This chapter will

■ describes the characteristics of visual stress
■ discusses the impact of visual stress on the ability to develop fluent reading skills
■ discusses the causes of visual stress and how to identify it
■ refers to different theoretical perspectives
■ provides guidance for intervention.

Introduction

Visual stress is the subjective experience of unpleasant visual symptoms when reading (especially for prolonged duration) and in response to some other visual stimuli. This is a surprisingly common condition: although reported rates of prevalence vary according to the criteria and type of sample used, incidence of visual stress in unselected samples is generally accepted to be about 20 per cent (Jeanes et al., 1997; Kriss and Evans, 2005; Wilkins et al., 1996). The symptoms of visual stress fall into two categories: first, discomfort (e.g. sore, tired eyes; headaches; photophobia); second, visual-perceptual distortions and illusions (e.g. illusions of shape, motion and colour in the text; transient instability of focus; double vision). These symptoms were first independently noted by Meares (1980) and Irlen (1983), who also both observed that the unpleasant effects can usually be alleviated by using colour, either in the form of acetate sheets placed over the text (‘coloured overlays’), or tinted spectacles. Since its discovery, the condition has been given various labels, including ‘Meares-Irlen syndrome’, ‘visual discomfort’, ‘visual dyslexia’ and ‘scotopic sensitivity syndrome’ (some of which are less suitable than others) but ‘visual stress’ is increasingly recognised as being the most appropriate term (Evans, 2001; Singleton and Henderson, 2007a; Wilkins, 2003).

Visual stress interferes with the ability to read for any reasonable duration and consequently children who suffer from this problem tend to avoid reading. As a result, they lack the amount of practice that is essential for the development of fluent decoding of text and good reading comprehension (Tyrell et al., 1995). Practice enables decoding to become automatic, reading eye movements to become smooth and disciplined, and the brain to cope with processing and understanding large amounts of text. Consequently, although visual stress can occur in normal
readers it is more often observed in poor readers (Jeanes et al., 1997). If visual stress is not identified and dealt with early on, children are at risk of remaining unskilled readers, particularly when trying to understand longer and more complex texts. Adults who suffer from visual stress tend to steer clear of activities involving reading, which can have implications for education and employment. In higher education visual stress has been noted to be an increasingly common problem that interferes with students’ studies (Grant, 2004).

Recent studies have revealed that the prevalence of visual stress is considerably higher in children and adults with dyslexia than in the rest of the population (Singleton and Trotter, 2005; Singleton and Henderson, 2006). Whiteley and Smith (2001) estimated the prevalence of visual stress in dyslexics to be in the region of 50 per cent, a figure that has turned out to be not very far from those reported in several recent studies. Using percentage increase in rate of reading with a coloured overlay as the criterion for assessing susceptibility to visual stress, Kriss and Evans (2005) found that 45 per cent of dyslexic children read 5 per cent faster with an overlay, compared with 25 per cent of non-dyslexic control children; when a more conservative criterion of 8 per cent increase in reading speed with an overlay was applied, these figures dropped to 34 per cent and 22 per cent, respectively. Using ViSS, a computer-based screening tool for visual stress, Singleton and Henderson (2007b) found that 41 per cent of dyslexic children in their sample showed high susceptibility to visual stress; the corresponding figure for the non-dyslexic control group was 23 per cent. White et al. (2006) found that 35 per cent of their sample of dyslexic children aged 8–12 years met criteria for visual stress while only 18 per cent of the non-dyslexic control group matched for non-verbal IQ met criteria for visual stress. Grant (2004) reported that of a sample of 377 university students referred for psychological assessment for dyslexia, 42 per cent showed strong evidence of visual stress and a further 34 per cent reported some visual stress symptoms.

These findings raise several important issues that will be the focus of this chapter, including theoretical issues regarding the relationships between dyslexia and visual stress, and professional issues regarding how visual stress can most efficiently be identified and treated, especially in dyslexics.

**Causes of visual stress**

The most widely supported theory of visual stress is that it is the result of a general over-excitation of the visual cortex due to hypersensitivity to contrast or pattern glare (see Evans, 2001; Wilkins, 2003). Wilkins’s theory is that the visual cortex functions normally until strong physiological stimulation results in stimulation of neurons that are close together. These neurons share inhibitory neurons and hence normal inhibitory processes will be compromised if they all fire together because the availability of inhibitory neurotransmitter is reduced. The outcome is the triggering of other neurons that signal movement or colours, which are consequently experienced as illusions or hallucinations. In other words, the visual cortex works normally until stimulation is too strong, whereupon a catastrophic non-linear failure of inhibition occurs, which spreads to other neurons (Wilkins, 1995; Wilkins et al., 2004b).

