DALTONIANA

NEWSLETTER
OF THE INTERNATIONAL RESEARCH GROUP ON COLOUR VISION DEFICIENCIES

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IRGCVD News

News from the Tübingen Symposium

Scientific Programme

The programme opened with the presentation of the Verriest Medal to Professor Marrion Marré whose work on acquired colour vision deficits was reviewed in an address by Professor Roth. There were more than 130 participants representing 19 countries. The papers (5 invited, 5 extended, 31 contributed) were given in 9 serial sessions. Posters (37) were defended in two specially dedicated 2 hour sessions. Abstracts of all 98 contributions are reproduced in this issue of Daltoniana. An interesting exhibition was mounted with new instruments in hands-on and working displays. In a new venture, an evening session with Professor Zeki's invited paper on "The construction of colour by the cerebral cortex" was opened to the public and attracted some 300 people. The half-day workshop on uses and calibration of monitor displays was well attended.

Social Programme

Our hosts provided a pleasant and relaxing social programme which was very much appreciated. Beginning with a reception on Sunday evening, it continued on Monday with a half-day trip to Lake Constance, including brief visits to Constance and Stein and dinner above the water falls at Neuhausen. On Tuesday evening, we attended a violin concert and dinner at the Bebenhausen Monastery, where we marvelled at the superb acoustics. The programme finished on Wednesday evening with a reception following Professor Zeki's discourse.

General Members Meeting

The President's vote of thanks to the local organisers, Eberhart Zrenner, Anne Kurtenbach and Lukas Ruttiger and their team of assistants, Elke Günther, Regina Nicolaidis, Ralph-Peter Tornow, Manfred Fahle and Christian Wehrhahn, was greeted with acclaim.

The General Secretary asked all members to send abstracts from or reprints of their recent publications for inclusion in Daltoniana. He reminded members that, as part of their membership fee, they obtain a copy of the Symposium Proceedings at 1/3 the retail cost.

The Directorial Committee had welcomed Professor Kenji Kitahara as a new member, on the recommendation of Professor Yasuo Ohta who had retired. Professor Ohta's work on behalf of the group was much appreciated; particularly his organisation of the splendid regional 1990 Symposium in Tokyo. The committee had accepted, with regret, the resignation of Professor Marrion Marré as Secretary-Treasurer of the former Socialist Countries.

As part of the process of increasing our impact on the vision science community, possibilities are being investigated for publishing the Symposium abstracts and papers in a refereed journal. With the same aim, suggestions were solicited from members for a shorter name for the group.

Elections: Nominations had been received for A Roth as President and for J D Moreland as General Secretary. In the absence of other nominations or objections, the nominees were declared elected for a further term of office.

Treasurer's Report

The IRGCVD has approximately 200 members (180 full members and 20 student/retired members). The exact number is uncertain because some members, particularly in the USA, have been slow in paying membership dues for 1993. The group is currently negotiating facilities for payment by credit card, which should make payment easier. Membership fees are the group's only source of income and it is essential that an accurate estimate of the number of members is available to assist the Directorial Committee with future planning.

Detailed accounts were presented to the Directorial Committee at their meeting in Tübingen. The following is a brief summary of the group's finances relating to the period from 1991 to 1993 which includes payment for the Sydney proceedings.

Income:	£
181 full members at £60	10,860.00
20 students/retired at £20	400.00
Sale of Cagliari/Sydney Proceedings	585.00
	11,845.00
Expenses:	
Sydney Proceedings	7,800.00
UK Costs:	
Daltoniana and administrative expenses	3,200.00
USA Costs:	
Refereeing and administrative expenses	1,500.00
	12,500.00
Excess of expenditure over income	655.00

The excess of expenditure over income prompted raising the full membership fee in 1993. Full members have paid a total of £70 for 1992 and 1993 which includes payment for the Tübingen Proceedings, Daltoniana and administrative expenses.

The current assets of the group are £11,200. Of this sum, approximately £10,000 is set aside for the purchase of the Tübingen Proceedings: as previously, these will be published in hardback by Kluwer. Further income will accrue from delayed fees payments for 1993 (£1,600) and from transfer of funds held in the former socialist countries derived from membership fees over a number of years (£3,000). A proportion of the primer fund (£1,700) transferred to Tübingen to finance the initial planning of the Symposium will also be returned after final expenses on behalf of the group, such as the expenses of guest speakers, have been deducted. The group will transfer a similar sum to the organisers of the Symposium to be held in Pau in 1995 to help finance the planning stages and the printing of promotional literature.

The present finances of the IRGCVD are sufficient to enable the group to continue with its present activities. However, the group has little financial reserve and its financial status is vulnerable to fluctuations in the exchange rate between Pounds Sterling, US Dollars and Dutch Guilders. In view of this, the Directorial Committee is reviewing its financial policy and is considering alternative methods of publishing the Proceedings of future Symposia. These policies will aim at streamlining the administration of the group's activities and reducing costs. A decision about the publication of the Proceedings of the Pau Symposium in 1995 with affect the membership fee for 1994 and these plans will be announced in Daltoniana before subscriptions for 1994 are requested.

Venue of the 1995 Symposium.

The meeting accepted the committee's recommendation of the bid from Pau, France. The special topics suggested for that Symposium are: 1) Variation of Colour Vision: Genotypes and Phenotypes. 2) Structure and Function in Colour Vision. 3) Colour Vision and Field Defects. A workshop was proposed on the Legal Requirements for Colour Vision.

ABSTRACTS OF PAPERS AND POSTERS AT THE XII IRGCVD SYMPOSIUM IN TÜBINGEN, JULY 1993

Minor editorial changes have been made in some abstracts.

Session 1 Acquired Colour Vision Defects - 1

Current and future applications of chromatic adaptation in clinical populations. J Pokorny and V C Smith, Visual Sciences Center, University of Chicago, Chicago, USA.

Since the pioneering work of Marion Marré in the early 1970's, spectral sensitivity functions obtained under conditions of selective chromatic adaptation have been extensively used in clinical populations both to aid in diagnosis and in understanding of the functional consequences of disease processes. Several recent reports have expanded the potential of selective chromatic adaptation techniques. Two analyses of the short-wavelength-sensitive (S-) cone threshold-radiance (TVR) functions suggest that it should be possible to differentiate a number of potential types of insult with psychophysical procedures. First, Greenstein, Hood & Carr (Appl Optics 26: 1385, 1987) suggest two types of sensitivity change attributable to eye disease: a reduction in absolute sensitivity (upward vertical shift in the TVR function) and/or a reduction in increment sensitivity (shift of the TVR function along the 45 deg diagonal). Second, Yeh, Pokorny & Smith (Vision Res in press) show that changes in S-cone activation achieved by variation of luminance (low- to high-luminance background) and by variation of chromaticity (yellow to white to violet along a tritan line) do not result in equivalent changes in sensitivity. These results are interpreted as due to an interaction between the Long and Middle-wavelength-sensitive cone types and the S cones early in the visual system. The logic of the interpretation of these studies will be discussed with examples of clinical conditions in which specific types of defect can be identified.

Colour contrast abnormalities in genetically determined types of retinal degeneration. G B ARDEN, A ECKSTEIN, J J WROBLESKI, J A WELLS, M JAY, F FITZKE, S BHATTACHARYA and A C BIRD, Institute of Ophthalmology and Moorfields Eye Hospital, London.

We have measured colour contrast sensitivity using computer-graphics techniques, in patients with characterised defects in the genes coding for rhodopsin, associated with autosomal retinitis pigmentosa, and in the genes coding for peripherin, which cause macular degenerations or retinitis pigmentosa. The technique allows us to measure central colour vision (using alphabetic letters) and also the colour discrimination of annuli of retina ranging from 2 - 12 degrees radius. The results are to some extent characteristic of the genetic abnormality, but in local macular defects, peripheral colour vision may be unaffected, while in ADRP like conditions, peripheral colour contrast is always affected, and only the rod-free area retains colour vision. Discrimination in the tritan axis is most severely affected. Even in cases where dark-adapted colour perimetry is normal, colour vision defects can be seen and in children a ring of paramacular colour disturbance can antedate any fundal abnormality.

Studies on SWS mechanism in diabetic patients by measures of the probe-flash threshold. H TERASAKI and H HIROSE, Dept. of Ophthalmology, Nagoya University, Nagoya, Japan.

Selective sensitivity loss of SWS mechanism has been reported in diabetic retinopathy with various psychophysical examinations. We have studied SWS mechanism in normals and patients suffering from diabetes by the modified method of the probe-flash threshold reported by D.C. Hood in 1979. That is, increment thresholds were measured with a three channel Maxwellian view system in which a 1° blue test spot was flashed for 50 ms on a 2° blue spot flashing simultaneously for 500 ms on yellow steady background field of 13°. In normals, threshold curves were rising away from straight lines as flash intensity increased. In patients with retinopathy, the threshold curves shifted upward as the stage of retinopathy progressed. In patients with IDDM under 30 years of age without retinopathy, the threshold curves shifted upward, however, in patients with NIDDM without retinopathy in fifth decades, the shifts were insignificant. Therefore, early functional changes in diabetes could be detected by this method.

Color vision and retinitis pigmentosa. M MÄNTYJARVI and K TUPPURAINEN, Dept. of Ophthalmology, University of Kuopio, Kuopio, Finland.

Color vision of 31 patients (13 women, 18 men) with retinitis pigmentosa was studied with the Standard Pseudoisochromatic Plates part 2 (SPP2), Farnsworth-Munsell 100 hue test (FM100) and Nagel anomaloscope. Three patients could not read the SPP2 plates and 5 patients could not complete the FM100 test. For them, the Lanthony Tritan Album and Farnsworth Panel D15 were used. The age of the patients varied from 8 to 69 years (mean 40 ±19, SD), the duration of disease from 0.5

to 60 years (13 ±16) and visual acuity from 0.1 to 1.2 (0.8 ± 0.3). Thirteen of the patients (42%) had defective color vision, a tritan defect, and 4 of them had also an additional red defect. The color vision test results of the right eyes correlated significantly to the visual acuity and to the cone threshold of dark adaptation. No significant correlation was found between the duration of disease, the rod threshold of dark adaptation and the extent of the visual field.

Session 2 Acquired Colour Vision Defects - 2

Macular pigment contributes to variance in 100-hue tests. J D MORELAND[1] and S L DAIN[2]. 1: Department of Communication and Neuroscience, Keele University, UK. 2: School of Optometry, University of New South Wales, Australia.

The Farnsworth-Munsell 100-hue test was performed by 10 normal trichromats viewing the text binocularly through artificial 'macular' filters with peak (458 nm) absorbancies of 1 and 2 and through a neutral control of approximately equivalent luminous transmittance. The 'macular' absorbance spectrum closely simulated the Wyszecki-Stiles average in shape and the peak absorbance change 0-1 corresponds approximately to the observed population range. Illumination (400 Lux, 6500 K) was provided by 'daylight' lamps. Increases in 'macular' absorbance were accompanied by increases in mean total error score (from 33.9 to 75.7 to 157.4), in bipolarity (relative amplitudes: from 0.27 to 0.37 to 0.83) of the mean cap error plot and by rotation of the bipolar axis towards the tritan direction (caps: from 40 to 43 to 46). While differences in effective illumination for filters and control were negligible, selective changes in cap chromaticity occurred characterized by dramatic increases in ellipticity of the 100-hue locus. Chromatic crowding near the vertices of the 'ellipse' correlated with increases in cap errors, accounting for the associated changes in bipolarity and chromatic precession around the 'ellipse' accounted for the change in axis.

Opponent colour detection threshold asymmetry: An indicator of optic nerve abnormality. V A BILLOCK, P E KING-SMITH, A J VINGRYS, S S GRIGSBY and S C BENES, College of Optometry, Ohio State University, Columbus, USA.

Thresholds for equiluminous opponent colours are almost always nearly equivalent (e.g., red/green and blue/yellow <.050 log units). King-Smith et al. (1989) summarized four cases where a gross asymmetry was manifested. In one case the subject had Leber's optic atrophy; in another, the subject had a microinfarct of the optic nerve fiber layer. In the other cases no pathology was known. However, we have recently discovered that the third case has optic nerve hypoplasia, and the fourth case has megalopapilla of the optic nerve. Additional subjects with Leber's optic atrophy and optic nerve hypoplasia have been examined and opponent colour asymmetries seem to be relatively common in these populations. Also, many normal observers and many observers with diverse visual pathologies have been studied. Every significant asymmetry can be tied to an optic nerve defect. Although there are differences between the asymmetries found in these groups (e.g., Leber's patients show only blue/yellow asymmetries, while hypoplasics show red/green asymmetries as well) it is important that strong asymmetries are always tied to an optic nerve abnormality. Moreover, the asymmetries are often manifested by patients with no other obvious symptoms of their conditions (e.g., hypoplasics with good acuity and subtle double rings can show asymmetries in excess of .300 log units). The sensitivity of opponent colour detection threshold asymmetries may make this technique a useful addition to the armamentarium of vision researchers and practitioners.

Monochromatic slow flicker thresholds in optic neuropathies. H KRASTEL and M G M BRAUN, University of Heidelberg Eye Hospital, Heidelberg, Germany.

Monochromatic stimuli of 435, 512, 566, 588 and 613 nm were presented on a white background (150 cd/m^2) at 1 Hz and 7 Hz repetition rates. In normal observers, 1 Hz spectral increment sensitivity exhibits the well known minimum at 566 nm which is interpreted as a result of an antagonistic interaction of long and middle wavelength cones' signals. In contrast, 7 Hz spectral increment sensitivity is coined by a maximum at 566 nm which is understood to result from synergistic interaction of long and middle wavelength cones' signals. Foundations of such findings have been explained by e.g. King-Smith & Alvarez, and by Zrenner & Gouras. In our present study, various optic nerve diseases are examined: optic neuritis, postinflammatory optic atrophy, tobacco amblyopia, compressive and ischemic optic neuropathies, and dominant infantile optic atrophy. Monochromatic slow flicker thresholds exhibit various decay patterns, ascribed to: i) loss of antagonistic interaction: ii) synergistic interaction at 1 Hz stimulation; iii) luminosity loss despite preserved antagonistic interaction; iv) luminosity loss combined with replacement of antagonistic by synergistic interaction; v) severe luminosity loss without any recognizable mode of interaction.

Heterochromatic brightness matching and wavelength discrimination in juvenile diabetics: A three year study. A KURTENBACH, L RÜTTIGER, U SCHIEFER, E ZRENNER and A NEU*, University Eye Hospital, Tübingen, Germany. * University Childrens Hospital, Tübingen, Germany.

