Visual Stress and its Treatment with Spectral Filters

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Abstract. Visual stress occurs from images with unnatural spatial structure and an excess of contrast energy at spatial frequencies to which the visual system is generally most sensitive. Visual stress can often be reduced using spectral filters, provided the colour is selected with precision to suit each individual. The use of such filters and their effects on reading speed are reviewed. The filters have been shown to benefit patients with a variety of neurological conditions, all associated with an increased risk of seizures.

Introduction

Critchley (1964) cited a case of a dyslexic child who was unable to read words on white card but could read words printed on coloured card. Nearly 20 years later, Meares (1980) described a syndrome of symptoms (visual perceptual distortions, eyestrain and headache) that some people experience when reading and which can be alleviated by using coloured card or coloured filters. Irlen (1983) developed a proprietary treatment system for this syndrome, which later became known as Meares-Irlen Syndrome or Visual Stress. Irlen claimed that the coloured filters need to be prescribed with great precision and different people need different colours. This attracted considerable controversy, especially since she claimed that the filters could only be obtained from her organisation.

Wilkins (1992) developed an instrument, the *Intuitive Colorimeter*, that facilitated a double-masked randomised placebo controlled trial of the use of precision tinted lenses in Meares-Irlen Syndrome (Wilkins *et al.,* 1994). The randomised controlled trial demonstrated that sufferers do indeed need different colours, and that the required colour needs to be defined with precision. The findings were replicated in another double- masked randomised placebo-controlled trial, conducted by Robinson and Foreman (1999a,b).

The mechanisms that underlie the benefit from coloured filters remain uncertain (Evans, 2001) although recently the weight of evidence has turned in favour of the following explanation.

Unpleasant images and stripes

Images (from contemporary art and from photographs of rural and urban scenes) are sometimes classified as "unpleasant". Unpleasant images have more power at spatial frequencies near 3 cycles/degree (Fernandez and Wilkins, 2007a). Some people find them very aversive, other people are relatively unaffected. In a few people stripes with this spatial frequency can trigger migraines or epileptic seizures (Wilkins *et al.,* 1980, 1984).

Stripes in text. Text is striped partly because of the lines. The lines have a spatial frequency within the range that causes discomfort (Wilkins *et al.,* 2004). Individual words are also striped because of the neighbouring letter strokes. The stripes from the letter strokes have a spatial frequency

within the range that causes discomfort, and for this reason striped words (e.g. mum) take longer to read, even for fluent readers. Reducing the periodicity of the stripes by varying the inter-stroke spacing can increase reading speed in poor readers (Wilkins *et al.,* 2007b).

People who dislike stripes tend to have frequent headaches. They see many perceptual distortions involving motion, shape and colour. Migraineurs are particularly affected (Wilkins, 1995; Marks and Ehrenberg, 1993).

Some people see distortions not only in stripes but also in text (Irlen, 1991). Sensitivity to striped patterns (pattern glare) plays a key role in producing these symptoms.

Coloured filters

Coloured filters can reduce the distortions seen in stripes and text. Reports of distortions are obviously subjective but they are associated with an impairment of reading speed that can be measured objectively (Wilkins, 2002; Wilkins and Lewis, 1999; Wilkins *et al.,* 2005). In addition to direct evidence implicating pattern glare in the aetiology of visual stress (Evans *et al.,* 1994, 1995, 1996a), several studies have excluded other potential mechanisms (Evans *et al.,* 1995, 1996, Simmers *et al.,* 2001b). Although these studies suggest that optometric anomalies are not causes of visual stress in the majority of cases, a thorough eye examination is important in the differential diagnosis (Evans, 2005).

Individual differences. There is no one colour that helps everyone: the best colour needs to be individually selected. This statement is supported by both single masked clinical trials (Bouldoukian *et al.,* 2002; Evans and Joseph, 2002; Kriss, 2002; Kriss and Evans, 2005; Singleton and Trotter, 2005; Wilkins *et al.,* 2001) and also by double-masked randomised placebo-controlled trials (Robinson and Foreman, 1999a; Robinson and Foreman, 1999b; Wilkins et al., 1994; Wilkins et al., 2002), in which filters of similar colour were offered as control. Additionally, a recent experiment studied reading speed at a large range of chromaticities and thereby directly addressed the issue of the precision with which the coloured filters need to be prescribed (Wilkins et al., 2005a).

People who read more quickly with their chosen coloured overlay see more distortions in striped patterns (Hollis and Allen, 2006). These people can be identified objectively by the decrease in search speed that occurs when the search task is surrounded by a pattern of stripes (Singleton and Henderson, 2006).