Potentially, any stimulus that creates square-wave on–off signals in the visual cortex can trigger these neural effects. Perhaps the most obvious examples are high contrast, rapidly flashing or flickering illumination such as strobe lighting, fluorescent lighting, CRT computer monitors with low refresh rate, and bright sunlight viewed through trees when moving in a vehicle. All these stimuli cause headaches in many people, especially those who suffer from migraine, and they also trigger seizures in people with photosensitive epilepsy (Wilkins, 1995). The most dramatic case of flashing stimuli on TV triggering epileptic seizures in children occurred in Japan
in 1997, when a ‘Pokemon’ cartoon transmitted on TV resulted in 685 people (most of them children) being admitted to hospital. Of these, 560 were found to have had epileptic seizures and of these 76 per cent of these had no previous history of epilepsy. The epileptic seizures experienced by these children were subsequently shown to be attributable to intense, rapidly flashing red/blue colour changes (Harding, 1998). The same cartoon, when viewed in black-and-white did not provoke seizures (Tobimatsu et al., 1999) Compared with non-affected children, significantly more affected children reported that they had been viewing very close to the screen and in an unlit or dimly lit room – i.e. under conditions of high contrast (Furusho et al., 2002). After the Pokemon incident was understood, guidelines on the use of coloured flashing images on TV were revised (see Binnie et al., 2002).

Similar effects have been reported with some computer and video games, which, in cases of photosensitive epilepsy, are often associated with the first reported epileptic seizure (Wilkins et al., 2004a). About 80 per cent of epilepsy patients between the age of 7 and 19 years were found to spend greater than one hour per day playing videogames (Quirk et al., 1995). Unlike TV, there are no guidelines regarding flashing images in computer games, but Nintendo and some other computer game manufacturers put warnings on their programs that they may be harmful if used by people who suffer from photosensitive epilepsy.

Geometric repetitive patterns, such as stripes, create square-wave on–off neural signals similar to those causes by flashing lights, which explains why such patterns can cause unpleasant somatic and perceptual side effects (McKay, 1957; McKay, Gerrits and Stassen, 1979; Wilkins and Nimmo-Smith, 1987). A proportion of people who suffer from photosensitive epilepsy also report that stationary gratings, stripes or checkered patterns, can trigger seizures, especially when there is a strong light/dark contrast in the pattern (Fisher et al., 2005). Harding and Jeavons (1995) found that about 30 per cent of photosensitive patients were also sensitive to patterns. The incidence of a family history of migraine in children who benefit from coloured filters has been found to be twice that in children who do not (Maclachlan et al., 1993).

Since text can resemble a pattern of stripes with visually stressful characteristics, this explains why it can provoke perceptual distortions and cause headaches. The visual grating created by moving the eyes across lines of print, especially where the pattern is glaring, can generate similar physiological effects to those created by flashing lights. These findings suggest a continuum of photosensitivity for people suffering from photosensitive epilepsy, migraine and visual stress. Individuals who suffer from visual stress (but not photosensitive epilepsy or migraine) would be regarded as ‘moderately photosensitive’, so that their symptoms are not as extreme as those of individuals who suffer from photosensitive epilepsy or migraine, and these symptoms are less easily triggered. Wilkins (1995, 2003) suggests that because the wavelength of light is known to affect neuronal sensitivity, the use of colour could reduce over-excitation, redistributing cortical hyperexcitability and thus reducing perceptual distortion and headaches.

**Visual stress and the magnocellular system**

An alternative perspective on visual stress comes from researchers investigating the magnocellular visual system. There are two types of cells found in the neural tracts between the retina and the visual cortex: **magnocells** are large cells that code information about contrast and movement; **parvocells** are smaller and code information about detail and colour. (The magnocellular system is also sometimes known as the *transient system*, and the parvocellular system as the *sustained system.* Cooperation between these two systems enables us to perceive a stationary image when we move our eyes across a scene or a page of text. When reading, the eyes do not move smoothly across the page but in a series of very quick jumps (saccades) in order to fixate
successive portions of the text. During saccades, which typically take about 20–40 milliseconds, vision is suppressed.

