blue- and UV-opsin, (2) a newly-discovered ventral area of unknown function with blue- and green-opsin and (3) the remainder of the compound eye with UV- and green-opsin. These results indicate that regionalization in the visual system of the cricket is more complex than assumed earlier.

P6 Spectral sensitivity in the harbor seal Phoca vitulina: facts and open questions

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On their way back to an acquatic life style, the ancestors of marine mammals experienced an environment with a spectral composition shifted towards shorter wavelengths with increasing water depth and a much stronger light attenuation than air. In order to improve gain of visual information, the visual system of marine mammals should have adapted to the spectrum dominating their under-water environment. In fact, selective pressure caused a loss of functional SWS-cones in pinnipeds and cetaceans but in the latter group, it has been shown that the absorption maximum of the remaining MWS-cones is shifted towards shorter wavelengths. Such a blue shift of sensitivity is still questionable in pinnipeds. Molecular biological analyses revealed that the spectral tuning of the MWS-cones of the harbor seal is equivalent to that of most terrestrial carnivores with λ_{max} ranging from 550 to 552 nm. Contrary to this finding flicker-photometric ERG indicated that λ_{max} is shifted towards 510 nm. We investigated spectral sensitivity in one harbor seal by means of color intensity adjustment. Experiments were conducted in air under an illumination of 9 lx. Stimulus pairs consisted of circular blue or green and grey discs of different intensity that were presented on a TFT monitor. The seal was trained to indicate the position of the brighter stimulus in a two alternative forced choice task. The observed point of equal brightness of the colored stimuli was compared to their point of equal brightness calculated from spectral sensitivity functions that were generated using the Govardovskii template. Preliminary results confirm a blue shift of spectral sensitivity in the harbor seal, with λ_{max} at 510 nm. However, a detailed investigation on spectral tuning as a function of luminance is necessary in order to exclude that the observed blue shifts are resulting from mesopic rather than photopic vision.

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Spatial organisation of the cone photoreceptor mosaic of the domestic chicken (gallus gallus) P7

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The domestic chicken, like most birds, has a keen sense of colour. This is due, in part to the presence of pigmented oil droplets found between the inner and outer segments of the cone cells. The oil droplets serve as a filter, sharpening the spectral response of the photoreceptor. These droplets can be classified using a combination of bight field and fluorescence microscopy. This method yields six classes of cone, named by their appearance: Red (R), Yellow (Y), Clear (C), Transparent (T) and the two 'halves' of the double cone: Principal (P) and Accessory (A) (Bowmaker *et al*., 1996, *Vision Research*, 37(16), 2183). The loci of these photoreceptors form a uniformly distributed mosaic, with each type uniformly distributed within it, yet attempts at assigning a 'crystalline' structure have been unsuccessful. However, a measure of order (Cook J.E., *Visual Neuroscience*, 1996, 13(1), 15) indicates that the mosaic is in fact highly ordered. To investigate this further, a statistical analysis of the connections found using a Voronoi based nearest neighbour analysis was undertaken. The results suggested that the high order may be explained by spatial constraints and a principle of exclusion - where the single cones exclude other single cones from the area surrounding them. A simple generative model constructed using this principle produced the same statistical distribution of neighbour pairings. Another analysis, using autocorrelograms (e.g. L.Galli-Resta *et al*. 1999, *European Journal of Neuroscience*, 11, 1461) was consistent with this mechanism. This analysis showed the retina to be unlike most reported in the literature. There is long range order amongst the double and C-type cones (reflected also by the individual order parameters) contrary to the apparent absence of a crystalline structure. This anomaly is compounded by the lack of circular symmetry in the autocorrelograms (the highest symmetry observed is D2), and non-central exclusion zones in the crosscorrelograms. This aside, it would seem that the apparent complexity is due to the number of cone types, and thus a result of the need for a uniform sampling of a large number of spectral components.

P8 Constructing a colour-difference acceptability scale

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The evaluation of colour-difference tolerances is a major issue in industry. Whereas the CIELAB colorimetric system has introduced perceptive dimensions - hue and chroma - to express perceived colour differences, the CIE94 and subsequent formulas are proposed to express colour-difference tolerances. Weighting functions S and parametric factors k may be chosen by the user to reflect changes in viewing condition and the acceptability judgements of the consumers. In practice, these factors are often empirically derived after the responses of a panel of observers. Little is known on how colour tolerances are related to just noticeable colour differences. Unlike colour discrimination which involves retinal mechanisms, colour difference acceptability judgements might involve post retinal mechanisms and cognitive processes. We have planned an experiment where the size (10, 10^o), the eccentricity (foveal up to 45^o) and the background (uniform or variegated) of the stimuli are varied in order to investigate their effect on colour-difference tolerances. Observers are asked to rate the level of colour-difference acceptability on a psychometric scale. Results are being collected on the colour-difference acceptability around a white colour centre. Trends in the colour scales will be analysed along the a^* and the b^* dimensions of the CIELAB colour space. The usefulness of modifying the parametric factors k according to eccentricity will be discussed.

New structure for a physiological model of colour appearance P9

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Since some decades, there is an ambitious scientific objective focused on the development of an integral colour perception model, which permits to correlate physical parameters (luminance, purity, etc) of visual stimuli with perceptual attributes (brightness, hue, colourfulness, etc). This problem has been tackled from different scientific approaches. Some works only try to fit one data set for reproducing so far as possible other data, and usually good results are obtained using this type of models. One example of that it is the CIECAM02 model, which is the latest colour appearance model adopted by CIE (CIE, 2004, A Colour Appearance Model for Colour Management Systems: CIECAM02. *CIE Publ*. 159). On the other hand, other studies try to take into account the visual pathways of the human visual system combining such as psychophysical as neurophysiological data (De Valois *et al*., 1997, *Vision Research*, 37(7) 885-897; Valverg *et al*., 2008, *Color Research and Application*, 33(6) 433-443; Gómez-Chova, *et al*., 2005, ATTD: a new colour vision model based on the physiology of the visual system, *AIC'05*, Granada, Spain, 1007-1010). Although they cannot fit some parameters as well as other models, they are useful and powerful tools for understanding of the process that have place in the human visual system. Particularly, our aim is to reconcile both ideas: trying to obtain a (physiological) neural model for colour perception that can reproduce colour appearance data such as unrelated and related colour stimuli. For this reason and considering new works (Wueguer et al, 2005, The cone inputs to the unique-hue mechanisms, *Vision Research*, 45 3210-3223; Johnson *et al*., 2004, Cone inputs in Macaque Primary Visual Cortex, *J. Neurophysiol*, 91 2501-2514), we have redesigned the previously shown ATTD05 model, giving more importance to the stage of the cortical process which was underestimated in the previous version.