10 juvenile diabetics have been tested, once a year over a three year period, using heterochromatic brightness matching (HBM), and wavelength discrimination throughout the spectrum. The Farnsworth-Munsell (FM-100) hue test was also performed. At the start of the study, the patients were aged between 11 and 18 years, and 2 showed signs of a mild retinopathy (Bresnick Stage 2). No fundus changes occurred over the testing period. Blood and urine were also analysed. The results were compared with those of an age-matched control group of 20 subjects with normal colour vision as tested by the FM-100. In none of the tests did the results of the 2 patients with mild retinopathy differ from the 8 who had no retinopathy. Mean scores for the FM-100 were 84.3 for the first year, 48.0 for the second and 49.8 for the third year. The mean score for the control group was 51.9. The results for the HBM, on the other hand show a worsening of sensitivity throughout the middle of the spectrum which is most pronounced for the third year. Wavelength discrimination on the whole tends to be worse for the diabetic group, and shows most consistent changes over the years at the short wavelength end of the spectrum.

Blue cone pathway vulnerability in glaucoma suspects. A U BAYER, C ERB, H J THIEL and E ZRENNER, University Eye Hospital, Tübingen, Germany.

67 high risk patients with ocular hypertension have been followed for 2.5 years, using pattern electroretinography, snow field campimetry (Tübinger Electronic Campimeter), and standard methods including the Tübinger automatic perimetry and stereophotography of the optic nerve head. Colour vision was tested by measuring spectral sensitivity functions between 400 and 480 nm and by the colour arrangement tests, Farnsworth-Munsell 100-Hue and Panel D-15 desaturated. On follow-up 28 patients developed glaucomatous visual field losses. The data of this study suggest that only snow field campimetry identify early functional loss in eyes at greatest risk for primary open angle glaucoma. Blue colour vision tests and pattern ERG's with checkboard grid size of 1° have only some predictive value for determining which ocular hypertensives are at risk of developing glaucomatous visual field losses. Additionally it is possible to better monitor the progress of glaucomatous damage by snow field campimetry. Moreover the results indicate although blue cone sensitivity may be more sensitive for the detection of incipient glaucomatous damage, in the manifest stages of glaucomatous damage, measuring blue cone sensitivity is less sensitive than is conventional perimetry for defining the extent of glaucomatous damage of the optic nerve head.

Visual field on blue stimulus in glaucoma. T STEINSCHNEIDER, U TICHO, T SCHWARZENBERG and E AVERBACH, Dept. Ophthalmology, Hadassah University Hospital, Jerusalem, Israel.

Blue-yellow deficiency in glaucoma is well known as early sign of optic nerve lesions. Performing visual field and blue sensitivity simultaneously meets some difficulties. The aim of this study is to compare lesions appearing in the visual field with white stimulus and those demonstrated by blue stimulus. Forty eight glaucoma patients (91 eyes), 24 males and 24 females with mean age 61.3 ± 13.2 years, were tested by programs 30-2 or 24-2 of the Humphrey perimeter with STATPACK analysis. After testing the white stimulus 4 basic points were tested by the blue stimulus. In the group with normal visual field (31 eyes) the blue stimulus threshold at the temporal superior basic point presents a close correlation with the patient's age (0.634, $P > 0.99$). Blue threshold with calculated pattern values at the 4 basic points showed a decrease of 4DB or more with blue sensitivity in the upper temporal and upper nasal basic points in 10 eyes, in the upper temporal in 5 eyes and in nasal upper point in 2 eyes. In 48 eyes with visual field defects a close correlation was found between the white and blue thresholds at the same points (0.648 - 0.800, $P > 0.99$). We propose that the 4 basic points of the blue visual field can detect early optic nerve defects in glaucoma, while performing the standard visual field test.

S-cone contrast sensitivity in glaucoma as a function of mean luminance. W H SWANSON[1], R L FELLMAN[2], J R LYNN[2] and R J STARITA[2]. 1: Retina Foundation of the Southwest. 2: Glaucoma Associates of Texas, Dallas, USA.

S-cone contrast sensitivity may be useful for detecting glaucomatous visual loss (Gündüz et al., 1988 Arch. Ophthalmol. 106: 929; Rosenshein & Cyrlin, 1991 Invest. Ophthalmol. Visual Sci. 32: 811). Before S-cone contrast sensitivity tests can be used in clinical settings it is necessary to determine how S-cone contrast sensitivity is influenced by mean S-cone quantal catch, which can be affected by factors such as pupil size or lens density. The current study measured S-cone contrast sensitivity of patients with glaucoma for 1.0 c/deg blue gratings superimposed on a bright yellow background. The photopic contrast was less than 0.1% and L- and M- cones could not detect the stimuli. Four mean luminances were used (0.5 log unit steps) and pupil size was monitored with a closed-circuit

TV. Inter-subject variability was reduced by plotting S-cone contrast sensitivity vs. retinal illuminance rather than stimulus luminance. Each patient's data were fit with a threshold versus retinal illuminance (TVR) function. The TVR analysis showed significant effects of mean S-cone quantal catch. These results indicate that for some patients reduced S-cone contrast sensitivity was due to factors such as pupillary miosis or lens yellowing, rather than optic nerve damage.

Ethambutol induces morphological alterations in cones and colour coding synapses. **K KOHLER[1], E ZRENNER[1], R WIELER[2]. 1: Dept. Experimental Ophthalmology, University Eye Hospital, Tübingen. 2: Dept. Neurobiology, University of Oldenburg, Germany.**

Ethambutol (Eb) can cause optic neuropathy and deficiencies in colour-opponent visual processing in patients treated for tuberculosis. In fish, Eb induces colour vision deficiencies similar to those observed in man and they might therefore provide a useful model to study the toxic effects of Eb. In fish, colour opponency is mainly mediated by a special type of synapse, so called "spinules", which act between horizontal cells (HCs) and cones. We examined by electron microscopy whether Eb affects spinule formation and, therefore, might alter colour processing at a very distal stage in the retina. In light- and dark-adapted retinae, Eb did not influence already formed spinules. However, application of Eb in the dark, prior to light-adaptation, inhibited light-induced spinule formation severely. Moreover, after Eb-treatment synaptic pedicles of the cones became necrotic. Our results indicate that Eb can influence the colour coding process already at the level of the HCs by altering connections between HCs and cones in a dose-related fashion.

Session 3 Basics of Colour Vision

Dual bases of color space. **K KNOBLAUCH, Vision Research Laboratory, The Lighthouse Inc, New York, USA.**

The directions in color mixture space to which the underlying color vision mechanisms are most sensitive form a dual basis to the set of isolating directions for these mechanisms. In other words, if the most sensitive directions form the columns of a matrix S, the isolating directions form the columns of the matrix $E = (S^{-1})^T$. A two-alternative forced-choice, double judgement procedure was used to determine the directions in color mixture space for which the modulation threshold of a 1 degree test spot on a dark background were lowest for identifying basic opponent hues in congenital color defective individuals. Mechanism isolating directions were calculated based on the duality relation described above.

Rapid determination of discrimination ellipses in colour deficiency. **B C REGAN, J P REFFIN and J D MOLLON, Dept of Experimental Psychology, University of Cambridge, UK.**

We have extended the computer-controlled colour vision test of Mollon and Reffin (J. Physiol., 1989, 414, 5P) in which we confront the colour-deficient with the task at which Nature shows best their disadvantage: detecting heterochromatic targets in a luminance-modulated field. We describe methods for (a) determination of the line of worst discrimination and (b) determination of a complete discrimination ellipse in as little as 20 minutes. We find: (i) very little scatter in the confusion lines for dichromats; (ii) a range in the chromatic sensibility of anomalous trichromats from normal to resembling dichromacy; and (iii) an impairment in the tritan direction of colour space for red-green dichromats as a population. Two possible explanations for the last finding will be discussed.

Tritan pairs for normal and colour deficient observers identified by modulation photometry of red, green and blue lights. **B LEE and T YEH, Dept Neurobiology, Max-Planck Institute of Biophys. Chem., Göttingen, Germany.**

Tritanopic confusion pairs are traditionally identified by the minimally distinct border technique (MDB, Tansley & Boynton, 1979). Here we report tritan pairs determined by heterochromatic modulation photometry (Pokorny, Smith & Lutze, 1989). Our aim was to determine observers' sensitivity to modulation along a tritanopic confusion line for comparison with S-cone modulation sensitivity determined physiologically. Stimuli were presented in a Maxwellian view system with red (636 nm), green (545 nm) and blue (470 nm) light-emitting diodes (LEDs) as light sources. The blue LED was modulated in phase with the red LED, while the green LED was modulated in counterphase with the other two. We changed the relative modulation amplitude of the LEDs in two dimensions: (1) the red to blue ratio, (2) the ratio of the green to the sum of the red and blue lights. Modulation frequency was 10 or 20 Hz. Results can be plotted in three dimensions, with threshold as the vertical axis. For dichromatic observers, this threshold plot formed a sharp ridge, of which locus and orientation depended on whether the observer was a deuteranope or protanope, and on his macular pigment density. For color normal observers, the threshold surface rises to a sharp peak close to the predicted tritanopic confusion line for the lights making up the stimulus. This was confirmed by MDB tritan pair estimates, which clustered around the peak. We conclude this technique allows precise

definition of modulation along a tritan line. The results can also be interpreted in relation to neurophysiological data.

Causes of interocular difference in Rayleigh matches of color normals. S K SHEVELL and JI CHANG HE, Visual Sciences Center, University of Chicago, USA.

The Rayleigh match sometimes is different in the left eye and right eye of a person with normal color vision. We confirmed this interocular difference: (i) in a sample of 38 observers and using a 2° field, 12 subjects (31%) showed a statistically reliable difference ($p<0.05$) between the match-midpoint in the left eye and the midpoint in the right eye; (ii) in a separate sample of 31 observers, 9 subjects (29%) showed an interocular difference. Causes of the interocular difference were examined by also measuring a 7° Rayleigh match, which assesses effective optical density, and a modified Rayleigh match with a 620 nm long-wavelength primary, which assesses the wavelength of peak sensitivity of photopigment. We conclude from these results that an interocular difference in Rayleigh-match midpoint is common and usually due either to effective optical density (caused by receptor misalignment or true variation in pigment density) or to pre-receptoral filtering.

Absence of lightness constancy as a deficit of monochromatic vision. C VON CAMPENHAUSEN and H TAUSCH. Institut für Zoologie, Mainz, Germany.

Dark adapted human subjects ordered a collection of coloured papers in a sequence according to lightness. The sequence of the papers, which all appeared gray to the subjects, varied under different illuminant spectra. The sequence could be quantitatively predicted taking into account the radiometric data and the scotopic sensitivity. By substituting natural illuminant spectra in the calculation, it was shown that lightness of objects cannot be reliably perceived by monochromats under natural conditions. This visual deficit had previously been demonstrated with dark-adapted subjects wearing tightly fitting goggles of low transmittance under natural conditions (C. v. Campenhausen: Photoreceptors, lightness constancy and color vision. Naturwiss. 73 (1986) 674).

Foveal densitometry and color matching in patients with oligocone trichromacy. S R S DE BRABANDERE, J E E KEUNEN, A T A LIEM and P T V M DE JONG, Erasmus University Rotterdam, University of Utrecht, The Netherlands.

Foveal densitometry and color matching was performed in four patients with oligocone trichromacy, measuring the foveal cone photopigment density and its time constant of regeneration. Oligocone trichromacy is a congenital, stationary, cone dysfunction with trichromatism (Van Lith, 1973). These patients have a reduced amplitude of the photopic ERG, a normal scotopic ERG and EOG, combined with a normal fundus and trichromatism. The hypothesis is that these patients have a reduced number of cones in and around the fovea. The improvement of visual acuity in dim light is striking in some patients. In our patients, we found a reduced density of foveal cone photopigment with a normal time constant of photopigment regeneration. All patients had normal color matching on the anomaloscope. We conclude that foveal photopigment screening in vivo in oligocone trichromacy confirms the hypothesis of a reduced number of cones (reduced density of visual pigment) with a normal function (normal regeneration and normal color matching). Ref: Lith, GHM van. General cone dysfunction without achromatopsia. In Proc. Xth ISCERG Symposium, 1973, 175-180.

Identification of photoreceptors involved in Haidinger's entoptic polarization phenomenon. E DODT and Y TSUYAMA, Max-Planck Institute for Physiol. & Clin. Res, Bad Nauheim, Germany.

Haidinger's polarization phenomenon consisting of yellow "brushes" against the blue sky around the fixation point is widely accepted to be caused by a radially symmetrical orientation of molecules of the yellow macular pigment surrounding the Henle-fibres. Alternatively Stanworth and Naylor, Brit. J. Ophthalmol. 34: 282 (1950) put forward a theory that Haidinger's brushes are due to postulate dichroic properties of the blue receptors of the macula. In an attempt to identify the photoreceptors involved in Haidinger's polarization phenomenon we recorded psychophysically the light threshold (absolute threshold, increment threshold) of ten healthy experienced observers to rotating (2 cy per rev) linearly polarized light of various intensities and wavelengths between 400 and 550 nm. Spectral sensitivity of the brushes was highest between 450 and 480 nm with a steep decrease at wavelengths > 515 nm. Absolute threshold for Haidinger's brushes was at 0.05 to 0.1 cd/m^2. Increase of adaptive illumination (I) above this value increased the increment threshold (ΔI) of the brushes about equally ($\Delta I/I = 1.0$). Comparison of the action spectrum of Haidinger's brushes with that of the blue cones (corrected for lens absorption and macular pigment) revealed big differences for wavelengths > 450 nm which indicates the participation of photoreceptors other than blue cones. Comparison of the increment threshold of Haidinger's brushes for test lights of $\lambda = 448$ nm during steady exposure to $\mu = 467$ and $\mu = 577$ nm with the action spectrum of short, middle and long wavelength cones revealed that all types of cones contribute synergetically to the perception of Haidinger's brushes which reflects the polarization capacity of the macular pigment.

Analysis of flash response from temporal two-pulse data. M L F DE MATTIELLO, M BRIZUELA and A TONTI, PRIVIS, Biofisica, DTo Fisiologia, Buenos Aires, Argentina.