The magnocellular system plays several important roles in visual functioning, including control of eye movements, selective attention and visual search (Facoetti et al., 2000; Iles et al., 2003; Stein and Walsh, 1997; Steinman et al., 1997; Vidyasagar, 1998; Vidyasagar and Pammern, 1999). Consequently it has generally been assumed that it is the magno system which suppresses information coming in via the parvo system during saccadic movements of the eyes, thus facilitating clear perception of text in successive visual fixations (Breitmeyer, 1993; Breitmeyer and Ganz, 1976). However, accumulating evidence suggests the opposite, i.e. that the magno pathway is suppressed during saccades, which would explain why we do not experience visual movement when moving the eyes from one fixation to another (Burr et al., 1994; Parke and Skotton, 1999; Ross et al., )

Many studies have reported deficits in magnocellular functioning in poor readers and dyslexics. For example, Cornelissen et al. (1995) found dyslexics to be significantly poorer than controls in perception of moving stimuli. Talcott et al. (1998) found dyslexics to have significantly higher thresholds for perceiving random dot kinematograms. Eden et al. (1996) found that dyslexics did not show activation of certain critical areas of the visual cortex that are normally activated by moving stimuli. Evans et al. (1994) reported a number of anomalies in the magnocellular processing of dyslexics, including in contrast sensitivity. These studies, and others like them, have provided the basis for the magnocellular deficit theory of dyslexia (Stein, 2001). However, reviewing 22 different studies of magnocellular functioning in dyslexics, Skottun (2000) found that only four were clearly in support of the hypothesis that dyslexia could be attributed to magno deficits. Deficits in motion perception are certainly not found in all dyslexics (e.g. Everatt et al., 1999) or with all motion-perception tasks (e.g. Raymond and Sorensen, 1998). White et al. (2006) found that magnocellular tasks did not significantly discriminate dyslexic from control children; only two out of 23 dyslexic children showed deficits in visual motion while three out of 22 control children showed deficits in visual motion. Thus while it remains a possibility that a minority of dyslexics have deficits in magnocellular functioning, the evidence for the magnocellular theory of dyslexia is not convincing (Skottun, 2005).

However, deficits in the magnocellular visual system have also been suggested as the cause of visual stress. For example, Lovegrove and his colleagues (Lovegrove, 1991; Lovegrove et al., 1986; Lovegrove et al., 1990) hypothesized that an abnormality in the magnocellular subsystem causes visual stress by diminishing the inhibition of the parvocellular system after each saccade and thus the capacity to erase the previous visual image. While this might account for some of the symptoms experienced in visual stress (e.g. blurring of text, illusions of movement and eye strain) it is not clear how magno deficits could cause illusions of colour, not how coloured overlays might work as a treatment. Nevertheless, Lovegrove’s hypothesis has a number of supporters (e.g. Chase et al., 2003; Cornelissen et al., 1994; Livingstone et al., 1991; Robinson and Foreman, 1999).

**Threshold shift theory**

The evidence reviewed in this chapter so far suggests that dyslexia and visual stress are probably quite different conditions. The magnocellular deficit theory (Stein, 2001) proposes a causal link between dyslexia and visual stress mediated by the visual system but, as we have seen in the previous section, this theory is undermined by conflicting evidence on impairment in visual motion processing amongst dyslexics and by probable misunderstanding of the inhibitory
mechanisms in saccadic eye movements. Against this, a more convincing explanation is provided by the theory that visual stress is due to hyperactivation in the visual cortex caused by contrast or pattern glare (Wilkins, 1995, 2003). As far as dyslexia is concerned, the greatest weight of evidence is consistent with the phonological deficit theory (Farmer and Klein, 1995; Ramus, 2001; Ramus et al., 2003; Snowling, 2000; Vellutino et al., 2004; White et al., 2006).

According to the phonological deficit view, the problems of the dyslexic arise not because of difficulties in visual processing but because of difficulties in mapping graphemic representations (letters and words) on to phonological representations (sounds) and in holding phonological information in working memory.