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P10 Connecting disciplines to ground a design study. An emotional response to clothing and colour

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This paper aims to present the research project for a PhD degree presently being carried out for the Doctorate in Design at the Faculty of Architecture, Technical University of Lisbon, on the subject concerning the relationship between Colour, Clothing and Emotional Response, from the standpoint of the neurological findings namely using fMRI-functional magnetic resonance images studies. The fact that looking at a piece of clothing involves a perceptual process wherein senses and cognition are intertwined and constitute an experience associated with an emotional network. For that purpose the understanding of the neurological process is required in terms of mapping the neural activations induced by the act of seeing a piece of clothing, completed with the enquiry of the content of the feeling expressed by the experienced. The disciplinary founding the presentation discloses a complex system of data collection that integrates an extensive literature review pertaining to the neurological process of visual perception of artifacts , and emotions as well as to the meaning of affective relations established between human beings, clothing and colours. Seeing, identifying and feeling something about a piece of clothing is an associate process. The process that leads to the brain is multi-layered and comprises the signals that are sent through the eye and the retina to the brain where images are identified, interpreted and meaning associations and feelings are constructed and evolves a multiple array of areas of the neural system. We may anticipate that the neurological process involved in the identification of a piece of clothing is different from the one induced by other objects, and hence demonstrate that the cognitive dimension of our relation with clothing probably identify the feelings we associate with it.

Visual communication and inclusive design - colour, legibility and aged vision

P11

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This research project, a work in progress developed in Doctoral Design Course-FAUTL, has the aim of determining if there are specific design principles to be applied to visual communication design objects, in order to be easily read and perceived for all individuals; develop the study of aspects related with vision, colour vision, perception, chromatic contrasts and legibility so as to identify the problems related with the decrease of vision in the normal ageing process; what is easily perceived by young designers (some colour combinations, colour contrasts, typography), sometimes is difficult to perceive by the majority of people who do not fit this young profile. With aging, quality of vision worsens independently of aging eye diseases, colour vision and contrast sensitivity are also affected. “Color vision deficits cause difficulties in discriminating colors on the three most important perceptual dimensions of color: hue, lightness and saturation. Colors are best chosen to differ dramatically on all three dimensions”. (Arditi,1999, Effective color contrast: Designing for people with partial sight and congenital color deficiencies. NY: Lighthouse International). “Our research indicates that vision impairment increases dramatically with age. It is our goal to underscore the need to incorporate principles of universal graphic design into all visual media, so that they are truly useful and legible to the largest possible population. (Silverstone, 2007, Big Type Is Best for Aging Baby Boomers. A Case for Universal Graphic Design. Lighthouse International).The visually accessible design is a relevant approach, once the world population is getting older, life expectancy is enlarged; and “the vast majority of people benefit from having things made easier to see”. (Evamy and Roberts, 2004, In sight - a guide to design with low vision in mind, Rotovision). Scientific knowledge about vision, colour, colour vision, can improve design process and contribute for inclusive and efficient design practice.

P12 Is natural variation in image spectra partly responsible for the lower population density of S-cones?

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The lower population density of human S-cones has been explained as a response to the greater blurring of the retinal image at short wavelengths. Here we consider the possibility that the natural variation in image spectra may also have a role. We examined the variability of energy captured by L, M and S cones in published sets of images of natural scenes, both hyperspectral images (Foster DH, Amano K, *et al*., 2006, *J Opt Soc Am A* 23, 2359-72) and images from calibrated trichromatic cameras (Olmos A and Kingdom FAA., 2004, http://tabby.vision.mcgill.ca; Vazquez J, Párraga CA, *et al*., 2009, *J Imaging Sci Tech*. 53(3), in press). The images, cropped to the central 512x512 or 1024x1024 pixels were divided into quadrants, and within a quadrant, the difference between each pixel value and that of the quadrant mean was determined. The coefficient of variation of the squared differences was plotted as a function of spatial scale as the quadrants were themselves divided into quadrants iteratively. As the quadrant dimension decreased, the average coefficient of variation increased, and it did so in the same way for L and M cone energy. For S cone energy, however, the coefficient of variation was generally larger. The difference emerged in most images except those of snow and sand, and was less pronounced in images that included sky and blue pigmented objects. Although its physical origin has yet to be determined, some natural variation in image spectra may perhaps help to explain the lower population density of human S-cones.

Accuracy of photometric stereo with textures calibration samples

P13

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Colour appearance in object imaging depends upon several factors: imaging device and geometry, lighting conditions and the object itself. When dealing with textured objects these factors become critical (e.g. keeping fix the position of the camera and the object, the colour appearance of the object changes if we change the direction of illumination) and can be a problem for object characterization. Photometric stereo methods have been used for number of years and allow recovering normal vectors and albedo (Barsky and Petrou, 2003, *IEEE Transactions on Pattern Analysis and Machine Intelligence*, 25(10), 1234-1252), a quantity that has long been used in computer graphics to characterize textured surfaces. However, the evaluation of the accuracy of such a system is a difficult task. We introduced a calibration method where a set of seven samples of different colours are used. Each sample is composed by five chips made with the same material (polymer clay) and having the same colour. One of the chips is flat, and each of the other four is made of different textures. Within each calibration sample, albedo recovered from the flat sample is used as reference, since in this case the absence of textures allows obtaining a perfectly smooth albedo, and the albedo recovered from the four samples are compared with the reference. This method was used to compare albedos recovered using two alternative algorithms: one which does not correct for highlights or shadows and one which compensates for these factors. It was found that correcting for highlights and shadows lead to an improvement of about 50% in the accuracy of the recovering procedure thereby making technique suitable for visual applications.

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P14 A behavioural investigation of human visual short term colour memory

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Previous studies of Visual Short Term Memory (VSTM) have indicated the existence of high fidelity memory mechanisms for visual attributes such as orientation, spatial frequency, velocity and contrast in addition to colour. However, studies that have examined short term memory for colour have not produced consistent results. In this work, we assessed the effects of different time delays on the colour discrimination ability of 3 colour normal observers using a delayed match to sample task. In preliminary experiments based on a colour categorisation process we identified 12 chromatic axes in DKL colour space, the 4 unique hues, the 4 adjacent colour categories and the 4 hues that are identified by the cardinal axes of the cone opponent mechanisms. As reference stimuli we used circular patches of these 12 hues. Test stimuli were rotations away from the reference axis within a 40° range ($\pm$ 20^o), we had 11 test chromatic axis per reference axis. Stimuli were equally saturated isoluminant circular sharp edged patches and their diameter subtended 1.5^o of visual angle. Reference and test stimuli were presented simultaneously and with 1, 5, 10, 15 second time delays in a multiple probe design where 4 different chromatic axis and their corresponding test axes were combined in a random order in one experimental run. Results were plotted as a percentage of the correct answers as a function of the chromatic axes. The increase in the retention interval resulted in an increase in discrimination thresholds and a decrease in sensitivity. However, we did not find significant or consistent hue shifts. We have been unable to identify relationships between memory performance and the different perceptual colour mechanisms. These results suggest that there is only a small deterioration in colour memory during the course of the examined time delay.

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Basic colour names for 2D samples: effects of presentation media and illuminants

P15

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We have previously shown that colour memory is independent of presentation media and of the illuminants under which colours are viewed [Bloj *et al*., 2008, *Proceedings of the 2nd Material* & *Sensation Meeting*, Pau-France]. In the present study we investigate whether colour naming is also unaffected by these two factors. Forty-seven colour samples that spread over the whole hue circle were chosen from the Natural Color System. They were presented either as real paper samples or as accurate computer simulations displayed on a calibrated monitor. The colour swatches could be presented under either a daylight illuminant (two intensities, 85 ('D1') or 50 cd/m^2 ('D2')) or a highly artificial purple illuminant (45cd/m^2 ('Lily')). The colour samples were shown in arrays of 16 (4 x 4 layout) and observers' task was to assign one of the eleven basic colour terms to each of the samples. Six observers repeated this colour naming task five times for each presentation medium and illuminant. Analysis of colour naming for each medium revealed that each colour sample was assigned the same colour term in 86% (or 87%) of the time when presented as real papers (or on a monitor). This consistency was the same regardless of the illuminant under which colours were presented. Therefore, the consistency of colour naming is independent of presentation media and illuminants. This confirms our previous findings from the colour memory experiment. However, on average, the same colour term for surface and display colours was only assigned in 73% of the cases. This level of agreement was highest for colour samples under daylight (D1-82%, D2-73%) and poor for Lily (65%). Despite the high consistency found in colour naming within a presentation medium and illuminant there are limitations to cross-media agreement.

