A System for Precision Ophthalmic Tinting and Its Role in the Treatment of Visual Stress

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10.6.1 INTRODUCTION

Tinted glasses have a long history of use in optometric practice, not only as protective filters, but also in the treatment of eye-strain (Giles, 1965; pp. 263–281). It is only recently, however, that the advent of 'plastic' (resin) spectacle lenses has made it possible to obtain almost any desired spectral transmission cheaply and quickly. The technology has been used for cosmetic dyeing for more than a decade, but only in the last few years has the breadth of its therapeutic potential been realised. The purpose of this chapter is to describe a new system for precision ophthalmic tinting and the clinical results obtained using the system.

When resin lenses are tinted, the lenses are simply dipped for a few minutes into hot organic dyes. Molecules of dye penetrate the surface, and are held beneath the surface when the lens cools, and so the dye deposition is independent of the lens thickness. Because the dyes do not interact chemically with one another, it is possible to deposit successive layers and, by combining the spectral absorbance of several dyes, to obtain any desired tint.

Helen Irlen (Irlen, 1983; Irlen and Lass, 1989; Irlen, 1991) developed a system for dyeing lenses, available at the Irlen Institutes she founded. She described a 'scotopic sensitivity syndrome' which included many non-specific symptoms of visual fatigue (e.g. blurring, headache). Wilkins and Neary (1991) examined 20 patients described as suffering this syndrome. A variety of optometric and psychophysical tests were undertaken with and without Irlen's lenses. The glasses improved the speed of visual search and reduced the anomalous perceptual effects seen in epileptogenic gratings. The perceptual effects seen in such gratings are known to be associated with headache and eye-strain (Wilkins *et al.*, 1984) and are symptoms of what has been termed *pattern glare* (Wilkins and Nimmo-Smith, 1984). An 'intuitive colorimeter' was designed to facilitate further investigation of the effects of coloured light on perception (Wilkins *et al.*, 1992a). The instrument turned out to be valuable in the clinical investigation of patients, and this discovery led to the development of a system for precision ophthalmic tinting (Wilkins *et al.*, 1992b). Open trials using the system (Maclachlan *et al.*, 1993) motivated a double-masked study (Wilkins *et al.*, 1994), which indicated that the benefits from lenses tinted using the system are more than can reasonably be attributed simply to placebo effects.

10.6.2 A SYSTEM FOR PRECISION OPHTHALMIC TINTING

The system for precision ophthalmic tinting has been in use in optometric practice in the UK since 1992. It enables an ophthalmic tint to be chosen according to a patient's subjective assessment of its effects on perception and visual comfort. A precise tint can be selected rapidly and efficiently. The system uses the Intuitive Colorimeter and associated tinted trial lenses (see below). The Colorimeter is used to assist the patient in obtaining a suitable colour. This colour is then matched with a combination of tinted trial lenses, which are given to the patient to try out, and alter, if necessary. After the combination has been selected, the chosen lenses are used to guide the dyeing of spectacle lenses. Each aspect of this system will now be described in turn.

10.6.3 INTUITIVE COLORIMETER

The Intuitive Colorimeter is a simple apparatus for mixing coloured light that enables the three subjective dimensions of colour (hue, saturation and brightness) to be varied separately. Figure 10.6.1 shows the instrument in profile. The main viewing window on the front of the instrument has a sliding cover which can be raised to reveal an inner surface on which visual material can be placed. The material is illuminated by coloured light and separate controls on the side of the instrument allow the hue, saturation and brightness to be controlled. The instrument is designed to be placed on a table with the examiner sitting on the patient's right. The controls on the right side of the instrument can then be operated by either the examiner or the patient. One control changes the hue, another changes the saturation, and two alter the luminance without altering the colour. One attenuator reduces the luminance by half (◓), and one reduces the luminance by three-quarters (◒), i.e. to one-quarter of the unattenuated value. Operating the two attenuators together reduces the luminance to one eighth the unattenuated value.

Figure 10.6.2 shows a simplified cross section of the instrument. A collimated cylindrical beam of white light from a tungsten-halogen lamp (L) is reflected from a cold-light mirror (M) and passes through a wheel (W) and into a box with matt white inner surfaces (S). The wheel is divided into three sectors, each covered with a different filter so as to transmit light of a different colour. One sector transmits long-wavelength light (and is red in colour), one intermediate wavelengths (appearing green) and one short wavelengths (blue). The coloured light is mixed as it is reflected and scattered from the inner surfaces of the box. Text (T) is mounted on one surface of this box and viewed through a window in the front.