However, if we accept that dyslexia and visual stress are different conditions, an explanation still has to be found for the increased prevalence of visual stress amongst dyslexics compared with the general population. Singleton (2008b) has suggested that the link between dyslexia and visual stress may not necessarily be causal. Visual stress discourages inclination to practice reading, which will create a ‘Matthew effect’ (Stanovich, 1986), i.e. the gap between good and poor readers will progressively widen as a function of differences in reading experience. It is likely that the dyslexic person’s lack of automaticity in word recognition (e.g. due to underlying deficits in phonology or memory) forces them to adopt techniques for processing text (e.g. detailed scrutiny of individual ‘problem’ words) that increase their sensitivity to the physical characteristics of the print. In turn, this will naturally tend to make symptoms or effects of visual stress worse.

Susceptibility to visual stress varies from person to person: the majority of the population is only mildly susceptible (i.e. they have a high threshold), but nevertheless most people will experience visual stress under certain conditions, e.g. when viewing a particular visual pattern or seeing flashing lights. At the extreme end of the spectrum, individuals who suffer from photosensitive epilepsy or from migraine tend to be highly susceptible to visual stress (i.e. they have a low threshold). Singleton (2008b) has hypothesized that there is a continuum of physiological excitation (sensitivity) to visually stressful stimuli from low sensitivity to high sensitivity, which may be assumed (for the time being, at least) to be approximately normally distributed. All individuals will lie at a point somewhere on this continuum of physiological sensitivity as a consequence of genetically determined cortico-visual functioning. This point is their physiological threshold for visual stress. Individuals who suffer from migraine or photosensitive epilepsy will be near to the upper (high sensitive) end of this distribution and hence will have a low threshold. Singleton also posits another point on the continuum of physiological sensitivity that constitutes a clinical threshold for visual stress, i.e. a point above which individuals find that symptoms of visual stress interfere significantly and substantially with everyday functioning such that aversive action to mitigate symptoms is called for. For any given individual, there will be a difference (on the continuum of physiological sensitivity) between their physiological threshold for visual stress and their clinical threshold for visual stress. This difference is the amount to which the threshold for visual stress has been shifted as a result of non-physiological factors. It is anticipated that in almost every person the clinical threshold will be lower than the physiological threshold, because various factors will tend to increase sensitivity. The degree of threshold shift will be determined by the following factors:

1. **Cognitive factors** (e.g. dyslexia, reading problems; working memory) The greater the difficulty in decoding text and in holding the information in working memory while deriving meaning, the greater the sensitivity and lower the threshold.
2. **Demand factors** (e.g. demands created by education or employment circumstances) The greater the amount of reading the person has to do and the higher the cognitive load placed
on the person by that reading, the greater the sensitivity and lower the threshold.

3 **Ophthalmic and orthoptic factors** (e.g. amblyopia, astigmatism, diplopia, hypermetropia, nystagmus, detached retina, cataracts) The presence and severity of these visual problems will tend to increase sensitivity and lower the threshold.

4 **Optical factors** (e.g. lighting conditions, font type and size, line spacing, contrast, glare, flicker) The more that these factors diverge from the ideal, the greater the sensitivity and lower the threshold.

5 **Subjective factors** (e.g. personal tolerance of discomfort).

This theory of the relationship between dyslexia and visual stress can be called **threshold shift**. In a nutshell, this view is that dyslexia tends to increase a person’s susceptibility to visual stress, because the effect of dyslexia is to shift the threshold for visual stress from higher to lower. The threshold shift theory is consistent with much of the current evidence on visual stress. It predicts that visual stress will be more prevalent in dyslexics and in other poor readers than in the rest of the population, which has been shown in many studies (e.g. Kriss and Evans, 2005; Singleton and Henderson, 2007b; White et al., 2006). Connah (2008) tested undergraduate students with dyslexia using ViSS (Singleton and Henderson, 2007c) and found that the average increase in visual search time for this group on visually stressful items compared to that on non- visually stressful items was 33 per cent; the corresponding figure for non-dyslexic controls was 11 per cent.

The threshold shift theory also predicts that the more severe the reading/dyslexic difficulties, the greater the sensitivity to visual stress and the lower the threshold. This prediction has some support, Connah (2008), for example has found that severity of dyslexia accounts for a significant proportion (11 per cent) of the variance in severity of visual stress. The threshold shift theory also predicts that in situations where intensive reading is called for (e.g. at university), visual stress will be more prevalent. Evans and Joseph (2002) studied 113 unselected university students and found that 89 per cent reported beneficial perceptual effects of a chosen coloured overlay and these students read significantly faster with an overlay than without it. Eighty-one of the students experienced headaches, of which 44 per cent said they were associated with reading. These figures are higher than in studies of school children. In addition, the threshold shift theory predicts that people with ophthalmic and orthoptic problems are more likely to display symptoms of visual stress, which has been reported (Evans, 2001; Garzia and Nicholson, 1990).