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P16 Perceptual antinomies due to the watercolor illusion: how does the brain solve them?. The problem of visual wholeness

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The purpose of this work is to study how the brain solves perceptual antinomies, induced by the watercolor illusion in the color and in the figure-ground segregation domain, when they are present in different parts of the same object. The watercolor illusion shows two main effects: a long-range coloration and a figural effect across large enclosed areas (Pinna, 1987; Pinna, Brelstaff & Spillmann, 2001; Pinna & Grossberg, 2005). This illusion strongly enhances the unilateral belongingness of the boundaries (Rubin, 1915) determining grouping and figure-ground segregation more strongly than the well-known Gestalt principles. Due to the watercolor illusion both the figure and the background assume new properties becoming respectively a bulging object and a hole both with a 3-D volumetric appearance (object-hole effect). When the coloration and the object-hole effects induced by the watercolor illusion are opposite (antinomic) within different portions of the same shape some questions emerge: Do the antinomies split the shape in two parts (a half shape appears as an object and the other half as a hole) or are they solved through a new emergent perceptual result beyond the single effects?. Is there a predominance of one component over the other that is less visible or totally invisible?. What is perceptible and what is invisible?. Is there a wholeness process under conditions where perceptual antinomies coexist?. By imparting motion to a watercolored object that gradually should become a hole while overlapping another object placed behind, is the wholeness of the watercolor object weakened or reorganized in a new way?. The same questions can be asked in relation to the coloration effect of the watercolor illusion. The results of psychophysical experiments suggested that the antinomies tend to be solved through a new emergent way (e.g. by creating transparency) or not to be perceived at all. Some principles of perceptual wholeness are suggested (e.g. the part for the whole and the object/color inertia). The results are explained in the light of the FACADE neural model of biological vision (Grossberg, 1994).

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The role of Petter's rule in explaining illusory contours and neon color spreading

P17

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Petter's figures (Petter, 1956) concern all the conditions where a chromatic or black homogeneous irregular pattern is perceived as made up of independent surfaces separated in depth and delineated by illusory contours in the area of apparent intersection and stratification. Petter suggested that the perceived stratification occurs according to a general rule stating that the surface with the shorter contours, placed in the region where the surfaces look superimposed, has a greater probability of appearing in front of the other surface. The main purpose of this work is to study psychophysically whether Petter's rule may have a bearing on illusory contour formation or neon color spreading. The aim of the experiment was to obtain a quantitative study of the role of Petter's rule under dynamic conditions on three kinds of stimuli: Petter's figures, illusory contours and neon color spreading. The results clearly demonstrate the basic role played by Petter's ratio in influencing presence/absence, strength and depth organization of the component parts of Petter's figures, illusory contours and neon color spreading. We suggested that Petter's rule is a contour formation rule due to global boundary contour interactions determining the depth organization of the visual components. This rule derives from the formation of two different kinds of contours, modal and amodal, linked together by the dynamics of filling-in of contour gaps. The results are interpreted in terms of Grossberg's FAÇADE model (Grossberg & Mingolla, 1985a, 1985b).

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P18 Attentional modulation of chromatic onset visual evoked potentials

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Past studies have shown that behavioral, fMRI, and visual evoked potential (VEP) responses may be subject to changes with attentional modulation. Other studies report that responses from early visual areas generally do not show attentional effects. Attentional modulation of the VEP has clinical significance in that it is often only possible to monitor patient attention indirectly (e.g. through direction of gaze). The magnitude of reported attentional effects depends upon the stimulus/distractor geometry as well as the task-relevance of the distractor. We report here the results of a series of experiments to ascertain the degree to which attentional manipulations affect the characteristics of the spatio-chromatic, pattern-onset VEP. In this series, we investigated the effects of spatial separation as well as task difficulty and relevance on the amplitude and latency of the response. The chromatic VEP responses showed little or no change in amplitude or latency for manipulations of attention. This suggests that the chromatic onset VEP response may reflect lower level visual mechanisms that are relatively unaffected by attentional feedback. The results also suggest that in clinical settings direct monitoring of attention is not necessary for the chromatic-onset VEP and that monitoring of fixation or gaze is sufficient.

How does the color influence grouping, numerousness, reading and calculation?. The role of chromatic wholeness and parcelling-out

P19

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Pinna & Reeves (2006) have recently introduced the notion of "figurality", defined as the phenomenal appearance of what is perceived as a figure within the three dimensional space and under a perceived illumination. It concerns the shape, the color, the 3D appearance of an object with light and shaded regions, as well as the direction and the color of the light emerging from the object. Some "principles of figurality", similar to the Gestalt ones, were suggested (see also Pinna, 2008; Pinna & Tanca, 2008). The figurality is a subset of a more holistic property: the perceptual wholeness. This property includes also the grouping problem studied first by Wertheimer (1923), who put the following question: "How do individual elements create larger wholes separated from others?". The wholeness can be studied by measuring the strength of the grouping and of the cohesiveness of the elements within a whole but also through related effects like the apparent numerousness and unitarity. This work investigates the following questions: What is the role of color in determining the wholeness of an object?. How does the color interact by inhibiting or exciting other main factors inducing wholeness, like the shape, the figure-ground segregation and the grouping principles?. To answer these questions we studied psychophysically conditions where equiluminant colors are used to favor or break (parcelling-out) the wholeness of objects like geometrical composite figures, words and numbers. The tasks were: to evaluate their cohesiveness and numerousness; to read texts and calculate additions. The results showed that the color determines the wholeness and figurality of the stimuli by strongly influencing (enhancing or reducing) the performances of the subjects during these tasks. The results are interpreted in the light of a chromatic parcelling-out process of separation, division and breaking of a whole object into unconnected and ungrouped elements. Some general principles of whole formation are suggested.

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P20 Differential color congruency effects across metacontrast and object substitution masking in equiluminant viewing conditions

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When a second visual stimulus (the mask) is presented shortly after an initial stimulus (the target) and in close proximity to it, visibility of the initial target can be severely reduced, a phenomenon called visual masking. Prior studies have identified a color congruency effect in visual masking, whereby larger masking effects are typically observed when the target and mask match in color than when they do not. However, prior studies have often failed to equate the luminance of masks and targets of different colors, allowing for the possibility that the color-congruency effect may have in fact arisen from congruency along the luminance channel rather than along hue channels. Here, we study color-congruency effects under conditions of perceived equiluminance using two types of visual masking procedures: Metacontrast Masking (when the mask stimulus has contours that closely follow, but do not overlap those of the target stimulus) and Object Substitution Masking (when the mask stimulus consists of four small dots surrounding the target that onset with the target but remain visible after it offsets). Further, we examine whether the observer's task (shape identification versus color identification) interacts with the color-congruency effect and whether this interaction is different across these two forms of masking. Our results show that (a) color-congruency effects are most prevalent in forms of masking that are sensitive to the surface properties of the stimulus (such as MM), and (b) they suggest that OSM might not depend on the interaction between contours. Finally, the results are also consistent with the proposal that at least part of OSM is mediated by motion-processing mechanisms (that update the position and identity of objects as they change over time) because low-level motion detectors are blind to hue, so one would expect a lower-degree of color-driven congruency effects in OSM.