When the wheel is concentric with the beam, the three filters each pass a similar proportion of the light, and white light results when the beam is mixed. However, the wheel is free to slide downwards so that the beam can pass eccentrically through it. The area of the filters through which the light passes is then no longer the same. The colour of the mixed light becomes progressively deeper and deeper (increasingly saturated) as eccentricity increases. The wheel is also free to rotate. This changes the colour (hue). Figure 10.6.3 gives a demonstration of the principle of the Colorimeter, which is an extension of the colorimeters described by Burnham (1952) and Gunkel and Cogan (1978). The Intuitive Colorimeter has several advantages for assessing the subjective effects of coloured light: (1) It provides a standard source of illumination of appropriate[1] and constant luminance that allows colour (CIE UCS 1976 hue angle, h_{uv}) and depth of colour (CIE UCS 1976 saturation, s_{uv}) to be varied separately and therefore intuitively; (2) the variation is continuous rather than discrete; (3) a large range of colours (gamut) is available (colours that are outside the gamut are very strongly saturated, and could be reproduced only with

inappropriately dark lenses); (4) no coloured surfaces are visible within the Colorimeter, so it is possible to study chromaticity independent of the particular spectral power distribution of the illuminating light, and related colour constancy mechanisms; (5) the perceptual effects of colour can be studied while the patient's eyes are colour-adapted; and (6) the assessment is quick and efficient.

10.6.4 TRIAL LENSES

The Intuitive Colorimeter is designed to be used to provide a chromaticity that is optimum for visual perception and visual comfort. This chromaticity is then matched using trial lenses. The trial lenses serve six purposes: (1) they provide a calibrated colour standard; (2) they enable a patient to try out a tint under different lighting conditions before it is made up; (3) they allow the adjustment of the tint; (4) they indicate the amount of each dye necessary to achieve the required spectral transmission thereby enabling practitioners to issue an

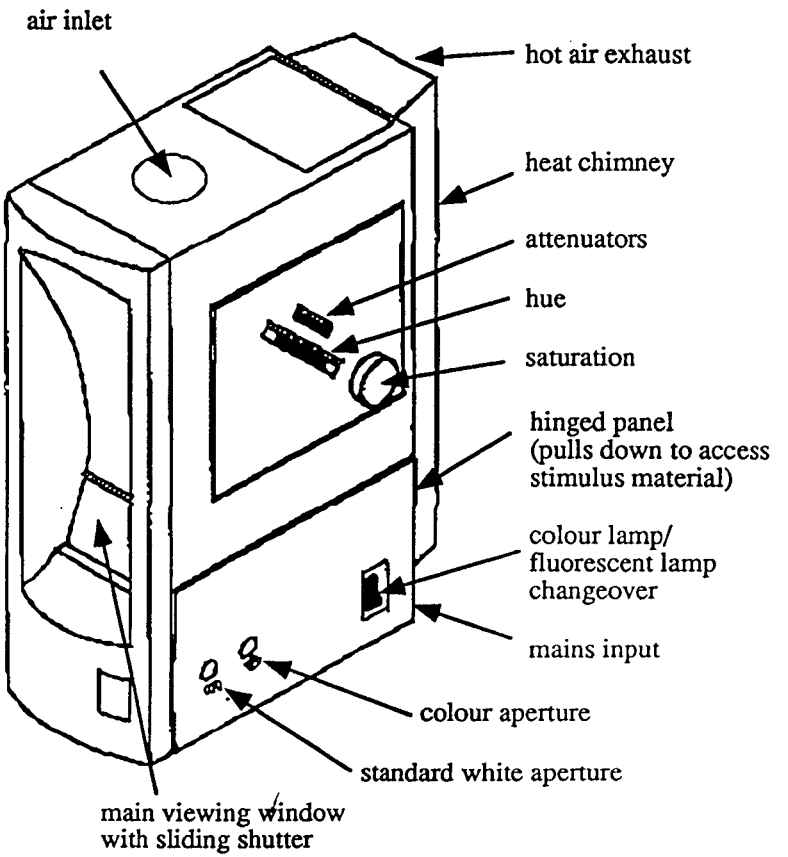

Figure 10.6.1. The Intuitive Colorimeter.