Optical factors have also been found to influence susceptibility to visual stress. Hughes and Wilkins (2000) not only found that children’s reading speed is a function of font size and characteristics of the text, but those children who were susceptible to visual stress were disproportionately affected by font size and text characteristics. Wilkins (2002) has observed that the levels of illumination often found in classrooms is up to four times that recommended by European standards, with the result that contrast is increased and children become more vulnerable to visual stress.

A further prediction of the threshold shift theory is that the distribution of reported symptoms of visual stress in unselected samples would not be normal, but would be positively skewed (i.e. an elongated right tail with mode<median<mean) because the non-physiological factors listed above will shift the threshold and extend the number of cases in the right (higher) tail of the distribution. There is some evidence for this: Singleton and Trotter (2005) and Singleton and Henderson (in preparation) found that the distribution of reported symptoms of visual stress in unselected samples [number of symptoms X severity of symptoms] has a positive skew. However, the threshold shift theory raises some unanswered questions. For example, we do not
know whether the use of coloured tints (a) *lowers the physiological threshold* making the person less sensitive and less likely to experience symptoms of visual stress, or (b) *lowers the clinical threshold*, thus reducing threshold shift and bringing the clinical threshold closer to the physiological threshold, or (c) a combination of these two effects.

**Identifying visual stress**

The techniques most commonly used for identifying visual stress rely either on the person reporting symptoms of visual stress or on them making a judgement that text is easier to read with a certain colour rather than another. Both these approaches carry the disadvantage of subjectivity, which, in turn, can result in unreliability of the measures.

The use of symptom questionnaires (e.g. Irlen, 1991; Conlon and Hine, 2000) has more justification when assessing adults (Evans and Joseph, 2002; Singleton and Trotter, 2005) than when assessing children, who can be suggestible and/or unreliable in their reports of symptoms (Northway, 2003). Children who suffer from the condition do not necessarily know they have a problem, and if they do report symptoms these may not always be accurate. Many adults who suffer from visual stress fail to appreciate why they find reading so tiring, or notice particular symptoms, and may not realise that this problem affects their work efficiency.

Assessment of whether colour makes reading more comfortable may be carried out using either overlay screening or an *Intuitive Colorimeter*, which is an apparatus in which the optimal colour of illumination for reading can be determined from the whole colour range (Wilkins et al., 1992). In overlay screening, which is the most widely-used method to identify visual stress (Tyrrell et al., 1995; Wilkins, 1995; Wilkins et al., 2001), pairs of overlays from a set of about 10–12 are successively compared in order to determine the colour (or, if necessary, combination of colours) that is perceived to be most comfortable for reading. The number of colours is therefore restricted to probably fewer than 30, compared with the full range in the case of the colorimeter. However, whichever tool is used, the main snag with this approach is that – given the choice – most children, as well as adults, will select a colour, even though many of them don’t really need it. Furthermore, while colour is an effective treatment for most people with visual stress, it does not work for all (Evans and Joseph, 2002; Singleton and Trotter, 2005), so not everyone with visual stress will be detected in an overlay screening. Wilkins et al. (2001) found that of a normal sample of children aged 8–11 years, 60 per cent chose an overlay. Using a slightly wider age range (5–11 years) Jeanes et al. (1997) found that 53 per cent of children chose an overlay. Evans and Joseph (2002) found that 88 per cent of an unselected sample of university students chose an overlay. In most studies, however, after two to eight months, voluntary sustained use is generally found to have dropped to between 20–30 per cent. For an adult that may not be of great concern – we can safely assume that if they stop using an overlay then that is probably because they don’t feel any real benefit –although if tinted lenses have been prescribed and then just left in a drawer this is a significant waste of money. But where children are concerned, parents and teachers don’t know if the child has just forgotten to use the glasses or the overlay, or is just being lazy, or whether they simply don’t need them after all.