Working with red-green pulses separated by different SOAs (Stimulus Onset Asynchrony), and at frequencies not higher than 10Hz., three zones of discrimination can be observed: a) between 150 ms and 80 ms, independence of pulse; b) between 80 ms and 60 ms, cancellation of the second pulse by the first pulse presented within the chosen period of time; and c) between 60 ms and 5 ms, partial summation of the pulses. Finally, at SOA = 0, total summation. The cancellation zone is studied for heterochromatic, opponent, non opponent and monochromatic pulses. This zone varies according to the characteristics of the stimulus, the state of the observers' adaptation, and the normal or pathological condition that the visual system presents. The data obtained can be fit by a damped oscillatory function which represents the temporal response of a negative feedback control system of the second order. In our case, it is a low-pass filter with a bandwidth that varies according to the experimental conditions adopted and the observers' visual state. Fitting the results by a mathematic function allows quantification of the dynamic properties of vision, making possible a new analysis of ocular pathologies, and the transference of results to engineering of control.

Session 4 Rod-Cone Interaction

Suppressive rod-cone interactions: Underlying mechanisms and practical application. T E FRUMKES, Dept. of Psychology, Queens College, Flushing, USA.

Dark adapted rods exert tonic suppression upon cone-mediated vision. There are probably many mechanisms but, to date, we have specified two by combining psychophysical and electrophysiological procedures. (1) Sensitivity to rapid flicker progressively decreases during rod-dark adaptation, and increases if rods are adapted to increasing intensity backgrounds. This "flicker effect" is mediated in distal retina and involves a prominent role for horizontal cells. (2) Sensitivity to high spatial frequency gratings similarly decreases during rod-dark adaptation, and increases if rods are adapted to increasing intensity backgrounds. However, this "grating effect" is as prominent with interocular adapting fields as with one-eyed stimulation, and psychophysical data are inconsistent with an electrical coupling model accounting for the flicker effect. Analysis of research in other laboratores shows that increasing ambient levels of illumination from dim scotopic levels to scotopic levels still clearly below cone-theshold nevertheless improves cone-related vision involving accuracy of binocular vergence and motion perception, and often eliminates night myopia and fixation disparity. Supernormal suppressive rod-cone interactions probably explains night-vision difficulty in many "clinically normal" individuals, particularly among the elderly population.

Interactions between rods and long-wavelength cones in incomplete achromats. M SCHNECK, G HAEGERSTRÖM-PORTNOY and W VERDON, School of Optometry, University of California at Berkeley, USA.

We have found three types of interactions between L cones and rods in incomplete achromats. 1) On flashed backgrounds, achromats' residual L cones elevate rod thresholds, steepen rod TVI functions, and decrease the light level of rod saturation. In contrast, L cones do not affect rods under steady state conditions in achromats as they do in trichromats. 2) More recently, we demonstrated interactions between rods and L cones using classic Stiles techniques. Threshold vs. radiance curves measured on blue backgrounds were characterized by the expected increase in threshold as backgrounds radiance increased up to 3 log scot. tds. Beyond this, threshold dramatically decreased. Saturating rods reduce the sensitivity of L cones by as much as 1.5 log units. Steady state interactions like these do not occur in normal trichromats. 3) Most recently, we found that saturating rods interfere with cone mediated flicker detection in achromats. CFF rises initially to a peak at approximately 2 log scot tds, then CFF drops as luminance is further increased, reaches a minimum at approximately 3 log scot tds, and shows a prominent secondary rise with further luminance increases. This pattern is similar to that observed under the steady-state conditions in (2); saturating rods 'knock out' cones, and cone sensitivity returns when rods are completely saturated. These interactions are not evident in the CFF of trichromats. We conclude that the achromats' post-receptoral 'wiring' is unlike that of trichromats.

Rod and cone signal processing in mesopic heterochromatic photometry. F VIENOT and A CHIRON, Muséum National d'Histoire Naturelle, Paris, France.

Photometric measurements in the mesopic range show a gradual change in relative spectral sensitivity when assessed by direct comparison brightness (DCB) matching but a disruption in the mid-mesopic when assessed by heterochromatic flicker photometry (HFP) (Viénot & Chiron, 1992). Furthermore, on the basis of flicker experiments, it was suggested that differences in latency between rod and cone signals could explain cancellation of flicker around 1 scot Td and that rod signals could have access to slow and fast pathways (MacLeod, 1972; Sharpe et al, 1989). We addressed the

question whether allowing for a physical temporal phase shift between the test stimulus and the reference stimulus in a HFP experiment would yield a stable measure in the mid-mesopic and whether a vectorial model could be derived. We compared photometric measurements assessed by HFP and by DCB matching at 10 mesopic levels (3.10^{-3} to 10^{2} phot Td) and at short wavelengths (445/506 nm). The results showed that allowing for a temporal phase shift facilitated HFP matches and increased the precision of settings. A vectorial representation of rod and cone signal processing will be discussed.

Characteristics of a large sample of X-linked achromats. A J ADAMS, G HAEGERSTRÖM-PORTNOY, M SCHNECK, W VERDON, S HEWLETT and S FISHER, School of Optometry, University of California at Berkeley, USA.

We have examined the vision of twelve X-linked (blue cone) monochromats using clinical and laboratory techniques. Four pedigrees are represented. Nine belong to a large pedigree with twelve living affected members. The other three each belong to a different pedigree. We compare their findings to our sample of 55 autosomal recessive achromats. All pass the Berson test, whereas all of the autosomal recessive achromats fail. Visual acuities varied considerably between individuals, (20/60 to 20/200 for right eyes; 20/80 to 20/320 for left, mean 20/140 for all eyes). Five showed significant (one line or more) interocular differences in corrected VA. Only 3 (25%) had significant eye turns; 80% of our autosomal recessive achromats have eye turns. In agreement with others (François, J. et al. Am. J. Ophthalmol., 61, 1101, 1966), we find most (10/12) to be myopes. CCS on the D-15 ranges from 113 to 236, with axes falling between deutan and scotopic. The Sloan achromatopsia test shows a predominant rod pattern, similar to that of the autosomal recessive achromats. The performance of the two groups differs meaningfully only on plate 4 (yellow). For all X-linked achromats, spectral sensitivities on blue as well as yellow backgrounds reveal the presence of only S cones of normal sensitivity and rods; we do not see evidence of L cones in any of them, unlike Smith V. et al. Invest Ophthalmol. Vis. Sci, 24, 451, 1983.

Low illumination and color vision deficiencies. H KUDO, F OBARA and Y OHTA, Dept. of Ophthalmology, Tokyo Medical College, Japan.

We evaluated the performance of the Panel D-15 test under reduced illumination in color vision deficiencies. Forty anormalous trichromats (10 protanomalies and 30 deuteranomalies), who passed the Panel D-15 test at normal illumination, served in the experiment. Ten color normals also performed the experiment. We used six light levels ranging from 0.9 to 900 lux. At 3.5 lux about 60% of the color vision deficiencies failed the Panel D-15 test, but all color normals passed. The color defectives were more sensitive to reduced illumination than color normals. The direction of confusion lines were changed with decreasing illumination levels.

Session 5 Electrophysiology

S-cone responses in the flash ERG and VER. P GOURAS, C J MACKAY and S YAMAMOTO, Harkness Eye Institute, Columbia University NYC, USA.

We detect an S-cone mediated response in the strongly light-adapted ERG defined by its unique action spectrum and its presence in an S-cone achromat. The response consists of a small initial a-wave, a distinct b-wave and a later negativity. This S-cone ERG is elicited only by short wave flashes and rides on top of an earlier response produced by L and M cones. In protanopes the S-cone b-wave is reduced compared to normals and deuteranopes; this reduction is accompanied by a larger L and M cone ERG to short wave flashes. We can identify the S-cone VER by matching short and long wave flashes to produce identical L and M cone ERGs. By comparing the VER to these matched flashes the S-cone response stands out in the short wave VER, just after a faster L and M cone response.

Evaluation of macular function by red-flicker electroretinogram in optic media opacities. M FIORETTO, C ORIONE, C BURTOLO and G P FAVA, Eye Clinic, University of Genoa, Italy.

The evaluation of macular function in patients with optic media opacities is very difficult. We have studied the reliability of the red flicker electroretinogram (FLIERG) in 173 patients with visual acuity less than or equal to 1/10 due to corneal opacities (19 cases), cataract (117 cases) and uveitis (37 cases). Results were compared to those obtained in 82 age matched normal subjects and in the same 173 patients after surgery or when the optic media became clear in uveitis patients. Fllergs were recorded after 15 minutes of dark adaptation; full field red flash stimuli were of 0.5 J intensity at 31 Hz. Amplitudes were measured from peak to peak and in normal subjects was 85 μV ± 21.5 .(s.d) Results suggest the efficacy of red FLIERG in the diagnosis of maculopathies when optic media are opaque.

Colour evoked component N87 of the visual evoked potential: localization of its cerebral generator by application of the regional source technique. H PLENDL, D PRÖCKL, S SCHULZE, M MAYER, K BÖTZEL and W PAULUS*. Neurologische Universitätsklinik, München. *: Abt. Klin. Neurophysiologie, Universität Göttingen, Germany.

A component N87 of the colour evoked visual potential was described by Paulus et al. (1984), which seemed to be rather color specific. Because of the short latency of this component and its occipital maximum a generation in the primary visual cortex was assumed. In a new experiment we tested the hypothesis of a generation of N87 in the visual area V1. The same stimulation equipment as in the previous experiments was used: it consisted of an array of green and red LEDs behind a translucent screen, the size of the visual field stimulated was 4 degrees. Both hemifields were stimulated in 8 subjects. The VEPs were recorded with a 32 electrode montage and analysed off-line using the dipole source analysis technique BESA. The regional source technique was applied presuming that within the analysed time window between 75 and 100 ms the main power of the evoked potential is produced by only one generator. The results of this analysis confirm a generator of N87 in the contralateral striate cortex.

Diagnosis of protan and deutan color vision deficiencies with pattern-ERG and VEP. J GERLING, T MEIGEN and M BACH. Universitäts-Augenklinik, Freiburg, Germany.

We compared electrophysiological [pattern-ERG (PERG) and VEP] and psychophysical measures to color stimuli to separate between different forms of anomalous color vision. PERG and VEP were simultaneously recorded from 10 normals and 11 volunteers with congenital color vision deficiencies. Stimuli were color checkerboards with 0.5° check size, phase reversing at 34 revs/s. The luminance of the red and green parts were varied in opposite directions from 0 to 30 cd/m^2 while hue and average luminance was held constant. This allowed for one equal luminance condition where flicker was fused. Subjective equiluminance conditions were determined by the method of adjustment. In the 10 normals, the subjective equiluminance (SE) was reached at 0.50 red/(red+green). At the same point, the PERG amplitude was moderately, and the VEP sharply reduced. Results for the color anomalous subjects: In protanomaly (one subject), SE and the dips of the PERG and VEP were shifted to 0.63, In protanopia (4 subjects) SE and PERG- and VEP-amplitude dips were shifted to 0.71. In achromatopsia (one subject), SE and dips were at 0.76. In deuteranomaly (2 subjects) SE was at 0.43, in deuteranopia (3 subjects) it was 0.41; in the PERG and VEP, the deuteranomals showed a sharp dip, whereas the deuteranopes showed a broad depression. These VEP and PERG measures may allow objective assessment of color vision deficiencies. Cone isolating stimuli should provide a better differentiation of protan and deutan color disturbances as we found in ongoing experiments.

Spectral sensitivity by flash, flicker and pattern ERG. H G SPERLING and J MISHRA, University of Texas Sensory Science Center, Houston, USA.

Rhesus b-wave spectral sensitivity was measured for 12°, 50 msec flashes against very large, intense neutral backgrounds. On humans, pattern ERG was measured with 1 cpd checkerboards alternating between spectral and neutral at each ten nanometers. Flicker ERG spectral sensitivity was obtained by the same method with the checkerboard reticles removed. The flicker ERG spectral sensitivities and monkey b-wave spectral sensitivities are identical, showing a small amount of red-green opponency and no blue sensitivity. The pattern ERG spectral sensitivities are radically different showing as much red-green oppency and blue sensitivity as in final common path psychophysical data. It is argued that they must represent ganglion cell stage response, since b-wave represents bipolar stage response.

Psychophysical and occipital responses to aberration-free blue/yellow and red/green gratings. D MCKEEFRY and J J KULIKOWSKI, Visual Sciences Lab, UMIST, Manchester, UK.

Selective stimulation of the blue-yellow opponent system critically requires a blue-yellow isoluminant grating with hues corresponding to the cardinal tritanopic confusion line (S-cone involvement). Chromatic aberration must be eliminated from any chromatic pair of hues by using a system which focuses different wavelengths on one plane (Mullen 1985, J Physiol, 359, 381), otherwise the achromatic intrusion may be present. Then, chromatic contrast sensitivity and spatial resolution for the blue-yellow gratings is slightly lower than for red-green gratings. The Visual Evoked Potentials (VEPs) elicited by on-off presentation of low contrast (suprathreshold) gratings also differ: grating onset (appearance) VEPs show longer latencies for blue-yellow than red-green gratings, as shown previously (Kulikowski et al. 1989, Colour Vision Deficiencies X). Significantly, the off-wave, though much smaller, is similar (negative) to onset wave of blue-yellow VEPs, whereas in the red-green VEP the off-wave resembles achromatic off-VEPs. This suggests that red-green, but not blue-yellow isoluminant gratings effectively stimulate the achromatic (M) system.

Receptive field dimensions of macaque retinal ganglion cells. J KREMERS, B B LEE and T YEH, MPI of Biophysical Chemistry, Göttingen; University Eye Hospital, Tübingen, Germany.

The receptive field properties of macaque retinal magnocellular (MC) and parvocellular (PC) cells with exclusively L- and M-cone input were studied using a bipartite field. The two halves of the field were modulated in counterphase and the edge was positioned at different locations on the receptive field of the cells. Light sources were 553 and 638 nm LEDs. Four types of modulation were used: luminance, chromatic and silent substitution of the L- and M-cones. PC-cells showed a clear minimal response when the edge was located at the receptive field's centre. The responses to silent substitution modulation could be described satisfactorily by a subtraction of two integrated Gaussian functions. Further, the response phase was constant except for a 180° response phase shift at the centre of the receptive field. Centres and surrounds therefore have Gaussian-like profiles, and there are no indications of mixed cone inputs to the surrounds. Gaussian widths of the centres varied between 1.5 and 10 min of arc in the parafovea. Most surrounds were 1 to 5 times the centre diameter. Using a linear model of PC-cell organisation with one cone type providing input to the centre and the other cone type to the surround with a centre surround latency difference of 3-8 msec, the responses to luminance and chromatic modulation could be predicted from the silent substitution results on the same cell. MC-cells respond in a more complex manner. The first harmonic response to luminance modulation however, went through a minimum at the cell's receptive field centre. But, frequency doubled responses occurred, indicating spatial nonlinearity. A Gaussian receptive field profile gave good descriptions of the first harmonic responses. MC-cell centres were normally slightly larger than centres of PC-cells at equivalent eccentricity. Our data indicate that the surrounds of MC-cells are relatively large, at least 5 times the centre diameter.