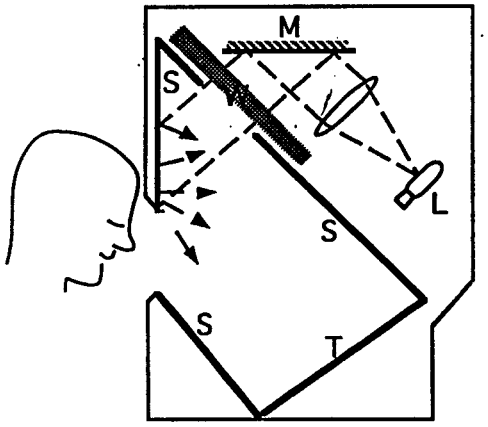

Figure 10.6.2. Cross section of Intuitive Colorimeter.

accurate prescription; (5) they govern the dyeing of spectacle lenses; and (6) they allow practitioners to check the accuracy of the dyeing.

The dyes for the trial lenses have been selected on the basis of six principles: (1) the dyes are stable; (2) the spectral transmission curves of lenses tinted with the dyes are as smooth as possible so as to reduce metamerism when lenses are combined; (3) the dyes are suitable for rapid tinting; (4) the hue angles of the dye colours are chosen so as to sample colour space evenly; (5) a large number of dyes (seven) has been chosen so there is one colour from the selection that will closely match any Colorimeter chromaticity; and (6) it is simple to superimpose trial lenses of similar colour to obtain a desired shade, and the choice of trial lenses necessary is intuitively obvious. When absorbed by a lens, the dyes have the following colour appearances: rose, orange, yellow, green, turquoise, blue and purple.

The trial lenses have different degrees of deposition of each of the above dyes so as to vary the saturation of colour. The lenses are arranged in pairs: two with identical transmission (one lens for each eye). Five pairs with increasing saturation are provided for five of the seven dyes (but with six pairs for rose and purple). In Figure 10.6.4 the peripheral

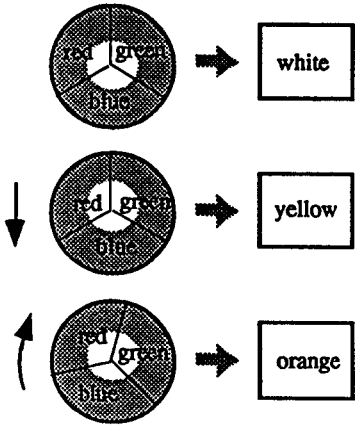

Figure 10.6.3. Principle of Intuitive Colorimeter.

panels show the transmissions of the lenses. Each curve represents the transmission of a trial lens (0–100 per cent, *y*-axis) as a function of wavelength (400–700 nm, *x*-axis). The chromaticity co-ordinates of the lenses of each dye are shown in the UCS diagram in the central panel of Figure 10.6.4 (large points).

The deposition of dye increases geometrically from one pair of lenses to the next. Thirty-one levels of deposition can be obtained by superimposing the trial lenses, adding them in all possible combinations.

The trial lenses for two dyes can be combined so that $31 \times 31 = 961$ tints are obtainable having colours (chromaticity co-ordinates) in between those of the two dyes. Figure 10.6.4 (central panel) shows the chromaticity co-ordinates of the 961 combinations of orange and rose, the 961 combinations of rose and purple, purple and blue, blue and turquoise, etc. As can be seen, a large area of the UCS diagram can be evenly and densely sampled (6727 points in all) using only two dyes at a time, both with similar hue angle. The sixth rose and purple lenses can be used to increase the gamut still further.

The spectral transmission of each lens is measured and used by a computer program that computes ultra-violet absorption, blue light transmission and Q-values for signal lights. The program issues guidelines for the optometrist and also (in non-technical form) for the patient. The guidelines are based on British Standard 2724 for sunglasses and concern ultra-violet protection, and the extent to which the tint is likely to interfere with the perception of traffic signals. The Precision Tinting System is patented by the Medical Research Council