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Difference of a colour contrast effect in 3-dimensional layout and 2-dimensional layout

P21

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An effect of colour contrast is the phenomenon in which colour appearance of a chromatic field is changed by an existence of a surrounding chromatic field. This effect can be observed strongly in the simple stimulus in which a colour patch at a centre is surrounded by a larger colour patch. However, we do not feel such kind of chromatic shift on a coloured object in a natural environment. There are some possible reasons for this little colour contrast effect such as colour constancy, object-based colour memory, surface pattern of a material, 3-dimensional perception between the object and the background, and so on. This research investigates the influence of 3-dimensional layouts between a coloured object and a coloured background without a binocular disparity. We asked an observer to match a colour of an object in a photo image presented on a LED screen to a colour square of 10 degree presented on a CRT. In the first condition, we used photo images in those the object was one of a book (purple), a CD-case (brown) or a soap case (orange) and was placed in front of a coloured wall. The colour of the wall was one of red, blue, yellow or green. In the second condition, we used the images in those the area of the object in images was painted by one homogeneous colour (processed by Adobe Photoshop), in order to eliminate influences by the object recognition and surface pattern. In the third condition, the area of the background wall was also painted by one homogeneous colour in order to make 2-dimensional layout. Colour of each matching point was measured by a luminance and color meter. The difference of matching points in chromatic coordinates between different background wall colours indicates the amount of colour contrast effect. The result shows that the effect of colour contrast was substantially observed only in the third condition (2-dimensional layout) but not other conditions (all 3-dimensional layouts including real object presentation as a control). It indicates that the 2-dimensional layout is important for the colour contrast effect, and the 3-dimensional layout, even presented on the screen, disturbs the colour contrast effect.

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P22 Very-long-chromatic adaptation and short-term chromatic adaptation: same or different mechanisms?

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This research tested whether very-long-term (VLT) chromatic adaptation and short-term chromatic adaptation share a common mechanism. VLT chromatic adaptation results from exposure to an altered chromatic environment experienced over hours or weeks. Color shifts from VLT adaptation are measured hours or days after leaving the altered environment. Short-term chromatic adaptation results from exposure for a few minutes or less, with color shifts measured within a few seconds after the adapting light is extinguished. In this experiment, both types of adaptation were combined. All adaptation was to reddish-appearing long-wavelength light. Shifts in unique yellow were measured following adaptation. Previous research showed shifts in unique yellow following VLT chromatic adaptation, but shifts in unique yellow caused by short-term chromatic adaptation can be 10 times greater than for VLT adaptation. This research determined whether the color shift from VLT adaptation is cumulative with the far larger shift from short-term adaptation or, alternatively, if short-term adaptation saturated a unified adaptation mechanism or inhibited VLT adaptation. For VLT chromatic adaptation, the subject viewed for one hour per day a CRT monitor that displayed a moving red/black grating composed primarily from the R phosphor (Judd $x = 0.60$, $y = 0.35$, 22.4 cd/m^2). Exposure was repeated daily for 12 to 14 days. Unique yellow was measured each day before the start of the VLT adaptation exposure, i.e., 22 hours after the end of viewing of the very-long-term adapting environment. The subject set an admixture of 540nm-plus-660nm light to appear equilibrium yellow at five luminance levels between 0.5 and 2.5 log trolands. For short-term adaptation, a three-minute exposure to a 660 nm light at 100 td was incorporated into a testing session just before the equilibrium yellow measurements. Shifts in unique yellow due to only short-term or only CRT adaptation were measured separately at all test-stimulus levels. The color shifts from VLT and short-term adaptation were cumulative, which is consistent with short-term and long-term chromatic adaptation acting on separate neural mechanisms.

Unique hues in the near peripheral retina; matching vs naming P23

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It is known that there is a distortion of hue and saturation in the peripheral visual field. However, some hues appear to be unchanged with eccentricity. When an asymmetric matching paradigm was used, four hues in the blue, red, yellow and green regions of colour space were unchanged and these were referred to as invariant (Parry *et al*., 2006, *JOSA*, 23, 7, 1586-97). Three of these invariant hues were similar to unique blue, red and yellow. However, for most observers there was a marked difference between unique and invariant green. To investigate this, we have measured unique hues using a range of eccentricities and saturations. An asymmetric matching and a 4AFC paradigm were used to establish invariant and unique hues, respectively. The task for the first procedure was to match in colour a peripheral spot with a para-foveal spot, for 24 different hues at 3 saturation levels and two eccentricities (18^o and 10^o). In the 4AFC paradigm, 21 hues were presented 20 times at three saturations and three eccentricities (18^o, 10^o and 1^o). The observer had to name the hues as red, blue, green or yellow. All invariant and unique hues were found to be constant with eccentricity and saturation. The unique green and yellow, established with 4AFC, was found to differ from the invariant green and yellow, determined using the matching task. However, red and blue invariant hues correspond well with unique hues. The data suggest that different mechanisms mediate the matching of green and yellow compared with the identification of unique hues. This is similar to the difference between detection and discrimination of spectral stimuli: the detection process is dominated by the cone opponent mechanisms and is most sensitive, whereas discrimination is influenced by more central processes (Mullen K. & Kulikowski J.J, 1990, *JOSA*, 7, 4, 733-42).

P24 Surface color matching under mesopic illumination

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Color appearance undergoes significant changes during mesopic vision. Such changes pose a problem for color perception when regions of a surface are differentially illuminated, as from shadowing. Color signals from each region may be processed differently (e.g., more or less rod involvement) depending upon the level of illumination. Thus, perceiving constant surface color may be impaired under low light levels. The present study used a visual search task to measure ability to match surface color across different levels of mesopic illumination. Dark-adapted observers viewed a two-chambered light box with each chamber containing an array of spectrally calibrated colored paper samples (Color-aid, NY). Light level in each chamber was independently controlled to produce different levels of illumination that were either the same or different. The observers' task was to view a color test sample (2^o x 2^o) under one level of illumination and locate its physical match from an array in the adjacent chamber. The physical match to the test sample was present in the adjacent chamber's array on 80% of the trials. Twenty test samples, chosen to represent a large region of color space, and 20 arrays of 25 color samples each were used. Matching performance depended on light level and uniformity of illumination across the two chambers. The general effect of decreasing light level between 20-2 Lux was sharply lower hit rates and higher false alarm rates regardless of sample color; below 2 Lux matching approached chance performance. A significantly larger decrement in matching performance was observed when light level differed across the chambers. Our finding that matching surface color is more impaired under non-uniform than uniform levels of illumination suggests that constant surface color perception mediated by mesopic vision is influenced by the spatial distribution of light level across a visual scene.