Session 6 Blue Cones

Electrophysiology and psychophysics of the blue cone mechanism. E ZRENNER, University Eye Hospital, Tübingen, Germany.

Cones with a maximum sensitivity in the short wavelength range of visible light (S-cones, blue cones) feed a neural pathway with very peculiar characteristics that can be observed in electrophysiological recordings and psychophysical tests: 1) In the electroretinogram, responses from S-cones show markedly delayed b-waves with a strong after-effect, while the positive off-response is missing. 2) In recordings from retinal ganglion cells, S-cone driven responses have a longer latency, a lower flicker fusion frequency, large receptive fields and show a peculiar interaction with longer wavelength sensitive cones. 3) In visually evoked cortical potentials again such marked differences between the responses driven by spectrally different cones can be observed. 4) With psychophysical increment threshold techniques a transient desensitising effect of longer wavelength sensitive cones on S-cones shortly after the offset of light can be observed (transient tritanopia) and used for studying effects of neuro-ophthalmological substances affecting interaction between cone pathways. 5) Measurements of colour discrimination have revealed that short wavelength sensitive cones and rods alone can mediate colour vision within a limited range of prevailing luminance. These characteristics point to a peculiar role of the short wavelength sensitive system and shall be discussed together with examples of congenital and acquired deficiencies of the S-cone system.

Consistent finding of transient tritanopia in blue cone monochromats. G HAEGERSTRÖM-PORTNOY, W VERDON, M SCHNECK and S HEWLETT, School of Optometry, University of California at Berkeley, USA.

Transient tritanopia, the temporary loss of sensitivity of the S cone pathway following extinction or decrement of a long wavelength adapting field, is thought to result from anatagonism between S cone signals and L and M cone signals. Therefore blue cone monochromats, who lack L and M cones, are not expected to show this effect. We have previously published transient tritanopia in one blue cone monochromat, though others have reported the absence of transient tritanopia in blue cone monochromats. Though we argued that the discrepancy is attributable to test parameters, the argument could be made that subject differences are responsible. The subject has no L or M cones. Here we present results from 7 additional blue cone monochromats, all of whom show some degree of transient tritanopia. None of these people have L or M cones. The transient tritanopia is observed as a loss in sensitivity to a short-wavelength target about 0.5 sec after a 1 log unit reduction in the luminance of a yellow background. The variability in the magnitude of transient tritanopia can be ascribed to differences in the detection mechanism following the transition. In some individuals, blue cones continue to detect the target after the transition, resulting in a relatively small (< 0.65 log unit) transient tritanopia. In others, rods detect the target after the transition, resulting in large (> 1.0 log unit) transient tritanopia. Trichromats also show two different detection mechanisms following transition, S cones and M cones.

The range of scotopic contrast colors matches that associated with S-cone activation. S L BUCK and J L BRANDT, Dept. of Psychology, University of Washington, USA.

Scotopic color contrast (hue induced by a photopic field into a simultaneously presented, purely scotopic test field) is usually reported to produce a blue hue. We sought to determine the complete range of hues produced by scotopic color contrast in order to provide clues about how rod signals are processed in the pathways that mediate color vision. Stimulus arrangements varied but observers typically viewed a monocular scotopic test field (500 nm, 2 deg diameter) surrounded by a photopic inducing annulus (8 deg outer diameter), centred 5 deg from fixation. Observers adjusted the wavelength of a foveal monochromatic comparison spot in the contralateral eye to match the induced hue percept. The scotopic test field, colorless when presented alone, was described as shades of violet, blue, or green, and was matched with 450 to 540 nm lights, in the presence of the various inducing fields. Inducing field wavelengths < 500 nm induced the greener colors, while longer wavelengths induced blues and violets. Thus, inducing field wavelengths associated with greater S-cone activation produced contrast colors associated with lesser S-cone activation, and vice versa. There was no analogous association with L- or M-cone signals or r/g opponency. Supported by NIH grant EY03221.

The necessary intensity of the white background when measuring the response of the blue cone system. A KUBO, H GUNJI, K KITAHARA and G TAKAHASHI, Dept. of Ophthalmology, The Jikei University, Japan.

The vulnerability of the blue cone system in various eye diseases is well known. Therefore, it is important to measure the blue cone response using color perimetry for early diagnosis. In this study, in order to investigate the necessary intensity of the white background when measuring the blue cone system, we measured the spectral sensitivity on various intensities of white backgrounds at the fovea and at 5°, 10 °and 15 °eccentricity. The apparatus used in this study was a Maxwellian view optical system with two channels. A 1°, 200 msec test flash was superimposed on a xenon white background. It was found that a background intensity of more than 100 photopic trolands was necessary to obtain the response of the blue cone system.

White and blue brightness comparisons under dynamic conditions. L R RONCHI and C CASTELLINI, Istituto Nazionale di Ottica, Florence, Italy.

The observer is presented with a bipartite field, half white, half blue. The two halves, equated for brightness, under steady state viewing, differ in luminance, being the blue (Wratten) filter a relatively narrow band one. The relation between (heterochromatic) brightnesses is found to be time dependent, depending on the adaptive response, as is shown in various experimental situations: ON - OFF - and during sinusoidally patterned stimulation at frequencies below 1 Hz, with variable modulation depth. The interpretation of the findings is related to what appeared in the literature during the past century. The question is raised whether our experimental situations may be proposed as a test of post-receptoral functionality and applied to some dynamic displays, since we find that the blue-on-white case strongly differs from the white-on-blue one.

Bipolar cells specific for blue cones in the Macaque retina. D MARSHAK, R JACOBY and N KOUYAMA, University of Texas Medical School, Houston, USA.

Antisera that recognize glycine-extended precursors of the peptide cholecystokinin labelled neurons in the macaque retina that resembled the blue cone bipolar cells described previously. They clearly formed a single population since the density and sizes of their perikarya varied monotonically with eccentricity, while the levels of their perikarya and axon terminals were constant. Their dendrites typically ran obliquely, and they had characteristic, diffuse terminals. Short-wavelength cones were also labelled in some preparations, either with Procion Black or anti-blue opsin, and the labelled bipolar cells received input exclusively from these cones. There were approximately 50% more labelled bipolar cells than short wavelength cones at any eccentricity, and, on average, there were 1.2 cones presynaptic to each bipolar cell and 1.8 bipolar cells postsynaptic to each cone. The dendrites formed the central elements at ribbon synapses in the short wavelength cones, sometimes forming atypical junctions with multiple central elements at single ribbon or with two or more ribbons presynaptic to a single dendrite. The axons of the labelled bipolar cells branched in the fifth stratum of the inner plexiform layer, where they contacted approximately equal numbers of amacrine cells and retinal ganglion cells. Taken together, these findings indicate that the labelled bipolar cells were different from the midget bipolar cells that contact middle- and long-wavelength cones. They also suggest that the labelled bipolar cells depolarize in response to increments in short wavelength stimuli. There were also numerous, unlabelled bipolar cell dendrites receiving inputs from short-wavelength cones at other types of contacts, however, and these presumably belonged to bipolar cells with hyperpolarizing light responses. (Supported by grant EY-06472 from the National Eye Institute).

Blue cones - morphology and color specific connections. P K AHNELT and H KOLB, Dept. Gen. & Comp. Physiology, University of Vienna, Austria. and Moran Eye Center, University of Utah, USA.

As a prerequisite for studying color specific circuitry we have identified criteria to distinguish blue sensitive (B-) cones from M- and L-cones. Subsequent EM-serial reconstruction has revealed first color related features in the retinal outer plexiform layer. B-cone synaptic terminals (pedicles) differ by deeper penetration into the outer plexiform layer, scarcity of telodendrial connections and shorter average length of their synaptic ribbons. While B-pedicles of central retina are relatively smaller, their shapes become peculiarly bi- or trilobated in the periphery thus extending their contact range. Selective connection with a B-cone bipolar cell (Mariani 1984) could be confirmed. Connectivity with Golgi-labelled horizontal cell subtypes reveals reciprocal weighting of spectral connections. HII type HCs are preferentially associated with B-cones at both their dendrites and the axon. HI and HIII dendrites have most or all of their contacts to L-cones. Thus neuronal patterns begin to emerge that underly at least the basic dichromatic subsystem of modern trichromacy.

Microcircuitry of bistratified ganglion cells in macaque fovea. D J CALKINS[1], S J SCHEIN[2], Y TSUKAMOTO[3] and P STERLING[1]. 1: Neuroscience, University of Pennsylvania, USA. 2: Psychology, UCLA, USA. 3: Hyogo College of Medicine, Japan.

Bistratified ganglion cells were identified in electron micrographs of serial sections. The dendrites arborized in the on layer at 70-100% depth and in the off layer at 20-50% depth. One cell received 25 synaptic contacts in the on layer from putative "blue cone" bipolar cells and 12 synapses in the off layer from a diffuse bipolar cell whose dendrites were traced to 5 non-S cone pedicles. This ganglion cell, apparently collecting on input from S cones and spatially coextensive off input from L and M cones, probably corresponds to the "blue/yellow" type II cell identified electrophysiologically. Another ganglion cell received 9 synaptic contacts in the on layer, 3 from putative blue cone bipolar cells and 6 from diffuse bipolar cells, and at least 7 contacts in the off-layer from 2 diffuse bipolar cells. This cell, apparently collecting on input from all three cone types and spatially coextensive off input from only L and M cones, may correspond to the "red/green" type II cell.

Session 7 Genetics and Congenital Red/Green Colour Deficiencies

Molecular genetics of human color vision. A G MOTULSKY, J WINDERICKX, A L JORGENSEN, D T LINDSEY, E SANOCKI, D TELLER and S S DEEB, Depts. Medicine, Genetics & Psychology, University of Washington, USA.

Human red-green color vision has its evolutionary origin in old world primates. A single red pigment gene and one or more green pigment genes on Xq28 are highly homologous. Illegitimate recombination is common causing deletions and various fusion genes and is the basis of color vision defects. "Red-green" fusion genes are associated with protan defects and "green-red" fusion genes are usually associated with deutan defects. Since only the proximal green gene is expressed, distally located "green-red" fusion genes may be found with normal color vision. Genotype-phenotype relationships in 65 individuals with color vision defects have been clarified. In a single instance, a rare missense mutation of a critical amino acid led to a deutan defect. A high frequency (35%) of a phenotypically silent intronic deletion of the red pigment gene and a high frequency (20%) of phenotypically silent green-red fusion genes were found among African-Americans. Among Japanese the frequency of phenotypic and genotypic color vision defects was similar (about 4%). Single amino acid variants unrelated to color vision defects and silent nucleotide polymorphisms are common. The most frequent polymorphism in all populations was a ser/ala variant of the red pigment gene. Carriers of the "serine" variant have a higher sensitivity to red light than those who carry the "alanine" variant. Differences in visual perception within the normal range can be mediated by genetic polymorphisms.

Correlation between Rayleigh match range in protan and deutan subjects with sequence of the red/green hybrid opsins. S S DEEB, J WINDERICKX and A G MOTULSKY, Depts. Medicine & Genetics, University of Washington, USA.

Certain protans and deutans have gene arrays comprised of red-green and green-red hybrid genes, respectively. We tested the hypothesis that chromatic discrimination depends upon the difference between the spectra of the normal and the hybrid pigments. Coding sequences of the relevant genes, the fusion points in hybrid genes and the presence of Ser or Ala at position 180 were determined in 19 protan male subjects by SSCP analysis and direct sequencing of PCR amplified exonic sequences. The resulting sequences of the normal and hybrid opsins were used to assign the wavelength of maximum absorption of the pigments as determined in vitro by Merbs and Nathans (Science 258: 464, 1992). Eight of 12 protan subjects whose hybrid and normal green pigments were spectrally identical tested as protanopes and the other 4 as protanomalous but with a high matching

range (41.5). Differences of 3 and 6 nm between the hybrid and normal green pigments were observed in one protanope and in 6 protanomalous subjects. Analysis of deutan subjects is in progress.

Neural network models with back-propagation learning for normal and dichromatic color vision. S USUI and S NAKAUCHI, Dept. of Info. and Comp. Sci., Toyohashi University of Technology, Japan.

Neural network models for normal and dichromatic color vision were constructed by a top-down approach rather than an experimental bottom-up approach. Back-propagation learning technique was used to train a multi-layered neural network model to realize the nonlinear mapping from cone space into perceived color space. Dichromatic color vision models were represented by the constraint of a loss of one type of cone. After learning was completed, emerging characteristics of the models were analyzed by using spectral lights as test color stimuli. It turned out that each model acquired by learning can predict the experimental evidences such as spectral response property, hue representation of spectral light and wavelength discrimination.

Deuteranopia under conditions of a large visual field. A ORAZEM and H SCHEIBNER, Physiologisches Institut II, Düsseldorf, Germany.

Colour vision of a deuteranope was investigated on a bipartite 10° visual field. He had to do suited two-variable colour matches. Additionally, there were measured neutral zones with the help of the perceptual criterion "neither blue nor yellow", and alychne traces with the help of heterochromatic brightness matches. Experimental finding: "Perfect" two-variable colour matches were feasible across the largest part of the chromaticity chart except for an "imperfect" region between the long wavelength spectral locus and the neutral zone. A separate evaluation of these two regions yielded the following results mainly for the deuteranomaly arising from the "imperfect" chromaticity region: a) The deuteranomalous long-wavelength sensitivity is shifted ("altered") towards longer wavelengths compared to the deuteranopic one. b) The data permit no conclusion on the shift of the deuteranomalous middle wavelength sensitivity. c) Both short wavelength sensitivities, the deuteranomalous and the deuteranopic, are identical and seem to contribute to brightness.

The red-green chromatic system in anomalous trichromats. E MIYAHARA, J POKORNY and V C SMITH, Visual Sciences Center, University of Chicago, USA.