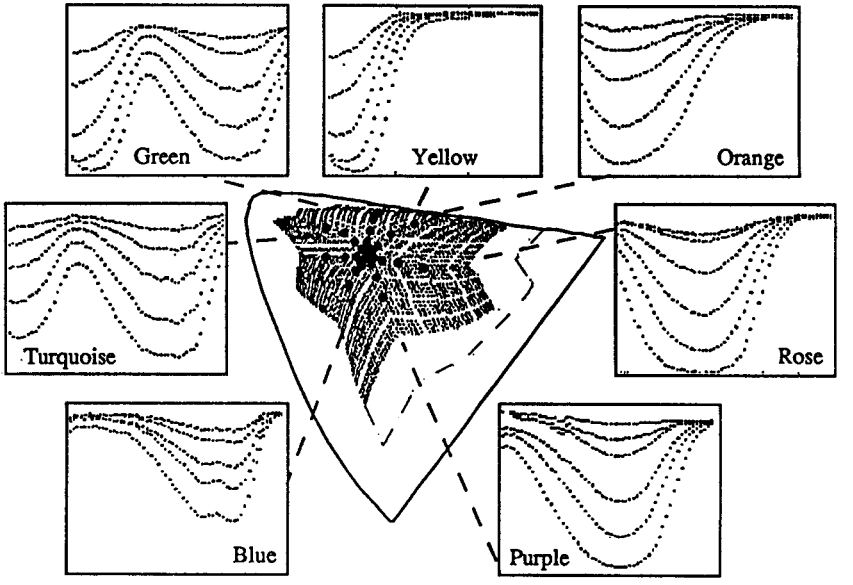

Figure 10.6.4. Centre: CIE 1976 UCS diagram showing chromaticity co-ordinates of the trial lenses (large points) and combinations of these lenses, when the dyes with neighbouring hue were combined two at a time (small points). For example, the small points with hue angles between purple and rose were obtained with combinations of purple and rose trial lenses. Periphery: transmissions of the trial lenses (0–100%, *y*-axis) as a function of wavelength (400–700 nm, *x*-axis). The dashed line shows the limits of the chromaticities available when the sixth rose and purple dyes are used.

and manufactured by Cerium Visual Technologies (Tenterden, Kent, England), who offer a commercial tinting service, now available internationally.

Over the first year that the tinting system was introduced into clinical practice in the UK, more than 1000 tints were prescribed. Figure 10.6.5 shows the chromaticities of these tints and confirms the preponderance of blue and green tints noted in open trials (Maclachlan *et al.*, 1993). Most prescriptions were based on a combination of two trial lenses, and such a combination is sufficient for a large range of chromaticities. The greater frequency of green and blue tints cannot be attributed to an artefact of the number of lenses used for the prescription. Figure 10.6.6 provides a histogram of the photopic transmission of the tints.

10.6.5 EXAMINATION PROCEDURE

For some patients, there are circumscribed regions of colour space within which perceptual distortions abate, and visual discomfort is reduced (Maclachlan *et al.*, 1993; Wilkins *et al.*, 1992a,b). The examination procedure is aimed at locating these regions without inducing discomfort, and then refining the measurements under conditions of colour adaptation. In a darkened room, the patient looks through the observation window of the Colorimeter and observes an array of random letters. The letters are arranged in strings to resemble words in a paragraph of text. The assessment is carried out under binocular viewing conditions unless there are indications that the optimal tint may differ in the two eyes and the patient is prepared to countenance wearing spectacles with differently coloured lenses.

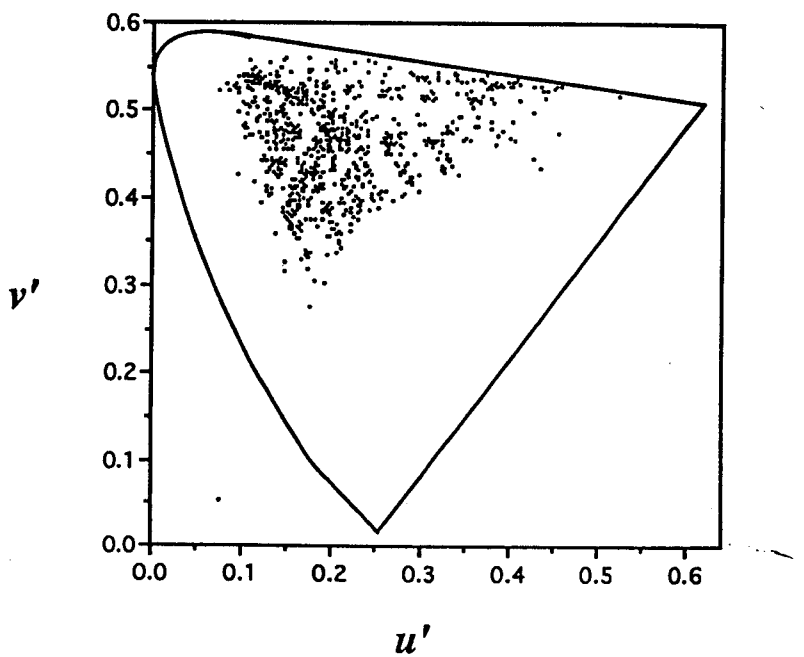

Figure 10.6.5. Chromaticity co-ordinates of the first 1000 spectacles tinted using the MRC system for Precision Ophthalmic Tinting.