In order to ascertain the impact of a coloured overlay or tinted lenses Wilkins devised the *Rate of Reading Test* (Wilkins et al., 1996), which can be administered to check that a chosen overlay makes a discernible difference to reading speed. This test requires speeded oral reading of a short passage of text comprising 15 high frequency words (which are familiar to children from 7 years) that are repeated in random order. The test is administered first with an overlay placed over the text, two times without an overlay and finally with an overlay again, to test for...
an immediate benefit in rate of reading with an overlay. This test reveals that improvements in reading speed are not seen in all those who choose an overlay. Wilkins et al. (1996) found that of an unselected sample of 77 children aged 8–11 years, 49 per cent selected an overlay and 20 per cent were more than 5 per cent faster on the rate of reading test with their chosen overlay than without it. In the Wilkins et al. (2001) study, 36 per cent read more than 5 per cent faster with their chosen overlay than without it, and in the Evans and Joseph (2002) study of adults, 34 per cent read more than 5 per cent faster with their chosen overlay than without it. But, as we have seen earlier, by no means all these individuals persist in using an overlay – suggesting that their difficulties were not sufficiently serious to merit treatment – so how is the effectiveness of this approach to be evaluated? One method is to calculate the sensitivity and specificity of the 5 per cent criterion for these various studies, as Kriss and Evans (2005) have done. Sensitivity can be calculated as the percentage of the sample who chose an overlay and continued to use it and who had initially showed an improvement of >5 per cent in rate of reading with an overlay. Specificity can be calculated as the percentage of the sample who either did not choose an overlay or did not continue to use it, and who had not showed an improvement of >5 per cent in rate of reading with an overlay. In the Wilkins et al. (1996) study, sensitivity was 73 per cent and specificity 90 per cent, and in the Wilkins et al. (2001) study the figures were 68 per cent and 79 per cent, respectively.

Another way of representing those data is in terms of classification errors. False positives are errors of classification where individuals who have been judged to have visual stress (on the basis of overlay screening and rate of reading test) but who did not turn out to have the condition (on the basis of overlay screening and rate of reading test) but who actually turned out to have the condition (on the basis of sustained voluntary use). False negatives are errors of classification where individuals who have been judged not to have visual stress (on the basis of overlay screening and rate of reading test) but who actually turned out to have the condition (on the basis of sustained voluntary use). In the studies quoted above, the average incidence of false positives was 16 per cent and of false negatives was 30 per cent. Although the 16 per cent false positive rate is within commonly accepted limits, the 30 per cent clearly is not (see Glascoe and Byrne, 1993; Grimes and Shultz, 2002; Kingslake, 1982; Potton, 1983; Singleton, 1997). In fact, the use of the criterion of ‘greater than 5 per cent increase in reading speed with an overlay’ for diagnosis of visual stress is limited in applicability because of interaction with reading accuracy, as Singleton and Henderson (2007a) have shown. Children with average or above average reading accuracy often show increases of less than 5 per cent with an overlay despite suffering from visual stress. Of course, the criterion percentage of increase in reading rate with an overlay could be altered, which would have the effect of reducing one type of classification error, but only at the expense of increasing the other (Bland, 1999; Singleton, 1997). In summary, overlay screening can result in unacceptably large numbers of false positives and false negatives.

There are other unsatisfactory aspects of this general approach. One of the problems with the Rate of Reading Test is that it only evaluates the impact of an overlay on reading speed over a short time, which may well be why it doesn’t always predict overlay usage in the long term very well. None of these techniques establishes objectively that the person definitely has visual stress and therefore needs an overlay or other treatment. One could, of course, give a person an overlay and wait and see. If they continue to use it over the long term it is probably safe to conclude that they suffer from visual stress. But if they stop using it, and the individual in question is a child, then the conclusion may not be so sure. And as a technique for identifying visual stress, ‘waiting to see’ is clearly a non-starter because of the unacceptably long delay in knowing the result.