We measured increment threshold spectral sensitivities in X-linked anomalous trichromats and a normal trichromat. The test stimulus was 10° diameter, presented on a spatially coextensive steady white 1000 td pedestal and a steady 1000 td white background of 19° diameter. Stimuli were presented within a 1 sec raised cosine wave in two procedures: a) increment detection threshold and b) hue identification. A normal trichromat showed the same threshold spectral sensitivities by both procedures, with a distinctive notch at 570 nm. Anomalous trichromats did not show a notch with the increment detection procedure. With the hue identification procedure, these observers' spectral sensitivities were lower than those from the increment detection procedure and showed a notch.

The spectral sensitivity characteristics of congenital red-green color vision deficiencies. K KITAHARA, A KUBO and A KANDATSU, Dept. of Ophthalmology, Jikei University, Japan.

We previously reported that the spectral sensitivities measured on a monochromatic background can be directly compared with the Stiles' II-mechanisms. In this paper, we investigated the spectral sensitivity characteristics in congenital red-green color vision deficiencies using an intense 430 nm and 700 nm backgrounds. In protanopia and protanomaly, the spectral sensitivity curves in the middle and long wavelength regions on both backgrounds coincided with the spectral sensitivities of the green cone mechanism. In deuteranopia and 6 of the 9 observers with deuteranomaly, the spectral sensitivity curve in the middle and long wavelength regions on both backgrounds coincided with the spectral sensitivities of the red cone mechanism. Three of the 9 observers with deuteranomaly showed the spectral sensitivity curve in the middle and long wavelength regions which was different on the 430 nm background than on the 700 nm background. As a result, it is felt that the pathogenesis of protanomaly differ from that of deuteranomaly.

Session 8 Testing

Heterochromatic luminance matches in automated Rayleigh and Moreland equations. J SOMMERHALDER, M PELIZZONE, B ROSSILLION and A ROTH, Ophthalmology Dept., Cantonal University Hospital, Geneva, Switzerland.

We have developed an automated color vision examination consisting of Rayleigh and Moreland matches on a computer-controlled anomaloscope. With this system, it is possible to vary

automatically the radiance (and saturation) of the test field when a given ratio of primaries is presented in the mixture field. The aim of these experiments was to test different methods of heterochromatic luminance matches so that a correct radiance of the test field could be used during the automated color vision examination itself. Luminance matches were obtained on seven normal subjects with two different methods: (1) by direct comparison of the two fields and (2) by the flicker method. Our computer-controlled anomaloscope was modified to allow both methods to be used on the same instrument. In the Moreland equation, luminance matches were easy to achieve. Both methods yielded very consistent results over the whole blue-green range. In the Rayleigh equation, luminance matches were more difficult to achieve. As expected, the flicker method was more precise than direct comparison, especially at the ends of the red-green range where differences in hue between the two fields are pronounced. While both methods yielded consistent results, they have their specific strengths and weaknesses when considering them as preliminaries to an automated color vision examination.

Automated Moreland equations on 7° and 2° fields. B ROSSILLION, M PELIZZONE, J SOMMERHALDER, D HERMÉS and A ROTH, Ophthalmology Department, Cantonal University Hospital, Geneva, Switzerland.

We made automated Moreland equations on 7° and 2° fields on a population of normal subjects. Before each test, we determined by direct comparison the radiance of the test field for luminance matches with different ratios of primaries in the mixture field. This relationship was used in the subsequent color vision examination to set automatically the correct radiance of the test field. The test appeared to be notably easier on the large field. Accordingly, the matching ranges of Moreland equation were significantly smaller on the 7° than on the 2° field. A learning effect can be ruled out because the large field was systematically used first. The population distribution of the match mid-points was also narrower on the large field. Our goal is to determine which field size in Moreland equation is optimal in terms of ease of use and clinical sensitivity. We will therefore present results of patients (with known color vision deficiencies) tested with the same protocol and compare them with those of the normal population study.

A new lantern test using light emitting diodes. N TAKAHASHI, K HAMANO, A TOYOGUCHI and Y OHTA, Dept. of Ophthalmology, Tokyo Medical College, Japan.

<Purpose and Methods> We developed a new lantern test using light emitting diodes to detect and classify color vision deficiencies. We evaluated the lantern test in congenital color vision deficiencies in comparison to other color tests. The lantern color lights are 1.5 mm in diameter and subjects view them from 2.5 m, with a resulting visual angle of 2'. The color light wavelengths used were: red, 620 nm; yellow, 577 nm; and green, 555nm. The three color luminances were approximately the same. Two color lights were presented simultaneously for 2 seconds, turned off for 2 seconds, then the next two color lights were presented and so on. <Results> We found a correlation between the results of the lantern test and Neitz anomaloscope, and between the results of the lantern test and the panel D-15 test. However, the color defectives made more errors on the lantern test than on other color tests.

A new lantern test using light emitting diode lamps. S TANABE, K HUKAMI, S YAMADE, K ICHIKAWA and S TAGAI, Nagoya, Fukui, Shiga, Tokyo, Japan.

A lantern test using LED lamps has been devised. In this model, two lights of each 4mm in diameter placed 15mm apart are presented simultaneously with an exposure of 2 seconds, for color naming. Viewing distance is 5m. Color of the light is either red, green or yellow. Every possible combination of three colors is included in one trial, which consists of 9 sets of lights accordingly. They appear in random sequence and the number of errors in the second trial is scored. Test results are printed out. Anomalous trichromats usually make from 3 to 7 errors in one trial, although rare cases of minimal anomaly make less or no errors. Dichromats usually make 7 or more errors. The lantern test is persuasive as well as important, especially for occupational purpose. This model is easy to operate and considerably handy. In addition, the three colors located on a confusion line of protanopia and deuteranopia provide a theoretical basis for it as a color vision test.

Protans and PAPI. B L COLE and J D MADDOCKS, Dept. of Optometry, University of Melbourne, Australia.

There has been a colour vision requirement for pilots of aircraft since 1919. The International Civil Aviation Authority has worded the requirement in a way that permits Nation States to adopt different means of assessing colour vision of pilots and to set different pass/fail criteria. In the UK, the Holmes Wright Type A lantern is used and in the USA the less demanding Farnsworth lantern. The appeal process in the USA involves a practical test recognising control tower signal lights which is more liberal again. In Australia, pilots with defective colour vision who had been limited to flying in daylight

hours successfully challenged the colour vision requirement on the grounds that the recognition of coloured signal lights was no longer of critical importance in aviation and the Australian Civil Aviation Authority undertook to develop a test of colour vision that was closely related to a practical colour discrimination task in aviation. The recognition of the red and white signals of PAPI and TVASI landing approach path signals was identified as one such critical task. We have developed and validated a lantern test that simulates the recognition of these signals from a distance of 1 nautical mile under conditions of reduced visibility. The results with the lantern for normal and colour vision defective observers are compared to those obtained with the Farnsworth and Holmes Wright lanterns and the implications for aviation safety of varying standards of colour vision for pilots are discussed.

Design and use of the Holmgren Wool test. J BIRCH and N PATEL, Dept. of Optometry and Visual Science, City University, London, UK.

The Holmgren Wool test was commissioned by the Swedish railway authority in 1875 and became the standard test for recruits in many national railway systems. The original test contained 125 wool skeins but the number of skeins was later reduced. The Holmgren Wool test is still commercially available and is favoured by some industries and transport systems as a vocational colour vision test in spite of reports of poor screening efficiency and lack of consistency. Modern tests have 49 wool skeins (3 test skeins and 46 comparison skeins) and a systematic method of examination is recommended. However, a test purchased in 1990 was found to have different coloured wools from an earlier test available in our laboratory. We have matched the wool samples of both tests with Munsell papers and have derived the C.I.E. chromaticity co-ordinates, for illuminant C, from published data. We have compared these data with established isochromatic zones for protan and deutan observers to establish the design criteria of both tests. Finally, we present results for a group of observers, dichromats and anomalous trichromats, having congenital protan and deutan colour deficiency. The possible clinical use of the test will be discussed.

Simulating blue-yellow deficiencies. S J DAIN, School of Optometry, University of New South Wales, Australia.

The three means of artificially inducing a blue-yellow colour vision deficiency are well known. These comprise making the stimuli sufficiently small, reducing the illuminance on the task and by limiting the duration of the stimulus. For brevity and simplicity one of the methods should be adopted. The induced colour vision deficiencies were assessed using the The City University Test (Second edition) and the SPP plates (Volume 2). All test plates were presented in a pseudo-random order and (for the TCU test) random orientation starting at the most difficult condition (darkest, briefest or smallest). For the reduced illumination experiment the subject viewed the test through neutral density filters giving an effective illuminance of 2 lux. Filter density was reduced until the level at which all plates could be identified correctly. The viewing time was reduced to 4 ms and increased to the point at which all responses were correct. For the size task, the subject approached the test plate until the correct responses were elicited. The specificity of the blue-yellow deficiency induced was used as the criterion for the most successful simulation. The order (decreasing) of specificity in the simulation was small stimulus then duration then low luminance. However, the relative effectiveness of each simulation varied as a function of both test and plate within each test. A detailed colorimetric assessment of the basis of the responses is indicated.

Study on color mechanism dependency in the off effect. M NOMURA and S YAMADE, Dept. of Ophthalmology, Shiga University of Medical Science, Japan.

The present study examines whether the off effect, the phenomenon of temporal edge emphasis, exhibits the same type of wavelength selectivity seen in the monochromatic Mach band which is the spatial edge emphasis. At first, off effect measurements were taken using a monochromatic background and a test light. However we were unable to demonstrate wavelength selectivity. In the second, the off effect-like overshoot of increment threshold on the chromatic change of background was studied. The off effect or the overshoot was observed in all combinations of test and background colors. We were unable to demonstrate any specificity, and this suggests that the degree of the overshoot seemed to depend solely on the chromatic difference of the background field.

Effect of supply voltage on Nagel anomaloscope settings. C R CAVONIUS, Institut für Arbeitsphysiologie, Dortmund, Germany.

While is has long been known that Nagel anomaloscope matches are influenced by the mains voltage (e.g., Schmidt, J. opt. Soc. Amer., 45, 514, 1955) there seem to be no reports of the magnitude of this effect. Because of a recent increase in the nominal mains voltage in Germany from 220 to 230 volts, with a permitted future range of 207 to 253 volts, it seemed prudent to see whether this could influence clinical measurements. Between 190 and 250 volts a trichromat's R/G settings increase by 0.047 Nagel units/volt, in a highly linear manner ($r^2 = 0.98$). Thus, a 10-volt increase will raise the R/G

setting by ≈ 0.5; and a change from 207 to 253 volts corresponds to just over two R/G units. The accompanying change in the brightness setting (-0.0056 units/volt) is trivial. While it is unlikely that these variations would lead to a clinical misdiagnosis, they could introduce error in comparisons between populations (e.g., Waaler, Nature, 215, 406, 1967), or in establishing whether Nagel settings are bimodal (Neitz & Jacobs, Nature, 323, 623, 1986). Mollon & Jordan have recently shown (Perception, 21, sup. 2, 11, 1992) that the Nagel can be used as an expensive thermometer. The present findings extend its versatility to the measurement of voltage.

Session 9 Cortex

On two patients with cortical disturbances of colour vision. A B MORLAND[1], C KENNARD[2], M LAWDEN[2] and K H RUDDOCK[1]. 1: Biophysics Section, Imperial College, London, UK. 2: Academic Unit of Neuroscience, Charing Cross Medical School, London, UK.

We present data for two patients, one, BL, with multiple small infarcts of the sub-calcarine cortex and the other, MW, with an apparent metabolic functional cortical disturbance. BL has normal colour matching and spectral sensitivity recorded with a white background, which indicates normal photoreceptoral and colour-opponent response mechanisms. None-the-less, BL exhibits general colour discrimination losses for monochromatic and non-monochromatic stimuli, and his colour naming is markedly abnormal for colours with chromaticities lying in certain areas of the CIE x-y chart. The second patient, MW, experiences spreading inhibition in response to coloured and particularly red stimuli (Hendricks et al. Brain 104, 813-840, 1981). We show that there is a close similarity between the chromaticities of colours for which MW experiences strong inhibition and those which BL can name correctly. We use these results to discuss the cortical representation of colour.

The effects of sub-cortical and cortical damage on colour vision. J J KULIKOWSKI[1] and V WALSH[2]. 1:Visual Sciences Lab, UMIST, Manchester, UK. 2: Experimental Psychology Lab., Oxford, UK.

Damage to retinal and cortical stages of colour processing produce fundamentally different colour vision deficiencies. Damage to colour-opponent retinal units, at the ganglion cells or optic nerve fibres, abolishes all aspects of colour vision. Conversely, cortical lesions of primate visual area V4 affect only one aspect of colour vision, namely colour constancy leaving colour discrimination and simple categorisation intact. The chromatic visual evoked potentials in macaques with bilateral V4 lesions are normal. It is argued on the basis of these differences that wavelength information can bypass area V4, that constancy functions should be different according to categorical location of the stimuli, and that V4 contains a colour constancy centre. This suggests both hierarchical and parallel nature of colour analysis: damage to a high-level centre destroys only its function, and does not obstruct the flow of information about lower-level colour vision. We discuss the anatomical basis of these findings, as well as similarities and differences between the results of experiments on monkeys and on brain damaged human subjects.

The construction of colour by the Cerebral Cortex. S ZEKI, Department of Anatomy, University College, London, UK.

The function of the visual brain is to acquire knowledge of the world through the sense of vision. But the acquisition of that knowledge is not easy because objects and surfaces in our visual world are in a continual state of change, as is the illumination in which they are viewed. The brain is inundated with too much information, much of which is unnecessary in its task. It therefore has to discount these continual changes and identify the constant, unchanging, properties of objects and surfaces. The best example of this is provided by colour vision where the brain has to "discount the illuminant", in the words of Helmholtz, in order to be able to assign constant colours to surfaces in spite of the wide-ranging changes in the illuminant in which these surfaces are viewed. To "discount the illuminant", and thus assign a (constant) colour to a surface, the brain has to compare the wavelength composition of the light reflected from a surface with the wavelength composition of the light reflected from surrounding surfaces. Colour is therefore a construction of the brain, resulting from that comparison. The lecture will describe the complicated apparatus that the brain has developed to undertake this extraordinary feat with such breathtaking efficiency that few have realised that there was a problem for it to solve. It will also describe the consequences of the breakdown in parts of that machinery.

Workshop Abstracts

The use of computer-controlled displays in the study of colour vision. J D MOLLON, Dept. of Experimental Psychology, University of Cambridge, UK.