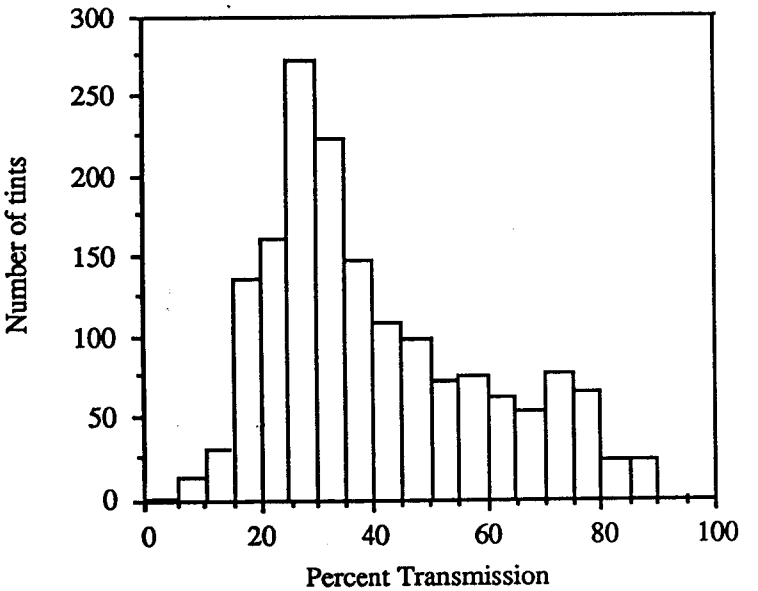

Figure 10.6.6. Photopic transmission of the first 1000 spectacles tinted using the MRC system for Precision Ophthalmic Tinting.

The test procedure recommended in the Intuitive Colorimeter Manual (Wilkins, 1993) can be summarised as follows. An initial screening procedure is undertaken at constant luminance (~20 cdm^{-2}) with the eyes adapted to white light. Beginning with a hue angle (h_{uv}) close to 0 degrees (a rose hue), saturation (s_{uv}) is slowly increased from white ($u'=0.23$, $v'=0.44$) to a moderately saturated rose (s_{uv} ~ 0.8) and then decreased until the light is again white. The observer is required to report any effects of the colour and compare them with white. The hue angle is then increased by 30 degrees and the procedure is repeated. Twelve hue angles (orange, yellow, green, etc.) are examined in this way. The purpose of the initial screening is to determine the range of hue angles that are beneficial and identify any that are aversive.

Following the screening, a second detailed examination takes place. The best hue angle is selected from the alternatives identified in the initial screening, if necessary by forced choice between the alternatives, presented in succession. Saturation is then optimised at this best hue angle, usually by a method of adjustment. Hue angle is optimised at the chosen saturation, usually by forced choice between two similar hue angles. At the revised hue angle thus obtained saturation is again adjusted. This procedure is repeated as necessary and will often, but not always, result in a stable choice of colour, particularly if the subject reports benefit. The procedure is based on the assumption that there are stable regions of colour space within which perception is improved. Note that during the detailed examination the eyes remain exposed to light of a particular colour, and the assessment is conducted while the eyes are colour adapted. The above adjustments are initially made at a constant photopic luminance similar to that which a person might experience under conditions of normal office lighting when wearing tinted glasses that absorb about half the light (Mills and Borg, 1993). The measurements are then checked at lower luminance levels.

The chosen colour is visible through the circular aperture in the side of the Colorimeter. Another circular aperture reveals a surface lit with a standard white light (CIE type F3) that is switched on when the sliding cover on the main viewing window is closed, preventing the entry of ambient light. In a darkened room both apertures appear as light sources rather than as surfaces. The combination of trial lenses likely to match the Colorimeter setting is obtained from tables. The combination of lenses is placed in front of the Standard aperture and the match is verified by the patient, adjusting the combination if necessary. A 'white' fluorescent lamp (CIE type F3) was chosen for the standard because: (1) it is a type of lamp that is commonly used for lighting offices and schools; (2) its spectral power distribution is easily controlled; (3) it has a chromaticity midway between that of daylight and incandescent light.[2] Because the apertures have the appearance of light sources, the matching of their colour is straightforward.