Variation of chromatic discrimination thresholds with luminance and state of chromatic adaptation

P25

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Colour discrimination is affected by both luminance level and the spectral composition of the adapting background. In this investigation we measured colour detection thresholds under conditions that isolate the use of colour signals (Barbur, 2003: *Progress in Brain Research* 144:243-259). We examined specifically how the luminance level of the adapting background field (range: $\sim$ 0.1 to 31 cd/m^2) and the state of chromatic adaptation of the eye affect both red/green and yellow/blue chromatic sensitivity. 20 subjects took part in the study, but only 4 subjects carried out the full set of measurements. The background chromaticities selected for the 12 states of chromatic adaptation employed were within the limits imposed by the CRT display. For each background luminance and state of chromatic adaptation we measured the subject's chromatic discrimination ellipse and computed the corresponding cone photoreceptor contrasts. The results show that the major and minor axes of the ellipse relate linearly to corresponding cone excitations, over most of the range. A model was produced that predicts colour detection thresholds based on the spectral radiance of the adapting background and assumed spectral responsivities for cone photoreceptors in the eye. The major and minor axes of the ellipse can be predicted from knowledge of background cone excitations levels and measured experimental data. For each adapting background chromaticity the orientation of the major axis of the ellipse is computed by establishing the direction in colour space that yields close to zero L- and M-cone contrasts. The model predicts well the parameters of the measured ellipses with typical errors of less than 10% (over most of the range of light levels investigated). In conclusion, the simple colour discrimination model developed in this study can be used to predict colour discrimination thresholds from a knowledge of the spectral radiance of the adapting background field.

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P26 Effect of the peak sensitivity wavelength of the photopigments on object colour

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Absorption spectra of cone photopigments peak at different wavelengths for normal trichromatic individuals. How does this variation in spectral positioning of photopigment peak sensitivity affect objects colour appearance? This issue is addressed from the theoretical point of view using a new colour space for object colour reported at the ICVS2007. This space is based on a set of rectangle spectral reflectance functions which make a complete colour atlas. The atlas is geometrically represented as a sphere in the 3D space. Being metameric to one of the elements of the atlas, each spectral reflectance maps to the corresponding point in the sphere. While the atlas itself is independent of cone photopigments, the position of its image in the sphere does depend on spectral positioning of photopigments (referred to as individual colour stimulus shift). (A particular case of such dependence is observer-metamerism.) This happens because for different observers a spectral reflectance is metameric to different elements of the atlas. Such an individual colour stimulus shift, measured in terms of spherical metrics, was evaluated for 1600 Munsell papers by varying peak sensitivity wavelength of the S, M, and L photopigments over the broad range of spectrum. The individual colour stimulus shift averaged over all the papers was found to be smaller than the difference between adjacent pages in the Munsell book measured in the same spherical metrics. It follows that the individual differences in colour appearance between trichromatic observers caused by variations in spectral positioning of photopigment peak sensitivity are practically insignificant.

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Pupil colour responses in patients with congenital and acquired hemianopia P27

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Objectives: To investigate and compare pupil responses to visual stimuli presented in both the sighted and blind regions of the visual field in patients with congenital or acquired occipital damage. Methods: The P_SCAN system was employed to generate luminance and chromatic stimuli and to measure the corresponding pupil responses. To ensure that the chromatic stimuli were not detected by achromatic contrast mechanisms and / or rods, the coloured stimuli had zero scotopic contrast, in addition to being photopically isoluminant. The luminance stimuli varied systematically in luminance contrast. All stimuli were presented both in the sighted and the blind regions of the visual field viewed binocularly. We report preliminary findings in patients with congenital (3 cases), acquired homonymous heminanopia (7 cases) and in 7 controls. Results: Pupil responses measured in the blind hemifield of patients with acquired cortical damage were in general of reduced amplitude to the luminance stimuli and were almost absent to the chromatic stimuli when compared to those measured in the corresponding regions of the sighted field and in normal subjects. However, for the congenital group, pupillary responses to both luminance and chromatic stimuli were in general of larger amplitude when imaged in the blind hemifield when compared to responses measured to identical stimuli presented to the sighted field. Conclusion: Pupil responses are in general of reduced amplitude in patients with acquired occipital damage. In contrast, patients with congenital hemianopia show enhanced pupil responses in the blind region of the visual field.

P28 Colorimetric comparison of the non-laminated and laminated 4^{th} edition HRR color vision tests

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The revised HRR color vision test by Richmond Products in 2002 (the 4^{th} edition) has been validated by both psychophysical and colorimetric studies. In 2007, a laminated version was offered to enhance color preservation. This is a particularly useful feature for testing young children because it allows the child to trace directly on the shapes. However, lamination has the potential to alter the colors. The purpose of this study is to use colorimetric analysis to determine if colors in the laminated book remain similar to those in the 4^{th} edition. A GretagMacbeth Spectrolino spectrophotometer was used to measure the chromaticities of the 4th edition and the laminated books. Four plates (#8, 14, 17, 20), selected from the four sections of the test, were analyzed. In these plates, the background is composed of four different gray dots. Each shape is made of three different colors. For each plate from both books, the colored dots were plotted on a CIE chromaticity diagram for direct comparison. Confusion axes were drawn to evaluate chromatic alignment. Colors in the laminated book are found to be only slightly different from the 4^{th} edition for all four plates. One interesting finding is that the background gray dots in the laminated plates are more clustered together than those in the 4^{th} edition. One not so desirable finding is that for plate #14 in both the 4th edition and the laminated books, both the protan and deutan colors are significantly misaligned from their respective confusion axes. Such misalignment could potentially weaken the protan/deutan differentiation efficacy. Overall, our data shows that the colors in the laminated book are not significantly different from the non-laminated 4^{th} edition.

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VEP to red-green stimulation in colour deficient children P29

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The purpose was to compare chromatic VEP response to isoluminant red-green stimulus in children with congenital red-green colour deficiency with a control group of 30 children with normal colour vision. 15 children (7-18 years) with congenital colour vision deficiency (8 in deutan and 7 in protan axis) and 30 healthy children (7-19 years) were included in the study. Colour vision was assessed with Ishihara plates, Nagel anomaloscope, Mollon-Reffin Minimalist test, Farnsworth-Munsell D-15 saturated and desaturated test and Farnsworth-Munsell hue 100 test. VEP were recorded to isoluminant red-green stimulus. Isoluminant point was determined for each child with normal colour vision subjectively by using heterochromatic flicker photometry, whereas for children with abnormal colour vision r 0.5 was used. The stimulus was a 7 deg large circle composed of horizontal sinusoidal gratings, with spatial frequency 2 cycles/deg and 90% chromatic contrast. VEP were recorded from Oz (mid occipital) position. Children were tested binocularly. Latency and amplitude of positive (P) and negative (N) wave were measured and so was mean amplitude (N-P wave). Results showed that N wave was present in 24/30 children with normal colour vision (110 $\pm$ 25.1 ms; 9.7 $\pm$ 4.8 μV) and only in 1/15 child with colour vision deficiency (93 ms; 3.2 μV). P wave was present in 30/30 children with normal colour vision (138 $\pm$ 21.1 ms; 21.1 $\pm$ 13.5 μV) and in 13/15 children with colour vision deficiency (131.9 $\pm$ 6.1 ms; 19.4 $\pm$ 10.7 μV). In children with normal colour vision waveform changed from predominantly positive to negative wave with increasing age, whereas in colour deficient children no obvious waveform changes were observed. VEP response to isoluminant chromatic stimulus showed different characteristics in children with congenital colour vision deficiency compared to children with normal colour vision.