In order to ensure that children and adults who need overlays or tinted lenses are identified promptly, objective evidence is required on whether the person actually suffers from visual stress
or not. To this end, Singleton and Henderson (2007a, 2007b) researched an objective method of screening for visual stress based on visual search. There is evidence that individuals with visual stress are impaired by visually stressful stimuli during visual search (Conlon et al., 1998; Conlon and Hine, 2000; Tyrell et al., 1995). In the task devised by Singleton and Henderson, individuals were required to locate a randomly generated three-letter word in a matrix of distractor three-letter words presented on a computer screen. The background on which the matrix is superimposed is either visually unstressful (grey) or visually stressful (alternating black/white horizontal stripes of equal duty cycle). In various studies, with children from age 7 upwards and adults, Singleton and Henderson (2007a) found that if there is a significant difference between search times in the visually unstressful and visually stressful conditions, this is a strong predictor of visual stress. Using this method, called ViSS (Visual Stress Screener), to screen unselected samples of children aged 7–17 years, it was found that children classified as having high susceptibility to visual stress had significantly larger increases in reading rate with a coloured overlay compared with those classified by ViSS as having low susceptibility to visual stress. Individuals classified by ViSS as having susceptibility high visual stress also reported more symptoms, although there were indications that reports of symptoms were less reliable in the younger age group. Subsequent studies showed that ViSS also had the same predictive value when used with adults (Singleton and Henderson, 2007c). The objectivity of ViSS not only makes it more accurate than other methods currently available, but Singleton and Henderson (2007b) also showed that the program is equally capable of identifying susceptibility to visual stress in children with dyslexia, because it is not significantly influenced by reading ability. In this study, visually stressful stimuli were found to cause significantly more disruption of visual search in the dyslexic sample than in the control sample, but on visually unstressful stimuli there were no differences between the groups. This not only demonstrates the effectiveness of ViSS for objective screening for visual stress in dyslexic as well as non-dyslexic children, but also indicates that ViSS is not simply measuring other cognitive abilities, such as memory or attention, which are clearly required for visual search but which may also be deficient in dyslexia.

Treatment of visual stress

The symptoms of visual stress can be alleviated by various techniques, including enlargement of print or use of a typoscope, which is a reading mask that covers the lines of text above and below the lines being read, thus reducing pattern glare (Hughes and Wilkins, 2000). However, the most widely used treatment is that of coloured tints, either in the form of acetate overlays or tinted lenses (Wilkins, 2003). Irlen was the first to use this technique systematically, but until the 1990s members of the medical, psychological and educational professions remained sceptical. Following the landmark studies of visual stress in the 1990s by Wilkins and colleagues, using rigorous double-masked randomised placebo-controlled trials (Wilkins et al., 1994; Evans et al., 1994, 1996), it is now generally accepted that coloured tints can reduce symptoms of visual stress and improve reading speed, fluency, accuracy and comprehension. Accurate specification for optimal tints for lenses (‘precision tints’) can be determined using the Intuitive Colorimeter (Wilkins et al., 1992). Precision tinted lenses are usually found to afford the greatest benefits because they are easier to use (e.g. with white boards and when writing) and because the colour can be precisely prescribed from the full range of possible colours. Alternative systems offering limited ranges of tints (e.g. Chromagen and Harris filters) are used by some optometrists, but the effectiveness of these in comparison with precision tints has yet to be properly determined and they have been criticized by Wilkins (2003).
Precision tinted filters have also been shown to reduce headaches in patients who suffer from migraine. About 40 per cent of patients with migraine report that headaches are triggered by visual stimuli (Hay et al., 1994). Wilkins et al. (2002) found that the frequency of migraine headaches was reduced 50 per cent on days when patients wore precision tinted lenses compared with days when they wore other lenses that were similar but not their optimal tint. This finding is consistent with the hypothesis that coloured filters are beneficial because they reduce cortical hyperexcitability (Wilkins, 1995, 2003).

Many studies have demonstrated the benefits of coloured overlays, including symptom reduction, gains in rate of reading (Bouldoukian et al., 2002; Jeanes et al., 1997; Whiteley and Smith, 2001; Wilkins and Lewis, 1999) and improvements in reading accuracy and comprehension (Robinson and Foreman, 1999). In a study of children aged 8–16, Tyrrell et al. (1995) found that differences between reading with and without a chosen overlay began to emerge after about 10 minutes in book reading. After this point, children who suffered from visual stress started to tire and experience unpleasant symptoms such as eyestrain when not using their chosen coloured overlay. But when using the overlay these children were able to continue reading unaffected. Those children who did not suffer from visual stress did not slow down or experience unpleasant symptoms, and using an overlay made no difference to their reading.

In a study of 426 children aged 6–8 years in 12 schools, Wilkins et al. (2001) found that initially 60 per cent of the children selected an overlay and after 8 months, 31 per cent of the children were still using their overlays. The average gain in reading speed of those using regularly overlays was 13.3 per cent compared with 2.5 per cent of the rest of the children. Although children who did choose overlays reported significantly more symptoms of visual stress than those who did not choose overlays, there was no significant difference in the frequency or type of symptoms reported by those who continue to use overlays compared with those who ceased to use overlays. This latter point underlines the need for objective methods of identifying visual stress (such as ViSS) as opposed to relying just on subjective methods such as overlay screening, as it is not clear whether those who ceased using overlays should have been encouraged to continue in their use.