The stack of trial lenses that matches the Colorimeter setting is selected by combining lenses from one main colour and one subsidiary colour. The main colour is the one that predominates and gives most of the colour appearance. The subsidiary colour is added to it to fine-tune the colour. The dye colours have been chosen so that the colour of the combination of two dyes is intuitively obvious, for example, a combination of blue and purple gives a purpley blue. As Figure 10.6.4 shows, the colour appearance of the two apertures can always be matched very closely by superimposing over the Standard aperture lenses from a main colour and just one colour with neighbouring hue, that is by combining lenses of just two colours and hence of just two dyes.

Once selected, the combination of trial lenses is worn by the patient under a variety of typical viewing conditions and lighting so that any adjustments to the combination of trial lenses can be made. Some patients prefer a lower saturation than that selected in the Colorimeter, presumably to reduce the darkness of the lenses and their effect on the appearance of surface colours.

10.6.6 RELIABILITY OF THE PROCEDURE

The reliability of the Colorimeter examination procedure has been assessed in three independent trials. In the first of these trials, 15 normal adults from the MRC Applied Psychology Unit subject panel aged 30–61 years (mean 50 years) were examined. They were assessed initially and then 24–26 months later by a different examiner who had no knowledge of the subjects' previous performance. The observers did not receive any treatment or other intervention in the two-year interval between examinations. Five subjects were emmetropic and ten wore their usual near correction. None was receiving orthoptic treatment. The optimal hue angle was assessed at each examination and the minimum absolute angular difference between the hue angles (h_m) was calculated. For example, if a hue angle of 285º had been chosen on the first occasion and 205º on the second, the angular difference would have been 80º; if the first hue angle had been 305º and the second 10º, then the angular difference would have been 65º. The mean angular difference for the 15 subjects was 63.1º. If the hue angles had been chosen randomly and all hue angles had been equally likely, the expected angular difference would have been 90º. However, the chosen hue angles tend to cluster between 90 and 270º, as can be seen from Figure 10.6.5. Therefore the expected value is difficult to obtain from distribution theory, and a randomisation technique was used to calculate the expected value. A given subject's initial hue was randomly paired with another subject's second hue and the angular difference obtained. Random permutations were undertaken, re-pairing all subjects, and the mean angular difference calculated. The process was repeated 10 000 times by computer and only on 114 occasions was the value lower than 63.1º. The p-value for the chance occurrence is therefore 0.0114. The 99 per cent confidence limits for the p-value were 0.0084 and 0.0140.

Data from two other trials have been treated in a similar way. The first was from a double-masked study by Wilkins *et al.* (1994) who examined children aged 9–14 years, offering them spectacles with lenses that matched an optimal Colorimeter setting or a suboptimal setting, comparing the incidence of headaches and eye-strain (Evans *et al.*, this volume, pp. 709–715). The children were examined for a second time at the end of the study, approximately one year after the first examination. During the interval most of the children wore coloured glasses. The mean angular difference between the optimal hue angle on the first and second assessments was 62.9º ($p = 0.0035$). The second trial was undertaken by Jenny Brown, who, working in optometric practice, assessed patients every six months on average. As in the above trial most were wearing coloured glasses. In 30 consecutive cases, the mean angular difference was 49.7º ($p < 0.0001$).

10.6.7 A REBUTTAL OF RECENT CRITICISM

In a recent abstract, Mason *et al.* (1994) criticised the Colorimeter on three counts.

1. *The assessment was 'unreliable'*. The subjects examined by Mason *et al.*, 'reported distortions whatever the colour'. If their subjects were unable to find a colour that could alleviate symptoms it is perhaps unsurprising that their settings were 'unreliable', although no statistics are quoted. It is clear from the previous section that normal observers generate reliable data when examined using the recommended techniques.
2. *Two or more colours cannot be presented in immediate succession.* Although this was not possible on the prototype Colorimeter used by Mason *et al.* because the hue wheel had a low gear ratio, the gearing has been changed on the production model and it is now simple to change colours rapidly. It is not, however, recommended that two colours are presented in immediate succession unless they have similar hue angle because the changing state of adaptation of the eyes may complicate any comparison.
3. *Colours cannot be presented simultaneously for comparison.* The Colorimeter does not permit the simultaneous presentation of different colours for a *fundamental* but subtle reason. As outlined above, the Colorimeter was designed to assess the effects of coloured light and to do so under conditions in which the eyes are adapted to that illuminant colour. Changing the colour of a light source is similar to wearing a coloured lens. It is for this reason that the Colorimeter provides a good guide to the colour appropriate for tinted spectacles.