P30 The parallel visual pathways in Parkinson's disease

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Motor effects of Parkinson's disease (PD) are well known but visual aspects are seldom studied. The aim of this study was to examine the effects of PD on the magnocellular (M) and parvocellular (P) visual pathways in a group of patients (n=28; mean= 50 $\pm$ 9 years old), using psychophysical tests designed to be selective for these pathways. This study also examined potential differences between early-onset PD patients (EOPD; n=19) and patients with PD onset between ages 45 and 65 (IPD; n=9). The M and P pathways were probed with computerized psychophysical tests: Pedestal Test (Pokorny & Smith, 1997; Gualtieri *et al*., 2006) and Checkerboard Test (Benoff *et al*., 2001; Costa & Ventura, 2005). The patients' results were compared with age-matched controls. Results. The Pedestal Test detected a difference between the PD group and the age-matched controls only for the M-pathway stimulus. For the Checkerboard Test, the PD group differed from the controls for both the M- and P-pathway stimuli. There was no relation between the duration of disease or medication and the PD patients' visual performance. The EOPD patients differed from controls for the M- and P-pathway stimuli in the Checkerboard Test. The IPD patients did not differ from the controls in any of the tests. Conclusion. Patients with PD showed impairment of functions probed by stimuli that activate the M or P visual pathway. Both psychophysical tests showed impairment of responses to M pathway stimuli; for the Checkerboard Test, a reduction in responses to the P-pathway stimuli was also found. The EOPD subgroup differed from the controls for both pathways in the Checkerboard Test while the IPD subgroup did not differ from the controls in any of the tests. This study reveals significant

losses in visual performance in PD patients.

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P31 Genetic and psychophysical evaluation of color vision in a large pedigree of Leber's Hereditary Optical Neuropathy of the 11778/ND4 mtDNA mutation

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Leber's Hereditary Optical Neuropathy (LHON) is a maternally inherited disease that may lead to acute loss of central vision predominantly affecting young males. In a large Brazilian family, 49% of asymptomatic carriers of LHON exhibited color vision abnormalities. The purpose of this study is to determine the correlation between the psychophysical and genetic features of the color vision in the affected and asymptomatic carriers of the 11778/ND4 mitochondrial mutation (mtDNA) LHON. Twenty three asymptomatic (12 female and 11 male) and six affected (1 female and 5 male) carriers of the LHON had their color vision evaluated psychophysically and genetically. Color discrimination thresholds were measured using the Cambridge Color Test (Cambridge Research Systems, Ltd) along the protan, deutan and tritan axes. A genetic screen using real time quantitative polymerase chain reaction was used to estimate the relative number of L and M cone opsin genes in the X chromosome array. Of the six affected LHON patients, four male carriers had deutan opsin gene arrays and the other two subjects had normal arrays. All showed losses in color vision with deutan thresholds worse than protan and tritan. Of the 23 asymptomatic LHON carriers, 12 had arrays with normal proportion of L opsin genes but they were deficient in the color vision test. The thresholds were higher than normal for the protan (131.4 $\pm$ 58.56), deutan (112.9 $\pm$ 35.6) and tritan (146.8 $\pm$ 59.4) axes. Five subjects were normal in both genetic and psychophysical evaluations. Six asymptomatic LHON carriers had reductions in the color discrimination and more than one L gene in the X chromosome array. We have two main conclusions: that there is a hereditary color vision deficiency in the Brazilian 11778/ND4 - LHON pedigree characterized as deutan defect and the asymptomatic LHON carriers with normal proportion of L opsin genes have color vision deficiency probably caused by the neuropathologic mechanism of the LHON disease.

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P32 Simulating monocular vs. binocular perceptions of chromatic images in pathological subjects

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Different pathologies (glaucoma, optic neuritis, diabetes, multiple sclerosis, etc.) alter the relative action spectra of the chromatic and achromatic mechanisms and cause frequency-selective reductions in achromatic and chromatic contrast sensitivity to spatio-temporal stimuli, resulting in alterations of the visual perception of affected subjects. In this work, we have used a modification of the Corresponding Pair Algorithm originally used to simulate the perceptions experimented by dichromatic subjects [Capilla *et al*. (2004)], including models of spatial and chromatic processing, to simulate how subjects with different pathologies perceive a coloured scene. Simulations evidence a variety of phenomena, including defocus chromatic and achromatic haloes, local contrast reductions, hue and colorfulness changes, etc. Since in most real cases, a pathology does not affect both eyes in the same manner, studying the differences in quality of vision between the eyes of a pathological subject is a matter of interest. We compare the images obtained with monocular and binocular contrast sensitivity functions and show some results demonstrating that the quality of the images simulating the monocular perceptions may differ, in degree (for instance, in both eyes a colorfulness reduction is observed, but not of the same magnitude) or even in nature (for instance, the color palette may be more reduced in one eye, but with small loss of spatial information, whereas in the other eye the situation may be even the inverse). An asymmetry of such magnitude, may cause binocular rivalry problems, and, beyond a certain limit, could lead to the suppression of one of the monocular images.

Multispectral analysis of colour deficiency tests and modelling of cones influence on test perception

P33

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Visual stimuli for colour deficiency tests are designed either for trichromatic computer controlled CRT or LCD displays and projectors, or by means of print technologies. Nevertheless, the standard characteristics of these tests fail, thus not allowing to diagnose unambiguously the degree of different colour deficiency. We use multispectral colour analysis scanning the image by use of tuneable liquid crystal LC filters (*Nuance II* spectral imaging system) to obtain measurable quantities of different colour deficiency tests. Different Ishihara plates from Rabkin polychromatic colour deficiency test book (PSM) were analyzed. Spectral images were taken in the range of 420 to 720 nm with the 10 nm step under the typical widely available light sources (halogen, luminiscent). The difference between the L and M cone signals is the basic perception source for the protan and deutan tests. The changes in the signals and spectral sensitivities of these cone types have the greatest impact on the perception of the colour. Hystograms of the image pixels chromatic coordinates (*x,y*) of the CIE colour space were analysed taking into account colour deficiency confusion lines. We propose the value of cross-correlation of the processed grey scale images in LMS colour space with a high contrast test object on white background for characterizing of the test ability to diagnose a definite level of a specified colour deficiency.

P34 Trichromatic and dichromatic relative sensitivity to green light in mild hypoxia

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Introduction. Several studies have found a relative decrease in sensitivity to green light using flicker photometry in hypoxic environments equivalent to altitudes above 4000 m and using participants with normal color vision. Because there is little information available for mild hypoxic environments (less than 4000 m) that included color-deficient participants, we examined the effect of mild hypoxia on the relative sensitivity to green light using color-normal and color-deficient participants. Procedure. Relative sensitivity to red and green lights was measured using the Medmont C100 at ground, 2440 m, and 3780 m in an altitude chamber. Twenty-four individuals participated in the 3780 m trial, 32 participated in the 2440 m trial, and 14 participated in both trials. The ratio of color-normals to the various color-defectives was approximately the same for all 3 trials with 6 color-normals:2.5 deuteranopes:3 deuteranomalies:2 protanopes:1 protanomaly. The red-green luminance ratio was determined from the average of 4 settings measured once during the 4-hr trial. Results. Consistent with previous studies, color-normals and anomalous trichromats showed a small, but significant, decrease in sensitivity to the green test light at 3780 m compared to ground performance. However, their settings at 2440 m were similar to their ground values. In contrast to the trichromatic results, the dichromatic mean settings at either altitude did not differ from their values at ground. Conclusions. Our results show that the relative decrease in sensitivity to green light occurs in mildly hypoxic environments that are equivalent to altitudes greater than 3500 m. The lack of any change in the relative sensitivity to the green light for the dichromats and the decrease in sensitivity for the trichromats at the higher altitude suggests that the hypoxic effects are taking place near the second adaptation site of the L- and M-cone inputs into the achromatic channel.