Computer-controlled displays offer the possibility of presenting stimuli that are complex in space and time. They also offer a wonderful variety of snares for the innocent. This tutorial will discuss the choice, assessment and calibration of colour displays, the merits of different graphics boards and waveform-generators, the computation of the gun outputs required to achieve a given chromaticity and luminance, conversion between colour spaces, and empirical methods for determining the cardinal directions for particular displays and particular observers. Among the sources of artifact to be considered are: transients on the outputs of graphics boards; persistence of phosphors; the spatial discreteness of the phosphor dots/lines; non-additivities of guns; and spatial non-additivities. The sceptical reader should distrust any study that varies surround colours and does not assess in detail the consequent variation in the physical chromaticity and luminance of the target.

Possibilities of colour visualisation on computer systems of today. N FIELES-KAHL, Automatisierungstechnik, FH für Technik und Wissenschaft, Reutlingen, Germany.

Since the operating system Windows is settled on a wide market the hardware for high quality colour visualisation was developed and is offered for an acceptable price. The systems which are available today, offer the possibilities of colour visualisation of 256 shades out of the total of 262,144 or 16.7 million colours. On this basis, the project ColorVision was developed. It shows the possibilities of visualisation on colour screens in correlation to colour visualisation and production of colours. A selection of these items are shown here in several experiments: Possibilities of visualization on screens and the limitation of the colour space due to the technical features of a screen; The definition of colours and their position in the different colour coordinate systems; The eye is the colour sensitive organ of human beings. There are shown experiments of the chromatics, like after images, the effect of surrounding colours, opposite colours and the tests of Goethe; Possibilities of testing the visual perception or the defective colour vision of persons; Demonstration of colour mixing out of dyestuffs, finding out recipes for certain colours.

Calibration of polarized video displays with a holographic grating spectroradiometer. S PEFFERKORN, F VIÉNOT and A CHIRON, Muséum National d'Histoire Naturelle, Paris, France.

Colour calibration of VDU screens implies exact knowledge of the colorimetric specification of the primaries. This is obtained through recording the spectral distribution of the primaries with a spectroradiometer calibrated against a known luminance standard. However, a spectroradiometer response is highly sensitive to polarized light, because of the characteristics of the diffraction grating. This is of concern when one has to calibrate polarized screens such as liquid crystal displays. We will address the question of how to obtain correct spectroradiometric measurements of polarized displays. Theoretical studies show that the spectral efficiency of a holographic grating depends upon polarization of the incident light. Firstly, we checked the ability of a Bentham spectroradiometer to yield light measurement equivalent to unpolarized light from measurements of polarized light along two orthogonal axes. Then, a similar check was performed with elliptically polarized light obtained from a liquid crystal material. This has led to the development of a method suitable for use with liquid crystal displays. Choice of the luminance standard and of the best procedure for calibrating liquid crystal displays will be discussed.

Poster Abstracts

Effects of a blue filter glass on the age related tritan type colour vision defect. E AARNISALO and E VAINIO-JYLHÄ, Dept. of Ophthalmology, Satakunta Central Hospital, Pori, Finland.

Fifteen healthy subjects aged 54 to 69 performed the Farnsworth-Munsell 100-hue test. A tritan defect was obtained by five subjects and they repeated the 100-hue test with a blue filter glass placed in front of the viewing eye. The use of the blue filter caused a reduction of the mean total error score but the difference was statistically not significant. However, with the use of the blue filter there was a significant reduction of the mean ratio of the blue-yellow error scores to the red-green scores from 2.71 ± 0.81 to 1.29 ±0.34 (p-value in the Student's t-test 0.003). The transmission properties of the calibrated blue filter and those of a normal human elderly lens are opposite which may explain the partial compensation of a tritan defect.

Blue filters alleviate visual discomfort when reading. A J S MASON, M S FOWLER and J F S STEIN, Physiology Department, University of Oxford, UK.

We have been investigating whether tinted lenses may alleviate the visual problems which some subjects experience when reading. Patients are asked if viewing through coloured filters helps them.

Coloured filters presented are yellow, green, red and blue and a 50% neutral density filter. Between 1989 and 1992 of 1000 patients seen we found 27 whose problems (difficulty reading in moderate illumination) were alleviated by blue filters. Their symptoms whilst reading included glare, blurring of words, and movement of words or letters. These were worse in bright light. Even when not reading they complained of glare in bright light and unusual motion illusions. The vision of these patients appeared normal to standard clinical tests. Preliminary observations suggested that their static contrast sensitivity was unusually high and that it was selectively reduced using blue filters. However this was not subsequently confirmed. We speculate that these patients have an abnormality of their magnocellular pathway. Therefore we are measuring their flicker contrast and motion sensitivity.

Macular and paramacular colour vision in homonymous hemianopias. J L VOLA, D DENIS and F DEVIN, CHU Timone, Marseille, France.

Examination of macular colour vision was carried out by routine tests: desaturated PD 15 and HRR and by the Stiles two colour technique giving $\pi 1$ and $\pi 3$ blue mechanisms and also with the Wald-Marré method. In the blind area at 15° above the blind spot the function of the three mechanisms was researched with Wald-Marré method. Results were discussed and compared with previous study.

Temporal fusion in patients with macular dystrophy. A GONELLA, M L F DE MATTIELLO and S ASHKAR. PRIVIS, Faculty de Medicina, Buenos Aries, Argentina.

By using a source of light-emitting diodes (LED), patients with macular dystrophy were tested and comparison made with normal adults. After fixing the luminance, the flicker fusion condition was recorded, by varying the temporal frequency of a sequence of square pulses. Plots of the luminance versus frequency at fusion, were well fitted by straight lines. The analysis of their slopes and intercepts indicate that in the case of green-dark or red-dark sequences, where the response is mainly mediated by the luminance channel, our patients had a loss in temporal resolution. Less straightforward conclusions may be drawn when considering the response to a red-green sequence, which probably calls into play the post-receptoral color-opponent system.

Tritanopia in retinitis pigmentosa - cross-correlations with other photopic functions. A NAKOWA, Medical Academy, Sofia, Bulgaria.

The study has been carried out on 311 patients with RP. The FM-100 hue test error score was correlated with the visual acuity (VA). Tritanopia was found in 25% of the eyes with VA = 10/10. More severe colour vision deficiencies correlated with VA = 5/10. The acquired dyschromatopsias correlated with visual field (residual area and horizontal meridian) and photopic ERG changes only by autosomal-dominant forms of RP. Visual acuity with a bipolar neutral zone (Nz), in Lanthony's New Colour Test, was significantly lower (3/10) than in cases with monopolar Nz. Dyschromatopsia with scotopic axis was observed in single cases under age of 20 only with ithe nverse form of RP (VA = 1.5-2/10). The same was observed in cases with VA = 4/10 and age over 60. Achromatic perception was found in 7.5% of eyes at saturation 8 of the New Colour Test and 57.3% at saturation 2.

Motion thresholds of coloured stimuli of different brightness contrasts are increased in early primary-open-angle-glaucoma (POAG). H P N SCHOLL and E ZRENNER, University Eye Hospital, Tübingen, Germany.

Several lines of evidence suggest that the large optic nerve fibres, which form the magnocellular retinocortical pathway, are preferentially susceptible to early glaucomatous damage. It is evident from studies of the functional architecture of the visual system that the magnocellular pathway underlies the global perception of motion and the parvocellular layer underlies the perception of colour. We have developed a psychophysical technique to assess the interdependence of the perception of motion and colour and the changes by glaucomatous damage. For this purpose we employed a dynamic random dot display that contained varying degrees of a coherent motion signal embedded within a background of random motion noise and two colours (red and green) of varying degrees of brightness contrast (100%, 95%, 78% and isoluminant). We used this technique to measure motion thresholds in POAG patients and age matched controls. The motion stimulus was produced under control of a 14 Mhz IBM-PC compatible computer, using software developed by the authors. Subjects were required to indicate the direction of perceived motion with a joystick, using a four-alternative, forced choice technique with a stimulus presentation time of 4 sec. The motion thresholds of each brightness contrast were extrapolated from a probit analysis curve to fit the data. The results of this test show the dependence of movement sensitivity on brightness contrast of two colours in normal vision and the specific changes in POAG. First results show, that motion thresholds at all brightness contrasts are increased in early POAG, especially at high brightness contrasts in comparison with normal subjects. These findings thus indicate that motion threshold testing in combination with testing of colour vision may reveal preclinical optic nerve disease in early POAG.

Cyanopsia as functional indication of optic nerve conduction defects. H KRASTEL and A SEPPICH, University Eye Hospital, Heidelberg, Germany.

Cyanopsia, though difficult to evaluate quantitatively, may provide a valuable indication of developing optic nerve disease. In many instances, cyanopsia is ascribed to toxic impairment of the visual system. However, cyanopsia may arise due to localized, e.g. optic nerve ischemic, compressive, and inflammatory (as Hess & Plant have reported impressively) damage. The phenomenon is ascribed to colour-dependent variations of optic nerve conduction. Cyanopsia was the presenting symptom in two personal observations. Despite unilateral involvement, any ophthalmoscopic and biomicroscopic correlate was lacking. The colour deficiency (Verriest type II) fitted into the assumption of an optic nerve disorder, and this suspicion was substantiated later by the evolving pattern of visual field defects. After angiologic examination, PION (posterior ischemic optic neuropathy) was diagnosed and an appropriate therapeutic regimen was initiated. The report underlines the clinical significance of cyanopsia as possible early symptom of optic nerve conduction defects.

Visual defects in subjects with Down's Syndrome. J PÉREZ-CARPINELL, M D DE FEZ and V CLIMENT, Dept. d'Optica, Universitat de València, Burjassot, Spain.

We have tested the possible existence of color vision defects in 72 subjects with Down's syndrome, 38 men and 34 women, using the Ishihara test and an anomaloscope. We found that, according to Pickford's classification, 13 of the subjects, 6 men and 7 women, were chromatically defective; in monocular vision 10 eyes were protan (5 simple, 3 extreme and 2 deviant), one eye was simple deuteranomalous and the remaining eyes were normal; in binocular vision 4 of the subjects were protan (2 simple and 2 deviant), 2 subjects were deutan (1 simple and 1 deviant) and the rest were normal. Our examination confirms the reports in the literature, that a large number of these subjects have lens opacities, strabismus, nystagmus, hypermetropia, high myopia and astigmatism. On the other hand, the measurement of the contrast sensitivity function in these subjects (evaluated with the VCTS test) shows a considerable loss of low-frequency sensitivity, with respect to normal subjects, which is more marked in severely handicapped subjects than in moderately handicapped ones.

Dichotopic mixtures in normal and acquired color defects. M L F de MATTIELLO, A BIONDINI and H SALINAS, PRIVIS, Faculty de Medicina, Buenos Aries, Argentina.

It is generally assumed that chromatic vision is mediated by three types of cone that would be treated by the visual system in a similar way. Practice has shown that this is satisfactorily fulfilled for green and red cones, but not for blue ones. Blue mechanisms are different from the red-green ones, for instance: in receptoral distribution and number in the retina; in antagonism and in the place where it would be produced; in the poor spatial and temporal responses; in their fast loss of adaptation; in their different dichoptic resolution. The present work comments on the result of dichoptic mixtures which involve blue radiations comprised between 400 and 500 nm. These mixtures produce a marked chromatostereopsis which is not observed when working with red-green stimuli. The zones in which this phenomenon is more remarkable are determined. For this purpose, the corresponding wavelength, intensity and purity in absolute and relative values, are described. The results obtained allow to advance that the main difficulty to obtain chromatic dichoptic mixtures with high blue radiation is the fusion of images, main cause of chromatostereopsis a topic extensively analysed in binocular vision.

Colour-flicker in retinal detachment patients. M FAHLE[1], T TROSCIANKO[2] and I KREISSIG[1]. 1: University Eye Clinic, Tübingen, Germany. 2: University of Bristol, U.K.

We tested colour vision to assess severity of retinal damage in patients suffering from retinal detachment, past or present. A yellow/green checker board was displayed on a high-resolution colour monitor, subtending about 15 by 11 degrees. The isoluminant match point between the yellow and green checks was measured by contrast-reversing the display at a rate of 12.5 Hz. In addition, the colour flicker fusion frequency (CFF) for a contrast-reversal of this pattern was measured. Most patients were tested foveally and at an eccentricity of 20 deg, only a few at 30 deg. The isoluminant match point between green and yellow rarely showed any abnormality. This seems to indicate that the green and red receptors suffer to a comparable degree from retinal detachment. CFF ranged from over 10 Hz (normal) to about 2 Hz for a severely impaired retina. Central visual acuity tended to be more severely affected than the (iso-luminant) CFF which can be normal in spite of problems with optic media. Thus, CFF may be useful in presence of opacities in the optic media (eg cataract), and the decrease of cff might not be directly caused by a decrease of acuity. We presently perform additional experiments on the interdependence of acuity and CFF in the assessment of patients after retinal detachments.

Colour vision after surgery for retinal detachment. A SERRA, I ZUCCA, C M DESSY, M FOSSARELLO, A TANDA and V PIRAS, Istituto de Clinica Oculistica, Universita di Cagliari.

In order to evaluate the recovery of visual function in patients after surgery for retinal detachment, we studied 18 eyes treated with scleral buckling or vitrectomy tested at different times. The clinical parameters were the following: extension of retinal detachment, occurrence of macular detachment, time length of detachment before surgery. The contralateral eye served as control. The battery of tests included: visual acuity, visual field, adaptometry, accommodation amplitude, and colour vision (Farnsworth-Munsell 100-hue, New Colour Test, Lanthony 15 - D). The results are discussed on a clinical and a physiopathological ground.

Color vision in cone-rod dystrophies. B SADOWSKI and E ZRENNER, University Eye Hospital, Tübingen, Germany.

Besides loss of visual acuity and alterations of the photopic electroretinogram color vision deficiency is one of the main symptoms in patients with cone-rod dystrophy. We investigated 40 patients with cone-rod dystrophy diagnosed by electrophysiology and ophthalmological investigation including perimetry. Fundus alterations were mild or absent while a reduction of visual acuity to 0.5 or below predominated. The total error score tested with the Farnsworth Munsell 100-hue test (FM 100) and the Panel D-15 saturated test increased when visual acuity was below 0.5. Up to 1.0 the total error score was within the normal range in most patients. Also patients with good visual acuity, however, had pathologic color vision. The FM 100 test of 37 tested eyes showed a prevalence of axis of confusion in the tritan axis (27%), the scotopic (27%) and the erratic axis (20%), followed by normal results (20%), deutan (4%) and protan (8%) axis. A reduction of the maxima of spectral sensitivity measurement was found in 15 of 16 patients for the M-cone and L-cone maxima and in 12 patients for the S-cone maxima. In transient tritanopia an elevated threshold was found in one third of the investigated patients. Color vision is a very sensitive parameter in cone-rod dystrophy. Good color vision is not necessarily linked to good visual acuity in this disease. Color vision deficiency can be the first sign in cone-rod dystrophies before a pathological electroretinogram, fundus alterations or loss of visual acuity does occur.