As Mason *et al.* point out, young children often find the effects of colour easier to assess when two colours are presented simultaneously. However, the state of adaptation of the eye then depends upon many factors, and the colour selection would not be appropriate for lenses. Simultaneous comparison of two colours is best achieved when the eyes are adapted to a conventional (white) light source and the colours are perceived as surfaces rather than as lighting. This can readily be achieved using overlays (e.g. Irlen, 1991; Wilkins, 1994). These are sheets of coloured plastic that can be placed side by side over a page of text that is illuminated conventionally. The British College of Optometry has issued guidelines suggesting that children should use overlays for a trial period before being assessed for tinted glasses.

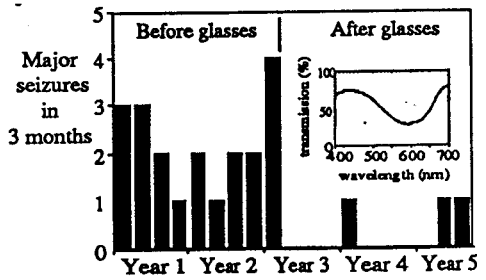

Figure 10.6.7. Incidence of major tonic clonic seizures before and after the provision of coloured spectacles.

As might be expected, the choice of colour for spectacles is predictable from the choice of colour in the Colorimeter and not from the choice of coloured overlays (Wilkins *et al.*, 1992a).

10.6.8 CLINICAL USE OF PRECISION TINTS

10.6.8.1 Reading

Children with reading difficulty can benefit from a reduction of eye-strain and headaches, as detailed in the chapter by Evans *et al.* (this volume, pp. 709–715).

10.6.8.2 Photosensitive epilepsy

Patients with photosensitive epilepsy are liable to seizures induced by light, particularly when it flickers. An electroencephalographic response to flickering light is usually obtained in these patients. The colour of the flickering light can affect the electroencephalographic response, although with differences between individual patients as to which colour is the most epileptogenic (Harding and Jeavons, 1994). It has long been reported that photosensitive patients may benefit from wearing coloured spectacles (Newmark and Penry, 1979), although most reports preceded the development of an effective anticonvulsant therapy (sodium valproate). Benefit is typically reported with spectacles that absorb red light. The author has examined several patients with photosensitive epilepsy using the Colorimeter (usually with concurrent EEG recording to reduce the risk of seizures). Spectacles tinted using the subjective methods described above appear to have successfully reduced seizures. In most cases to date, the interpretation is complicated by concurrent changes in medication, but in a girl with intractable major seizures the seizure reduction was immediate, sustained and, since there were no concurrent changes in medication, unequivocal. Her mother kept a seizure diary summarised in Figure 10.6.7. The patient wore the spectacles on a cord around her neck and put them on whenever she felt the need.

10.6.8.3 Migraine

Many adults with migraine and a sensitivity to light appear to benefit from precision tints (Maclachlan *et al.*, 1993; Wilkins *et al.*, 1992a), although double-masked studies remain to be conducted.

10.6.8.4 Colour vision deficiency

Fletcher and Voke (1985) and Birch (1993) have reviewed the literature on the use of coloured filters to ameliorate the effects of Daltonism in everyday life. They discuss the advantages and disadvantages of monocular and binocular filters, different filters in the two eyes, and filters that partially cover the field of view. They also present several case histories of patients who appeared to benefit from wearing binocularly tinted spectacles covering the entire field of view, some of whom preferred to wear their spectacles continuously. The author has also seen two patients who appeared to benefit from binocular tints, reporting that colours appeared less glaring. Both cases had an acquired colour vision deficiency. They reported that coloured surfaces appeared more normal with their chosen filter (selected from the range of trial tints) and, in one case, errors of colour naming were reduced considerably. These preliminary observations deserve further exploration.

10.6.9 WHY PRECISION TINTING WORKS

The following is one possible explanation as to why precision tints have their beneficial effects. It is only one among many, but has the merit of parsimony.