Colour choice. In order for susceptible individuals to obtain an effective filter, it is important to sample a large number of colours. The *Intuitive Overlays* are coloured transparencies that are placed over the page when reading. They are available in colours that sample the UCS diagram efficiently (Wilkins, 1994). They are designed so that 30 evenly spaced chromaticities can be obtained systematically by using the overlays singly, or in pairs with the same or similar chromaticity, one on top of another. The Cerium overlays have similar properties but some other systems have a range of colours insufficient to increase reading speed effectively (Smith and Wilkins, 2006).

Overlays examination. The overlays examination requires illumination similar to that under which the overlays will be used. Two identical passages of text of appropriate size are presented side by side. The overlays can be placed over each passage and compared. The overlays are compared in pairs, and the best of each pair retained, the other being replaced by another overlay. If the patient finds the choice difficult, the choice is repeated when all overlays have been assessed. Double overlays are used if symptoms remain (Wilkins, 2003).

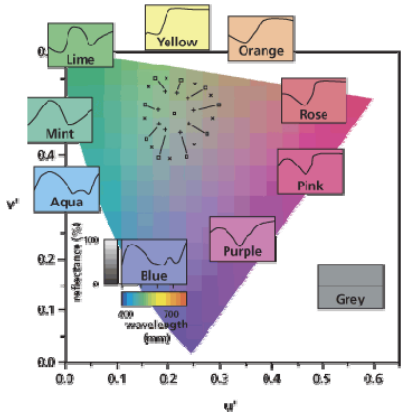

Figure 1. The *Intuitive Overlays*. The chromaticities of the nine coloured overlays are show in the inner ring. The outer ring shows the chromaticities of two overlays placed one upon the other. The isolated points are those from combinations of overlays with neighbouring chromaticity. The lines connect the chromaticites of single overlays with those from two overlays of the same colour.

Prevalence. In 6 studies of normal unselected children in mainstream schools, about 20% used their chosen overlay long-term (Jeanes et al., 1997). Those that used their overlays read faster with them: 5% read more than 25% faster (Wilkins, 2002b).

Reading speed. Reading speed can be measured quickly and efficiently using the *Rate of Reading Test* in which randomly ordered common words are read aloud for one minute (Wilkins *et al.,* 1996). The words are high-frequency and therefore familiar to poor readers. The random word order means that the words cannot be guessed from context but have to be seen to be read. The text is meaningless so readers are unaware of their errors. The text is small to increase fatigue. The benefit from overlays can be rapidly ascertained as an increase in reading speed, as measured by this test. Although the *Rate of Reading Test* is not a typical reading task it has been shown to predict performance when text is read silently for comprehension (Wilkins, 2002b). An overlay needs to be of a size sufficient to cover the text, but it does not have to cover the surround (Waldie and Wilkins, 2004). Individuals who find coloured overlays helpful usually prefer coloured lenses (Evans et al., 1999). The optimal colour for lenses is not the same as for overlays (Lightstone *et al.,* 1999), and it can be selected with far greater precision. Coloured lenses also have practical advantages over overlays, because lenses are easier to use when writing, reading a white board in class, and using a computer. Coloured overlays are therefore used for screening, with the precision tinted lenses representing the preferred treatment.

Coloured lenses

The colour for lenses can be selected while the eyes are colour-adapted using the *Intuitive Colorimeter*, an instrument that illuminates a page of text with coloured light, allowing the hue, saturation and luminance to be varied independently (Wilkins *et al.,* 1992a,b). The optimal tint can then be matched in coloured trial lenses. Under conventional lighting the lenses result in a spectral power distribution almost identical to that in the *Intuitive Colorimeter* (Wilkins and Sihra, 2000), allowing observers with colour vision anomalies to be tested. The *Intuitive Colorimeter* system will provide lenses that closely approximate any chromaticity. The lenses have a smoothly varying spectral transmission that minimises metamerism under different types of lighting (Wilkins, 2003).