Psychological factors and defective colour vision. J PÉREZ-CARPINELL, M C IBAÑEZ and J V DIAZ, Dept. d'Optica, Universitat de València, Burjassot, Spain.

In this study, involving students aged between 14 and 16 years, the psychological variables relative to cognition and personality were obtained, which were found to be affected, on testing a group of red-green colour vision defective subjects and a group of normal trichromat subjects. From the results of factorial analysis it appears that the influence on these variables, of the variable related to colour vision abnormality is always minor, and is correlated with cognitive variables as spatial aptitude and visual difference perception, and with personality variables as praxemia and submission; the weighting by the cognition and personality factors linked to the colour vision abnormality is variable, do not in any case contribute more than 20% to the total variance. These results are, in line with those obtained by R Lakowski (Proc. 1st Intern. Colour Congress, pp. 79-87, Stockholm, 1969) for a population of normal trichromat subjects.

Color vision - influence of some toxic agents. S SAVIC, Institute of Occupational Health & Radiological Protection, Belgrade, Yugoslavia.

Various chemical substances can exhibit toxic effects in the eye. The early clinical diagnosis of such disorders is extensive, and based on detection of morphological changes. The aim of the present study was to investigate possible early functional disorders in color vision occurring as a consequence of some toxic agents. In relation to control group, statistically significant difference ($p < 0.001$) in color vision (Farnsworth-Munsell 28) was found among those workers chronically exposed to carbon disulfide ($N = 251$), and various sorts of pesticides ($N = 125$), but not fluorides ($N = 98$). The findings could suggest guidelines for more accurate diagnostic criteria for epidemiological diagnosis of the disorders, and thus avoid expensive clinical analysis, based on individual rather than population approach.

Color discrimination under mesopic conditions in the cat. M F TRITSCH, Institut für Zoologie, Mainz, Germany.

The effect of mesopic illumination on color discrimination in three cats was studied using colored papers as stimuli and with a computer-controlled training schedule. Brightness discrimination was controlled for by a new method in which illuminant color was varied. Stimulus and lighting conditions were spectroradiometrically controlled. Color discrimination failed at a stimulus luminance close to the cone threshold reported by others from ganglion cell recordings. However, in the course of stepwise reductions of illumination towards this limit all cats had to be retrained on the color discrimination at least once, indicated that the appearance of the stimuli for the cats changed

considerably. In contrast, cats were able to transfer learned responses without retraining between color papers of varying saturation and lightness but fixed hue.

Age related changes in chromatic contrast sensitivity and sensitivity control. A WERNER[1], A U BAYER[2], G SCHWARZ[3] and W PAULUS[4]. 1: Physiolog. Inst., Freie Universität, Berlin. 2:Augenklinik, Universität Tübingen, Germany. 3: Klinikum Grosshadern, München, Germany. 4: Neuroligische Abt., Universität Göttingen, Germany.

Ageing affects visual functions in various ways including colour vision (e.g. Sekular et al., 1982. The purpose of this study was to investigate age related changes in spatial and temporal interactions between spectrally different cone mechanisms and to compare the ageing properties of the chromatic system with those of the luminance system. To this extent we measured: 1) chromatic and luminance contrast sensitivity (by determining detection thresholds for achromatic and for equiluminant red-green sinewave gratings (0.31 to 8.1 cpd), and 2) threshold versus intensity functions for a short-wavelength increment on a long-wavelength adapting light and the effect of transient tritanopia. Spectral properties of the ocular media in elderly eyes were mimicked in younger observers by using an additional long-wavelength filter. The test subjects were aged between 18 and 67. The study demonstrates different effects of ageing on chromatic (red-green) channel and luminance channel contrast sensitivity as well as age related changes in neural sensitivity control in the short-wavelength channel.

Contribution of two colour opponent mechanisms to Fechner-Benham subjective colours. J LE ROHELLEC and F VIENOT, Muséum d'Histoire Naturelle, Paris, France.

Fechner-Benham (FB) subjective colours are assumed to originate from retinal neural interactions. We addressed the question whether colours elicited by a rotating FB disk require the involvement of two colour opponent mechanisms L/M and S/LM. It was hypothesized that short presentations and narrow stripes would favour the L/M mechanism. In this experiment, FB disks, differing by width of the stripes (6, 12, 24, 48 min arc), were rotated at 7 Hz and presented for various durations (1, 2, 4, 8, 16 and 32 rotation cycles). Responses of three observers were collected with a hue naming procedure. The results showed, firstly that colour responses underwent changes as exposure duration decreased; inversion between blue naming and green naming frequently occurred with short exposures (1-2 cycles). Secondly, FB subjective colours varied with stripe width. We suggest that L/M mechanism can generate various FB subjective colours on its own but that interactions between L/M and S/LM mechanisms further modify the colours.

The spectral sensitivity of the acuity criterion: Effect of nonlinear summation of psychophysically isolated parvocellular receptive field centers. V A BILLOCK, USAARL, Fort Rucker, USA.

Spectral sensitivity for the detection of acuity targets (e.g., gratings) is approximately additive and similar in shape to Vλ (Pokorny, 1968; Ingling et al., 1992). Acuity is believed to be mediated by color opponent neurons with Type I receptive fields. The spectral sensitivity of Vλ is approximately 5R + 3G while the spectral sensitivity of the r-g channel is 2R-3G (R and G cone maximum sensitivity normalized to unity). Ingling & Martinez (1983) show that the opponent channel is additive for luminance gratings and should therefore have a spectral sensitivity of 2R + 3G, which does not resemble Vλ. Ingling and Tsou (1987) show that high frequency gratings (and other acuity targets) should not modulate surrounds of r-g Type I P cells, therefore if centers are isolated and present in the same proportions as cones, the spectral sensitivity of acuity may reflect the spectral sensitivity of the pooled centers, and not the spectral sensitivity of the r-g channel. This argument neglects the possibility of probability summation among isolated centers. I performed several computational experiments which show that probability summation does not grossly affect the shape of the resulting spectral sensitivity function. I also modelled the effect of allowing centers to retain their opponent channel weights prior to pooling. After being stripped of its surrounds and nonlinearly pooled, an opponent channel of 2R:3G actually gives a better approximation to Vλ than does a channel of 5R:3G after nonlinear pooling. These results illustrate the difficulty of working backward from spectral sensitivity to channel mechanisms.

The formation of cortical cells sensitive to chromatic and/or achromatic information from parvocellular neurons transmitting both chromatic and achromatic signals. V A BILLOCK, USAARL, Fort Rucker, USA.

P cells with Type I receptive fields transmit both chromatic and achromatic information to the striate cortex. Receptive fields of a least four cortical cell classes show evidence of being constructed from Type I cells by spatial frequency filtering or signal cancellation. Here, electrophysiological, anatomical, and pharmacological evidence is employed to model the formation of these four cortical cell types: (1) Cortical r-g Type II cells are plentiful in cytochrome oxidase "blobs" and outnumber

cortical y-b Type II cells, yet retinal r-g Type II cells are rare and vastly outnumbered by y-b Type II cells. This disparity is explained if cortical r-g Type II cells are formed from Type I cells. (2) Electrophysiological and pharmacological evidence shows that double opponent cells (DOCs) are formed from Type I cells of the same spectral sensitivity as the DOC center, ruling out cancellation. One filtering model is found to be compatible with all available evidence of DOC formation. (3) Random errors in the formation of the DOC surround lead to the 3/4 double opponent cells. (4) Many cortical cells have bandpass tuning for both chromatic and achromatic stimuli. This tuning is incompatible with cancellation, but can be explained by a cortical achromatic recovery system that bandpass filters P cells. Filtering results in a bandpass achromatic response and bandpass chromatic crosstalk, tuned to high frequencies. Because there is little high spatial frequency chromatic energy in natural scenes, this chromatic crosstalk is normally of little importance, although it would lead to powerful masking of achromatic gratings by chromatic gratings.

Midget cell circuitry distinguishes three cone classes in Macaque fovea. D J CALKINS[1], S J SCHEIN[2], Y TSUKAMOTO[3] and P STERLING[1]. 1: Neuroscience, University of Pennsylvania, USA. 2: Psychology, UCLA, USA. 3: Hyogo College of Medicine, Japan.

To determine what retinal circuits process spectral information the first step is to identify the axon terminals (pedicles) of S, M, and L cones. In an array of 54 pedicles studied in electron micrographs of serial sections, 3 were identified as S pedicles by their lack of an on midget bipolar cell. The other pedicles sorted into two types based on their midget circuitry. One type contacted paired midget ganglion cells (on and off) via small midget bipolar axons (29 ± 3 synapses). Another type also contacted paired midget ganglion cells but the bipolar axons were large (46 ± 2 synapses). The on and off midget circuits for a given pedicle were nearly identical (r=.99). We classified 40 more pedicles by off midget bipolar axon size, thus extending the array of classified pedicles to 81. In this array, 47 had "small" and 34 had "large" midget circuits. Pedicles of the same type formed small, irregular clusters, similar to those shown in recent microspectrophotometric measurement of patches of primate fovea (Nature, 360, 677-679, 1992).

On the development of colour memory in children. A PETZOLD and L T SHARPE, Neurologische Universitätsklinik, Freiburg, Germany.

Preschool children discriminate colours as well as adults, but are much poorer at naming and recalling them (cf. Charles Darwin, 1877, 'Biographical Sketch of a Young Infant'). The defect may be related to the development of specific colour categories in the maturating brain, which are important for the coding and remembering of hues; since the retinal processes for colour discrimination are intact and functioning normally even in infants. To find out, we tested 23 preschoolers (4-6 years old), 15 pre-adolescents (10-11 yrs old) and 21 young adults (20-28 yrs old) for both hue discrimination and hue memory. Our colour stimuli, matched in luminance and saturation, had dominant wavelengths (λ_d) chosen to correspond to either focal or boundary regions of colour categories. The stimuli were generated on a Macintosh Colour Display, controlled by a Macintosh IIvx computer and calibrated by means of a Spectra-Scan Spectroradiometer. In the hue discrimination task, the observer had to choose one of four simultaneously displayed colours that differed in hue. A modified Best-Pest algorithm was used to determine the minimum threshold value. In the hue memory task, the observer was presented with a test colour for 200 ms, then had to choose, after a 5-s retention interval, the colour judged from memory that best resembled it from 16 simultaneously presented colours. No significant differences were found among the three groups in the hue discrimination task: all were poorer in discriminating hues with λ_d near 520 nm than hues with λ_d near 490 or 560 nm. In the hue memory task, however, there was a progressive improvement with age: young adults were significantly better than pre-adolescents and pre-adolescents were significantly better than preschoolers in remembering hues. Preschoolers were especially poor at remembering the λ_d = 560 hue, which did not fall into a distinct colour-naming category.

Unique colors in Honeybees? W BACKHAUS and D KRATZSCH, Freie Universität, Berlin, Germany.

Neuronal color coding and color choice behaviour in ordinary color training experiments is very well described by the color theory for the bee on the basis of the excitations of two color opponent coding neurons (Backhaus. W. Vis. Res., 1991, 31: 1381-1397; Backhaus, W. Vis. Res., 1992, 32: 1425-1431). The results of double color training experiments, in which two different color stimuli are rewarded, do not agree with the predictions of the color theory and thus cannot be explained on the basis of the electrical properties of neurons alone. Color perception in bees has been suspected to be based, under certain conditions, on unique-colors (Backhaus, W. An. XVIII Reun. An. Psichol., 1988, 123-126) comparable to the six unique-colors blue, yellow, red, green, black and white in humans (Hering, E., 1905, Leipzig). Since bees ignore intensity differences in color training experiments, only five different unique-colors, four chromatic and one achromatic, were postulated. The amounts were assumed to be linearly related to the excitation values of the two color opponent coding neurons. In

double training experiments, the bee is expected to learn the unique-colors which the two colors have in common and to choose stimuli in unrewarded tests according to the amounts of these unique-colors. The presented results of first double training experiments agree well (χ^2, 5%-level) with the predictions from the unique-colors hypothesis. The results cannot be explained from the differences in the light fluxes, of the stimuli absorbed in the photoreceptors. Form vision is obviously not involved because of the low intensity contrast of the color stimuli with respect to the background.

Destructive interference between rod and cone flicker signals: psychophysical and electrophysiological findings. **B KIRSCH and L T SHARPE, Neurologische Universitätsklinik, Freiburg, Germany.**

At frequencies near 7.5 Hz, rod and cone signals elicited by 580 nm mesopic lights can destructively interfere to eliminate the flicker percept. A similar suprathreshold flicker loss or null is found at frequencies near 15 Hz, caused by destructive interference between slow (π_0) and fast (π_0) rod signals elicited by 500 nm scotopic lights. Both phenomena, which were first investigated psychophysically, have now been confirmed by electroretinographic (ERG) and visually evoked potential (VEP) recordings. Here we report some recent findings. (i) Measurements of the phase lag of rod signals relative to a cone standard as a function of frequency: Consistent with earlier reports, we find that there are approx. fixed time delays of c. 70 ms between the slow (more sensitive) rod and cone signals, c. 35 ms between the fast (less sensitive) rod and cone signals, and c. 33 ms between the slow and fast rod signals. (ii) Temporal modulation sensitivity: The normal shows a strong depression in temporal modulation sensitivity at frequencies around 7.5 Hz for intensities associated with the slow rod/cone flicker null, but not for lower or higher intensities. An achromat, who has no cone function, does not display a flicker null near 7.5 Hz nor a depression in modulation sensitivity. Both the normal and the achromat, however, show an abrupt loss of modulation sensitivity at frequencies above 15 Hz for intensities associated with the slow/fast rod flicker null. (iii) Simultaneous recordings of ERG and VEP: At 15 Hz, the phase of both the ERG and VEP signals changes by 180° as the intensity of the slow/fast rod flicker null is traversed, and the amplitude of both signals falls to a minimum. A similar 180° phase shift and amplitude loss is found at 7.5 Hz for both signals as the slow rod/cone flicker null is traversed.