1. In patients with photosensitive epilepsy there is considerable convergent evidence that seizures can be triggered in the visual cortex (Darby *et al.*, 1986; Wilkins, *et al.*, 1980, 1981).
2. The seizures can sometimes be provoked by patterns of stripes, and sometimes only by stripes in a limited range of orientations (Chatrian *et al.*, 1970; Soso *et al.*, 1980; Wilkins, *et al.*, 1979).
   Inference: The trigger can be quite focal in the visual cortex, involving a small hyperexcitable area with columns of cells having the appropriate orientation specificity.
3. The visual stimuli that trigger seizures in patients with photosensitive epilepsy provoke in others feelings of discomfort and anomalous perceptual distortions (Marcus and Soso, 1989; Wilkins *et al.*, 1984).
   Inference: Some of the perceptual effects are due to a spread of excitation in the visual cortex sufficient to excite neurones inappropriately, but not sufficient to provoke a seizure.
4. People with migraine or with migraine in the family are particularly susceptible to the perceptual distortions seen in epileptogenic visual stimuli (Marcus and Soso, 1989; Wilkins *et al.*, 1984). In those with consistently lateralised visual aura the distortions are similarly lateralised (Khalil, 1991).
   Inference: In these individuals the visual cortex of one or both hemispheres may be unusually excitable.
5. Text has spatial characteristics that resemble those of stressful patterns (Watt *et al.*, 1990; Wilkins, 1991; Wilkins and Nimmo-Smith, 1987).

6. Reading can provoke anomalous visual effects (Wilkins, 1991), headaches (Wilkins and Nimmo-Smith, 1984) and photosensitive epilepsy (Wilkins and Lindsay, 1985).
7. Covering the lines that are not being read, leaving only three visible lines, reduces these adverse effects (Wilkins and Lindsay, 1985; Wilkins and Nimmo-Smith, 1984).
   Inference: Certain spatial characteristics of text induce 'pattern glare' and make it stressful, particularly for individuals with cortical hyperexcitability.
8. Some cortical neurones are tuned for wavelength or for colour appearance. None can be indifferent to the spectral power distribution of the stimulating light (Lennie and D'Zmura, 1988).
   Inference: The colour of the illuminating light changes the pattern of excitation in the cortical network.
9. People with migraine show a consistency not shown by age and sex matched controls regarding their choice of coloured light for reading, avoiding red illumination (Chronicle and Wilkins, 1991).
10. Certain children report a reduction in distortion with light of a certain colour, different for each individual, but usually complementary to red (Maclachlan *et al.*, 1993; Wilkins *et al.*, 1992a).
11. These children usually have migraine in the family and suffer frequent headaches (Maclachlan *et al.*, 1993).
12. There are several early reports (Newmark and Penry, 1979) and one recent report (Takahashi and Tsukahara, 1992) emphasising the effectiveness of glasses that absorb red light in the treatment of photosensitive epilepsy.
13. Precision Tints (both blue and other colours, selected according to routine subjective methods) reduce the photoconvulsive EEG response to flickering light and patterns whereas neutral tints of similar photopic transmission are less effective (recent unpublished observations).
14. Precision Tints reduce seizures in some patients (see above).
    Inference: The colour that is therapeutic changes the pattern of excitation in the cortical network so as to avoid local areas of hyperexcitability.
15. The patterns that provoke seizures have characteristics that are reminiscent of the properties of magnocellular cells (Wilkins, 1995): patterns of stripes are not epileptogenic if the stripes differ in colour but not in brightness; the effects of pattern motion suggest that directionally sensitive neurones are involved in seizure induction; the effects of binocular fusion would be consistent with the action of disparity-tuned neurones; the low spatial resolution of cells in the magnocellular system would be consistent with the spatial frequencies at which aversive effects occur; the high temporal resolution would be consistent with the effects of flicker; epileptiform EEG activity in response to patterns is usually maximal over electrodes which record from parieto-occipital cortex.
16. Children with reading difficulty have a deficit in transient system function (Lovegrove *et al.*, 1986) implicating magnocellular dysfunction (Livingstone *et al.*, 1991).
17. They often have poor sensitivity at mid-range spatial frequencies but good sensitivity at high spatial frequencies (Lovegrove *et al.*, 1986).
18. They often complain of glare from the page (Wilkins *et al.*, 1992a).
    Inference: There may be a link between pattern glare and magnocellular function.

Drawing together the above inferences, it is proposed that when observers who report perceptual distortion choose a coloured light that improves clarity and comfort of text, they may be selecting a distribution of excitation in the visual cortex that reduces the excitation in hyperexcitable regions. It is unclear why the magnocellular system appears to be preferentially involved.

10.6.10 NOTES

1. A luminance of 20 cdm^{-2} is used for this examination initially because this is the luminance expected under conventional office lighting (Mills and Borg, 1993) when wearing a lens that absorbs about half the light.
2. Note that when the saturation control is at its minimum the colorimeter has a chromaticity similar to that of daylight (D65).

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