The colour change in cyanosis and its relationship to the confusions of congenital colour vision deficient observers

P35

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Visual recognition of cyanosis is an important clinical activity. While pulse oximetry is almost universal in the hospital environment, there are circumstances where it is not available or may be unreliable. Cyanosis recognition is affected by lighting colour. In addition, there is, mainly anecdotal, evidence that people with greater colour vision deficiencies (CVDs) have particular difficulty and there is no effective lighting strategy to assist in the observation. The change of blood colour with oxygenation has been shown to lie close to the direction of colour confusions made by congenital red-green dichromats. The important sites of observation are lips, nail beds and palm creases. 10 subjects who were known to be chronically hypoxaemic were recruited from the chronic respiratory program. Their oxygen blood saturation (sO_2) varied from 84 to 96% pre-exercise and 61 to 84% post-exercise. 10 normal subjects were recruited whose sO_2 was 99 or 100%. The spectral radiances of lips, nail beds and palm creases were measured using a Topcon SR-3 telespectroradiometer and compared with the spectral radiances of a white tile of known spectral reflectances measured in the same location. This is a non-contact method of measurement, avoiding the blanching caused by pressure of contact methods. The spectral reflectances were calculated and the chromaticities calculated for a Planckian radiator T=4000K. Measurements on lips yielded the most consistent results. The colour changes pre and post exercise and compared with normal colour lie generally along a deutan confusion line. These results confirm the direction of the colour change and illustrate well the, previously anecdotal, difficulties in detecting cyanosis by observers with CVDs.

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P36 Scale invariance of chromatic similarity and properties of chromatic motion examined with spatial and temporal chromatic plaids

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Chromatic plaid stimuli are created by superimposing two sinusoidal spatial patterns, each oscillating between a different pair of equiluminant hues; one pattern runs from lower left to upper right, the other from lower right to upper left. The dominant diagonal trend in a plaid depends on the less similar of the two hue pairs dominating the other pair, in a process of monocular rivalry, and provides a 'tetradic' judgement of colour similarity. Fifty-six such plaids were constructed from various combinations of 16 hues, with spatial luminance noise added to remove residual luminance artefacts. These stimuli were presented at a range of spatial wavelengths from 1^o to 10^o / cycle, and analysed with individual-differences multidimensional scaling, to test whether the relative salience of the two cardinal axes of the equiluminant colour plane varies with spatial scale. Such variations were a possibility since the detection threshold for chromatic contrast - as a function of spatial frequency - is not necessary identical for the L-M and S_o axes. Replacing one spatial dimension in the plaids with temporal modulation created stimuli in the form of moving waves rather than stripes, with ambiguity of motion rather than diagonal direction. These allowed the chromatic contribution to motion perception to be probed at various scales and angular velocities.

Cortical and subcortical origins of lateral interactions in flicker perception P37

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The perceived flicker strength in a luminance modulating central stimulus depends upon the relative phase difference with the luminance modulation in a surround stimuli. When the two stimuli are modulated in counter-phase then the perceived flicker in the centre stimulus is large. The perceived flicker is small when the two are modulated in phase. The response amplitude in LGN cells depends similarly upon the phase difference between a centre and surround stimulus. We therefore proposed that this interaction has a subcortical origin. To disentangle the cortical and subcortical origins of this lateral interaction, we used goggles with which the left and right eye could be separately stimulated. We compared the condition in which the centre and surround stimuli were presented in the same eye (revealing lateral interactions with both cortical and subcortical origins) with the condition in which they were presented in separate eyes (revealing interactions with cortical origins). The difference between the two conditions isolates the subcortical component. We found that at 3 Hz the lateral interactions have mainly a cortical origin. At 6 and 12 Hz, the subcortical component is larger than the cortical component, which is very small. The subcortical component is maximal at 6 Hz. These data confirm the results reported by D'Antona, Kremers and Shevell (VSS, 2008). In addition, the size of the surround stimulus was varied. At small surround sizes, the subcortical component was absent whereas the cortical component was present. The cortical component was constant as surround size increased, whereas the subcortical component increased. We conclude that, in agreement with our previous hypothesis, lateral interactions in the perception of flicker originate to a large extent in the interaction between receptive field centres and surrounds of LGN cells. The subcortical and cortical components have different spatial and temporal characteristics.

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P38 Why is colour vision on coral reefs so variable?

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Visual ecology links the physical constraints of the world to the physiology of visual systems. Freshwater fish living in a world often dominated by greenish to orange light (500-700nm), generally place rod and cone spectral sensitivities in this part of the spectrum in order to capture enough light. Ultraviolet (UV) sensitivities in species living close to the surface may also operate where there are UV wavelengths to see by. In the ocean, the spectral envelope of light is shifted to shorter wavelengths (350-500nm) and marine fish place sensitivities in this spectral zone. Again there are species with and without UV sensitivities and this and other fine tuning of spectral sensitivity may be correlated with depth and / or feeding habits such as planktivory. Ideas such as the sensitivity hypothesis and the twilight hypothesis (see John Lythgoe, Bill McFarland and co authors) effectively explain the spectral positioning, of rod (and maybe double cone) sensitivities. Single cone sensitivity placement, spacing and number are harder to explain. While single cone sensitivities also generally fit within the illuminant envelope, their variability between species suggests, either that unknown selection pressures are at work, or that, uncomfortably for a visual ecologist, 'neutral mutation' or relatively 'unconstrained' adaptation exists. Recent data from reef fish are examined here, including 3 closely related species of Apogonids (Cardinal fish) with similar lifestyle but variable single cones. What are we missing?. Why such diversity in apparently similar light habitats?. Are there sufficient behavioural differences to explain the observed diversity or is it related to the astonishing array of colours?. What do models of colour vision performance predict?. All these questions will be examined, chewed over and possibly swallowed.

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Experimental study of the individual differences on chromatic perception through blue-yellow metameric matches of a white-light continuum

P39

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Previous studies show how to manifest through psychophysical tests the individual differences on colour vision on observers, suggesting the possibility to link the chromatic space from the standard observer and the real perceptive space from any individual. A test to study the inter-observer variability through metameric colour matches was designed; using blue-yellow metameric matches of a white-light continuum on eight non-defective observers, we aimed to define the optimal wavelengths where each one of them achieved the match. The tests showed chromatic stimuli on a bipartite 2^o field, surrounded by an achromatic 15^o adaptation field with a constant luminance of 28 cd/m^2. On the right field a white-light continuum from an 8W florescent light was presented (matching on luminance the adaptation field), and on the left field there was a mixture from two monochromatic stimuli (484/576nm on a first series and 492/576nm on a second series). The luminance of these chromatic stimuli was adjusted by the researcher by a staircase method, where the observer provided feedback about the similarity on luminance and chromaticity between both fields. Since for a fixed yellow wavelength the match with the target white can be achieved by one (and only one) corresponding blue wavelength (which is particular for each observer), the blue wavelengths were a first approach based on the 2^o CIE1931 standard observer. The real observers could modify its value through a gear handle. Once the observers reached an achromatic match, they were asked to modify the blue wavelength to achieve a perfect match on both fields. Generally, the observers had to modify the blue wavelength to achieve the metameric match. On both series each observer had a particular optimal blue wavelength, different from one another. The difference between the deviations from the standard observer from both series had a constant value amongst the observers.