Dynamics of human rod and cone signals. **L T SHARPE[1], L A SPILLMAN[1], T ARESTOV[2] and C C FACH[1]. 1: Neurologische Universitätsklinik, Freiburg, Germany. 2: Moscow State university, Moscow, Russia.**

Human cone signals reach perception before rod signals. This difference gives rise to a compelling illusion in which two lights moving together, but differing in luminance, appear asynchronous. We exploited this illusion to estimate the differential response times of the rods and cones. Normal observers and achromats lacking cone vision adjusted the relative phase of two vertically-displaced, horizontally oscillating targets, until they were perceived to move synchronously. When one target was cone-detected and the other rod-detected, the maximum time delay observed was c. 75 ms. When both targets were cone-detected or both rod-detected, it was 30-40 ms. When one target was fixed in luminance, the delay decreased by c. 20 ms in the normals and by c. 10 ms in the achromats with each tenfold increase in the other target's luminance. We relate these values: (i) to differences in primate rod and cone photocurrent kinetics; (ii) to differences between the ON rod and ON cone flicker responses in cat OFF-alpha ganglion cells and the ON rod flicker responses in cat AII amacrine cells; and (iii) to luminance-dependent changes in the impulse responses measured at macaque phasic ganglion cells.

Differences in adaptation between on- and off-centre ganglion cells and rod mediated cone sensitization in cat retina. **E GUENTHER and E ZRENNER, Division of Experimental Ophthalmology, Tübingen, Germany.**

Retinal ganglion cells (RGCs) were investigated in cat in order to demonstrate interactions between the rod and the cone systems. Responses were determined for a cells' receptive field centre (RFC) in presence of large field adapting backgrounds. Using rod-effective test stimuli, clear differences could be seen in the adaptation behaviour of on- and off-centre RGCs. No differences were observed when a test stimulus was used which primarily stimulated L-cones. Additionally, in some off-centre cells a striking adaptation behaviour was observed. In the presence of dim short-wavelength backgrounds the receptive field centre became more sensitive than in the dark adapted state. This sensitization of the centre response in off-centre RGCs is only visible if the adaptation background exceeds the test stimulus diameter considerably. We conclude that surrounding rods can suppress L-cone-signals in the RFC of cat RGCs and that this suppressive influence on the L-cone-system is abolished after rods are weakly light-adapted.

Objective assessment of short wavelength sensitive (SWS) mechanisms with the spatio-chromatic VEP. M A CROGNALE[1], E SWITKES[2], J RABIN[1], M E SCHNECK[1], G HAEGERSTRÖM-PORTNOY[1] and A J ADAMS[1]. 1: University of California at Berkeley, USA. 2: University of California at Santa Cruz, USA.

Previous research has shown the VEP to be an objective and reliable indicator of suprathreshold visual function. Recently, it has been demonstrated that the VEP recorded in response to low spatial frequency patterns modulated along different directions in a cone activation space reflects the activity of isolated chromatic and achromatic mechanisms. This report describes the characteristics of the isolated SWS mechanism examined with the spatio-chromatic VEP. We include normative latency and amplitude data across a broad range of contrasts (Invest. Ophthal. Vis. Sci, suppl. 33, 701, 1992) and temporal frequencies. In addition, we discuss our findings in two congenital conditions, tritanopia and monochromacy. We have also used the VEP technique to explore the phenomenon of transient tritanopia. Transient tritanopia is characterized by a dramatic reduction in VEP amplitude for modulations which isolate S-cone responses following offset of a long-wavelength adapting field. The VEP technique has also proven extremely sensitive at detecting acquired losses of SWS pathway sensitivity in diabetes, and even a localized loss in central serous choroidopathy (In: Color Vision Deficiencies XI, Doc. Ophthalmol. Proc. Ser., 1993, 56: 229-239).

Analysis of EEG to colored lights by the maximum entropy method. M AKITA, Psychol. Labs, Kyoto Institute of Technology, Japan.

In color normal two subjects, EEGs were recorded against chromatic lights (15 cd/m^2), either red or green, presented on a CRT and were analysed by the maximum entropy method through which event-related spectral power density as a function of frequency of the brain waves was obtained. Frequency steps to analyse and lower limits for spectral power density were 0.1 Hz and 0.001 respectively. The analysis was applied to the entire length of EEG samples of 10-sec duration. In general, results in range from 8 to 30 Hz by the bipolar derivation on occipital area (V1) showed that components of both alpha (8 to 13 Hz) and beta (18 to 30 Hz) waves were constantly found, but less active while strong dominance of alpha waves with a few spectral peaks in range of beta waves were observed on inferotemporal area (V4) and more active beta waves were seen on frontal area. These results were all indifferent to the color-difference.

Light adaptation of the S-cone pathway to moderately intense fields. F NAARENDORP, P M KORTICK and C SPENCE, Dept. of Psychology, Northeastern University, Boston, USA.

Light adaptation of the S-cone pathway is slower on red than on blue fields (440 nm probe, 10° eccentricity). Adding a 480 nm pedestal (flashed with the probe) to the steady red field, transiently increased S-cone sensitivity (6-fold). This resembles Mollon and Polden's result (Nature, 286, 1980) but obtained here at much lower light levels. The transient increase in sensitivity could be abolished by a second pedestal (red, moderately intense). This effect of the second pedestal may be explained in terms of "re-polarizing" the opponent yellow/blue pathway. However, the second pedestal also shifts detection of the 480 nm pedestal, but not detection of the 440 nm probe, from S-cones to rods. We have, therefore, begun to explore possible effects of rods on light adaptation of the S-cone pathway to moderately intense adapting fields. Results and implications of these experiments will be discussed.

S-cone pattern-VEPs in glaucoma. M KORTH, X N NGUYEN and A JÜNEMANN, University Eye Hospital, Erlangen, Germany.

Background: Glaucoma can be associated with blue-color vision disturbances or with VEP abnormalities. Methods: In the present study pattern onset VEPs were studied with blue (460 nm) patterns presented either without (blue-black, BB) or on a yellow (570 nm) background (blue-on-yellow, BY) that reduces red and green cone sensitivity. Age-matched normals (35), ocular hypertensive (OHT) and open-angle glaucoma (POAG) patients were examined. Results: In normals the BB response is mainly positive, has a significantly smaller amplitude and shorter peak time while the BY response is negative, has a significantly larger amplitude, and longer peak time. The response variables are not age-dependent. BB amplitudes and peak times are not significantly different in the 3 groups. BY response amplitudes are significantly smaller only in POAG. BY peak times are significantly delayed in OHT and POAG. Sensitivity is 78.8%, specificity 94.43%; 42.9% of the OHTs are classified as abnormal. In POAG BY response measures correlate significantly with the mean perimetric defect, with the neuroretinal rim area of the optic disc and with the tritan score of the 100 hue test. However, this is not the case with the BB stimulus. Conclusions: The BY VEP peak time is a sensitive response measure in glaucoma research.

Dopamine antagonists impair "red-green" discrimination in goldfish. C MORA-FERRER and C NEUMEYER, Zoologie III, Universität Mainz, Mainz, Germany.

Under mesopic conditions the tetrachromatic color vision in goldfish becomes trichromatic. Dopamine is assumed to play a key role in the transition from the dark to the light adapted state. To elucidate the effect of dopamine on wavelength discrimination we performed behavioural experiments. Goldfish were trained on 599 nm and tested against adjacent wavelengths. Dopamine antagonists, haloperidol and SCH 23390, were injected into the dark adapted eye, and wavelength discrimination ability was tested under photopic conditions. Wavelength discrimination was reduced in the "red-green range, but normal in the "blue-green" and "violet" range. The fact that SCH 23390 was effective indicates that biphasic horizontal cells are essential for "red-green" color coding. Supported by DFG Ne (215/9-1) and Human Frontier Science Program (H Spekreijse)

Colour vision analyses by software application. M FIORETTO, S CAFIERO and G P FAVA, Eye Clinic Hospital, Genoa, Italy.

The Authors report on a new method to screen for color vision impairment using a personal computer program. A Farnsworth 85 hue test is presented on the monitor, driven by a graphical user interface. Patients move coloured targets with a mouse arranging them according to the usual scale. The software analyzes the results, which can be saved on disk and/or printed, statistical analysis and assessment of trends are possible. This method, tested on 86 patients, was found to be reliable and user-friendly.

An automatic scanner for color vision tests. M R LESSEL and F MERKSA, Dept. of Ophthalmology, University of Vienna, Austria.

Patients with color vision defects can be differentiated from normal trichromats by means of color tests. The results of these tests either in clinical or research laboratory application are dependent on several factors: the test has to be sensitive, the access to data should be fast and reliable and the diagnostic interpretation by the examiner should be accurate. To accomplish these requirements for the Farnsworth dichotomous Panel D-15 test and the Lanthony desaturated DD-15 test we developed an opto-electronic scanner. The patient places the caps according to his/her hue sensation. The arrangement of the caps and the corresponding cap number are scanned automatically using contactless infrared detectors. No rearrangement for reading the caps number at the back is necessary. Thus errors can be minimized. In connection with a personal computer system the scanned data of the 15 hue tests are displayed and plotted simultaneously. A computerized interpretation of the plots is also possible.

Comparison of Farnsworth-Munsell 100-hue scores in retinal and chiasmal lesions using software for quantitative axis analysis. A REITNER, M TITTLE, P NOVAK and C MATULA, University Eye Clinic, Vienna, Austria.

Acquired color vision deficiencies are tested clinically using the Farnsworth-Munsell 100-hue test. Beside the calculation of the total error score the different types of discrimination losses were diagnosed in a subjective manner. We developed a computer program to calculate the total error score, to print the FM 100 plots and to calculate individual error scores for the different error axes additionally. These individual scores describe the quantity and severity of errors along the tritan, deutan, protan, tetartan and scotopic axis. This calculation was done in 50 eyes suffering from retinal lesions (early senile macular degeneration) and 70 eyes with chiasmal lesions (pituitary adenoma). The average of the total error score of patients with early senile macular degeneration was 134 ±110, in patients with chiasmal lesions we found 161 ± 89. Comparing the quantitative axis analysis we found no significant difference in the configuration of the color discrimination defect in both groups. Within these groups we analyzed the average of these "axes scores" in patients with mild, moderate and severe discrimination losses. The distribution of the error scores within each subgroup showed no statistically significant difference. The relationship of our results to the different classifications of acquired color vision deficiencies will be discussed.

Evaluation of light sources for the D-15 color vision test. J HOVIS and P NEUMANN, School of Optometry, University of Waterloo, Canada.

Colorimetric analyses were carried out on 9 light sources to determine whether these sources were suitable for illuminating the D-15 color vision test. In order to determine the theoretical ordering of the D-15 caps under these lamps, the spectral emissions of these sources were measured and then multiplied by the dichromatic color matching functions and the D-15 cap reflectances. In addition, the normal trichromatic color matching functions were used to determine the cap spacing in trichromatic space. The theoretical dichromatic ordering of the caps was analyzed using the Color Difference Vectors scoring method. There were 4 sources similar to illuminant C in terms of the confusion angle, S-index, C-index, and total error score. These 4 sources had a General Color

Rendering Index (GCRI) of at least 90 and correlated color temperatures between 4700K and 5500K. As expected, lamps with a high GCRI produced a similar cap spacing in trichromatic space as Illuminant C.

Computer controlled Landolt-ring test for the examination of colour vision deficiencies. W JAEGER[1], H LANG[2] and J SCHANDA[3]. 1: University of Heidelberg, Germany. 2: BTS, Darmstadt, Germany. 3: CIE, Wien, Austria.

A Landolt-ring test for the examination of colour vision deficiencies is described. On a monitor coloured Landolt rings with different opening directions are presented on different coloured backgrounds. The colours of the ring and background are chosen on iso-colour zones for dichromats. The colours, ring diameter, presentation time and number of presentations are controlled by computer, as well as the evaluation of test responses. A calibration procedure for the monitor allows the specification of display colours in CIE X,Y,Z colour coordinates. Test results for different types of colour vision deficiencies are presented. The test has originally been developed for the investigation of visual contrast sensitivity for lightness, hue and chroma differences in small areas. Results of this investigation have been presented by the Authors Schanda and Lang during the 3rd International Scientific Conference on Work with Display Units (WWDU '92) in September 1992 in Berlin.

Colour vision screening in young children. J BIRCH and C PLATTS, Dept. of Optometry and Visual Science, City University, London, UK.

Five hundred children between the ages of 3 and 11 years were examined with a small number of plates selected from three pseudoisochromatic tests involving different visual tasks. The symbol designs of the Ishihara test for Unlettered Persons were found to be the quickest and most reliable method for screening children under 7 years of age. Children over 5 years of age, and most children over 4 years of age, were able to respond verbally to these designs at the first attempt. After 7 years of age the symbol designs and the numeral designs of the standard Ishihara plates were equally effective. However, children under 7 years of age frequently needed more than one attempt at numeral designs or needed to draw over the design or select a matching replica as an aid to identification. Drawing over designs increased the viewing time and enabled children, in all age groups, to detect both the normal and "confusion" figures and pathways in transformation designs. Children under 7 years of age had difficulty performing the symbol orientation and matching task required in the Velhagen Flügertrident test and this test was found to be ineffective for colour vision screening even in older children. A protocol for screening young children for colour deficiency will be proposed.

New "Windows"-based computer programme for analysing 100 hue test results. W D THOMSON, R ROTTIER and J BIRCH, Dept. of Optometry and Visual Science, City University, London, UK.

The Farnsworth-Munsell 100 Hue test is a well-established method for detecting and differentiating colour deficiencies. However, scoring and analysing test results can be time-consuming and laborious. A number of computer-based systems have been produced to speed up and simplify the scoring and analysis stages. A new computer programme which greatly simplifies data entry and analysis of test results will be described. The programme runs on PCs under Microsoft Windows and exploits the graphics user interface provided by the Windows environment. A graphical representation of the Munsell chips is displayed on the screen and chip order can be rapidly changed using a mouse. The programme calculates the error scores and displays the results in a variety of polar and linear formats. Data may be filtered using various algorithms and a number of statistical indices are calculated. The programme also establishes a provisional diagnosis. Data can be filed on disc, linked to other programmes (eg. spreadsheets, word-processors) or output to a wide variety of printers and plotters.

VISION SCIENCE AND ITS APPLICATIONS

(formerly the Noninvasive Assessment of the Visual System and the Ophthalmic and Visual Optics topical meetings)

FEBRUARY 11-15, 1994

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Abstract Deadline: September 7th, 1993

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