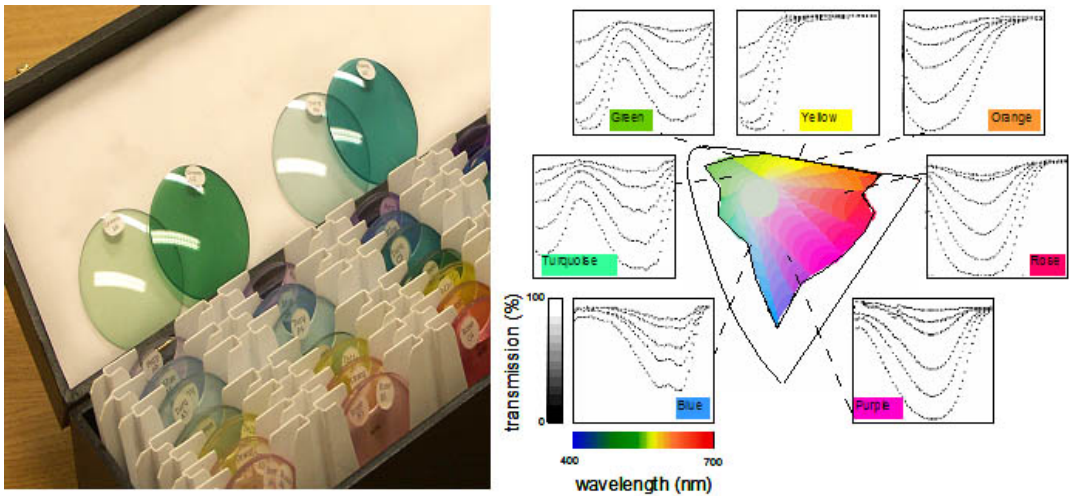

Figure 2. With the Intuitive Colorimeter system, tinted trial lenses can combined to provide a close approximation to any required chromaticity. Lenses from only two dyes are necessary: those with neighbouring chromaticity.

Each individual reads most quickly with a particular individual optimal chromaticity. Departures from this optimum, whether in hue or saturation, result in slower reading. The greater the difference in chromaticity the slower the reading, unless the CIE colour difference (ΔE*) exceeds about 100, in which case the speed is similar to that under white light. Despite this specificity, calculations suggest that most tints offer at least some benefit under most types of lighting (Wilkins et al., 2005a).

Several different tinting systems are available, but most have only a few tints. Indications are that at least 1000 tints are needed to provide sufficient precision to increase reading speed optimally (Wilkins et al., 2005b).

Examination with the *Intuitive Colorimeter*

With the *Intuitive Colorimeter* system the typical examination and prescription has 6 stages, usually taking a total of 20-30 minutes:

1. The optimal chromaticity is selected using the *Intuitive Colorimeter*. 12 hues are compared. Saturation is optimised at those hues that improve perception, and these are then compared. The eyes remain colour adapted while hue and saturation are alternately adjusted by small amounts to find the best chromaticity.
2. The matching combination of tinted trial lenses is calculated using a computer program.
3. The trial lenses are offered to the patient and the combination adjusted, if necessary.
4. The combination of lenses constitutes the (calibrated) colour prescription which is sent to a dyeing company.
5. Spectacle lenses are dipped into two dyes to obtain the appropriate spectral transmission.
6. A spectroradiometer and computer program check the transmission and supply individual information for the prescribing practitioner and patient (Wilkins, 2003).
7. Using trial lenses the practitioner carries out a visual check of the colour of the supplied spectacle lenses.

Neurological disorders involving visual stress

The patients who benefit from precision spectral filters include those with

- reading difficulty (double-masked trial of lenses) (Wilkins *et al.*, 1994)
- photosensitive epilepsy (open trial of lenses) (Wilkins *et al.*, 1999)

- migraine (small-scale double-masked trial of lenses) (Wilkins *et al.,* 2002)
- autism (open trial of overlays) (Ludlow et al., 2005)
- multiple sclerosis (double-masked trial of overlays) (Wright et al., 2007)

All these disorders (with the possible exception of reading difficulty) are associated with an increased risk of seizures, suggesting cortical hyper- excitability. There is good convergent evidence for cortical hyper-excitability in migraine (Welch, 2002; Welch, 2003) and for pattern glare in consequence (Harle and Evans, 2004; Harle *et al.,* 2006).

A hypothesis

Pyramidal neurons share inhibitory interneurons. Strong stimulation leads to a local depletion of GABA. The local impairment of inhibition results in a spread of excitation (Meldrum and Wilkins, 1984). It is hypothesised that this spread of excitation results in the inappropriate firing of cortical neurons and the perception of illusions/distortions. By virtue of the topographic encoding of chromaticity in the cortex (Xiao et al., 2003), and the large variation in spectral sensitivity of cortical neurons (Zeki, 1990), comfortable colours redistribute excitation so as to reduce excitation in hyperexcitable areas.

Evidence

Blood oxygenation in the visual cortex (as evidenced by the fMRI BOLD signal) shows an increase in response to stripes with spatial frequencies in the aversive range (Huang *et al.,* 2003). In migraineurs this increase is abnormally large at these spatial frequencies. In a preliminary study the abnormal increase has been shown to be reversed in V3 when precision tints are worn, but not when control tints are worn (Huang et al., 2004).

Clinical protocol

The Intuitive Colorimeter was patented by the MRC in 1994 and there are now over 250 of the instruments in use in the UK, mostly by community optometrists and a few by hospital orthoptists. A clinical protocol was published over 10 years ago (Lightstone and Evans, 1995) and is widely followed by colorimeter users. A Society for Coloured Lens Prescribers has recently been set up to oversee the administration of a Code of Conduct to which members of the society subscribe. Evidence-based practice is codified and ratified by the society.

Conclusions

Individually prescribed spectral filters are a safe intervention for visual stress and have been widely used in the UK over the last 15 years. Their efficacy has been demonstrated in three independent randomised controlled trials.

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