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P40 A magnocellular deficit and a parvocellular preservation in normal aging: dissociation of the two cognitive visual systems in a categorization task

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The study aimed at evaluating the modification during normal aging of the two main systems of visual processing using a comportemental test : the dissociation between the parvocellular (high contrast and central presentation) and the magnocellular (low contrast and peripheral presentation) systems was tested using a categorization task of photographs of natural objects. The experiment included two age groups (MMSE >26 and normal visual acuity): 30 young (mean age of 20.7) and 30 older observers (mean age of 72.4). They had to perform two semantic categorization tasks of 24 pictures each (animal vs. vegetal or tool and piece of furniture vs. vegetal or tool). Picture contrast level varied (8% or 30%) and pictures were presented centrally or at 21.7^o of eccentricity (left or right). Results showed a mean age-related increase in RT and decrease in percent correct. Accuracy and response time decreased when contrast decreased, when eccentricity increased and when the target was a piece of furniture rather than an animal. A 4-way interaction was also observed between age group, picture eccentricity, picture contrast, and object semantic category : the more pronounced decrease of performance according to picture contrast found for the older than for the young participants, was higher for central picture than for peripheral picture, especially for piece of furniture relative to animal. However, there was no statistical difference of performance according to age group when pictures were presented centrally and at high contrast, whatever the semantic category. Altogether, these results are consistent with an age-related deficit in the magnocellular system whereas the parvocellular system seems to be spared. Moreover, the magnocellular dysfunction can account for the category-specific deficit found in aging considering that the visual primitives (presumably the low spatial frequency content) required for identification of manufactured objects are preferentially conveyed by the magnocellular system.

Functional evaluation of damage to chromatic pathways in Multiple Sclerosis

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Multiple Sclerosis (MS) is the most frequent acquired disease of the central nervous system in young adults, frequently associated with Optic Neuritis (ON), that is generally manifested as blurring, graying, or loss of vision, most often unilaterally. However, subclinical cases may occur, in the absence of visual symptoms. The goal of this work was to evaluate and quantify subtle dysfunction of chromatic visual pathways in MS, with or without previous ON, and its correlation with clinical parameters of disease progression. Forty-four subjects (12 males, 32 females; mean age= 42,29 $\pm$ 10,89) with MS, with or without previous history of ON, with no other ophthalmologic disease was compared with age-matched controls (12 males, 16 females; mean age= 49,71 $\pm$ 11,54 years). Patients were submitted to a standard neurological examination, including clinical staging (EDSS - Expanded Disability Status Scale). Standard and novel computed psychophysical tests were used to evaluate chromatic visual function (Ishihara plates, Anomaloscopy and the Cambridge Colour Test). Visual Evoked Potentials was also applied in order to evaluate objectively the effect of demyelination on bioelectrical conduction along the visual pathway.Using computerized evaluation of chromatic function, we have found evidence for damage of all cone pathways in MS, even in the absence of ON and in cases of preserved visual acuity. Interestingly, evidence for axonal damage in the optic nerve dominates over functional evidence for demyelination in MS without ON. Correlation analysis between EDSS and visual dysfunction confirms that damage in MS without previous ON is distinct from MS with previous ON (significant only in the former). Novel computerized quantitative psychophysical methods for chromatic function evaluation can detect subtle visual dysfunction, revealing impaired optic nerve function in MS even in the absence of ON and provide new insights into distinct stages of the pathophysiology of this disease.

P42 Chromatic diversity of indoor scenes rendered with CIE illuminants and white LEDs for normal and colour deficient observers

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The colour quality of a light source is typically evaluated by the colour rendering index (CRI), a quantity that measures how much the colours under the light source differ from the colours under daylight. The goal of this work was to evaluate the quality of lighting by estimating instead the chromatic diversity light sources produce in indoor scenes for normal and colour deficient observers. Reflectance spectra of objects typically found in indoor scenes (like books, coloured fabrics, children toys, fruits, indoor plants, among others) were obtained using an hyperspectral imaging system with a low-noise cooled digital camera with a spatial resolution of 1024 (H) x 1344 (V) pixels and a fast tunable filter with an infrared filter in front of the lens. Images were acquired from 400 to 720 nm in 10 nm steps. Care was taken to avoid shadows and multiple reflections. Chromatic diversity was estimated for 60 illuminants, 55 CIE illuminants and 5 LED light sources (Luxeon, Philips Lumileds Lighting Company, USA), by computing the CIELAB colour volume of the objects and by counting the number of non-empty unitary cubes of the segmented CIELAB volume. A large variation in chromatic diversity was found across illuminants, with the best illuminant producing about 50% more colours than the worst. A weak correlation between the number of discernible colours obtained with a particular illuminant and its correspondent CRI was also found. For normal observers, the best illuminant was CIE FL3.8, producing about 7.5% more colours than CIE illuminant A and 8% better than D65. For colour deficient observers, increases in relation to illuminant A of about 12% (CIE FL3.7), 7.6% (CIE HP2), 17.8% (LED LXHL-BW02), 8% (CIE HP1) and 6% (CIE FL3.14), for protoanomalous, deuteroanomalous, protanopes, deuteranopes and tritanopes observers, respectively, were found. These results suggest that both normal and colour deficient observers may benefit with a careful choice of the illuminant to maximize the chromatic diversity perceived in indoor scenes and this choice is not necessarily based on the CRI.

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Chromatic effects of metameric illuminants on art paintings P43

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The visual impression of an art painting is strongly influenced by the colour temperature of the illuminant but the perceptual influence of metameric illuminants has not been investigated. The aim of this work was to estimate computationally some chromatic effects of metameric illuminants of the D65 on art paintings. Eleven oil paintings from the collection of the Museum Nogueira da Silva, Braga, were imaged by a hyperspectral imaging system. The hyperspectral imaging system had a low-noise Peltier-cooled digital camera with a spatial resolution of 1344x1024 pixels (Hamamatsu, C4742-95-12ER), and a fast-tunable liquid-crystal filter (VariSpec, model VS-VIS2-10HC-35-SQ, Cambridge Research & Instrumentation, Inc., MA, USA) mounted in front of the lens. The spectral reflectance of each pixel of the paintings was estimated from a gray reference surface present in the scene. The metameric illuminants were generated with a variable number of spectral peaks and the radiance reflected from each painting under each metamer was estimated. In each case, the colour rendering index and the average colour for each painting was computed. In addition, the number of discernible colors was estimated by computing the painting representation in CIELAB space and by counting the number of non-empty unit cubes in that space. It was found that the average colour of the paintings changed only a little across the set of metamer used; on the other hand, the colour rendering index and the number of colours changed over a much wider range but a low correlation was found between the two. In addition, the maximum number of colours was obtained in most cases by metamers with three spectral maxima. These results suggest that the visual impression from an artistic painting can change significantly across metameric illuminations and that metamers with three spectral peaks may be the ideal for maximizing chromatic diversity.

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