Coloured overlays are normally supplied in A4 size, but these can be cut down if required. Recently, however, a range of inexpensive small overlays called Reading Rulers [www.crossboweducation.com] has been introduced which are proving popular in schools. These are about the width of an A4 page but only 60 mm high, with a black horizontal stripe across the middle to assist keeping on the line of text. Reading rulers have the advantage that they are conveniently sized and will fit easily into a pocket or pencil case, or can be kept in the pages of a book as a bookmark. They are more discreet than whole sheets of coloured acetate and hence may be more acceptable to older children and adults who might be embarrassed about using larger sheets of acetate. Smith and Wilkins (2007) compared Reading Rulers with conventional overlays and found that children with visual stress did not show any significant increase in reading speed using Reading Rulers whereas using the conventional overlays they did. This effect was not due to the smaller size of the Reading Rulers but, rather, to the limited range of colours in the set which dramatically reduced the chances of coming close to the optimal tint for any given child. As a direct result of this research, the range of colours available in Reading Rulers has now been increased from five to ten, which should address this particular problem although unlike conventional overlays, Reading Rulers are only for use singly and are not suitable for use in combination. However, there remain concerns about the way in which Reading Rulers may be used in the classroom, as children are often permitted to select colours by idiosyncratic preference on a day-by-day basis rather than by systematic pair-wise comparison in a screening situation so that the teacher can ensure that the most effective colour is
being used by the child. There is a real danger that if, by chance, children choose a colour that is not effective for them, they may decide that colour, *per se*, does not help their reading when they have not had a proper opportunity to determine the most effective colour.

Unfortunately, few controlled studies of use of coloured filters or overlays have been carried out with adults. Robinson and Conway (2000) reported positive benefits of coloured filters in a small-scale study of adults, and Evans and Joseph (2002) studied 113 university students of whom 100 chose an overlay as improving their perception of text. These students were significantly more likely to report visual stress symptoms than those who did not choose an overlay, and they read 3.8 per cent faster with their chosen overlay than without it. This gain seems much lower than that typically found in comparable studies with children. Again, objective assessment would have helped to clarify whether those that chose an overlay really suffered from visual stress; some of these university students may have heard or read that coloured overlays improve reading and this may have affected their subjective judgement.

Singleton and Trotter (2005) compared university students who reported high frequency and intensity of visual stress symptoms with those who did not report visual stress symptoms. These participants were selected so that half of the group had dyslexia and the other half had no literacy difficulties. It was found that only the dyslexic students with high visual stress significantly improved reading rate with an overlay (average improvement of 16 per cent); the dyslexic without visual stress showed a non-significant 3 per cent gain and both groups of non-dyslexic participants (high visual stress and no visual stress) had non-significant gains of 4 per cent. Although all groups had similar reading accuracy scores, the non-dyslexic students read significantly faster than the dyslexic students in all conditions. It is notable that the average reading speed of the dyslexic high visual stress group in the optimal colour condition was essentially the same as that of the dyslexic low visual stress group when reading without colour. Thus while the benefits of colour were not sufficient to raise their reading speed to similar levels as those shown in the non-dyslexic group, nevertheless, effectively, it did bring them up to the same level as other dyslexic students who do not suffer from visual stress.

In the Singleton and Trotter (2005) study, the failure to find a significant improvement in reading speed in the non-dyslexic high visual stress group when using an overlay should not be over-interpreted. Compared to the Evans and Joseph (2002) study, this was a small-scale experiment with a high-ability adult sample, specifically designed to examine the effects of visual stress in combination with dyslexia. In addition, classification of susceptibility to visual stress was based on reported symptoms rather than any objective method. However, it should be noted that although coloured tints are usually beneficial, this is not the case for everyone who displays symptoms of visual stress. In the Evans and Joseph study, 32 per cent of participants did not read any faster with their chosen overlay than without it, and only one-third of their sample demonstrated a significant benefit of overlays, despite 88 per cent of the sample having chosen overlays. It is also clear from the Evans and Joseph study that many adults benefit from using coloured overlays when reading, despite not reporting any symptoms of visual stress. In small-scale studies such individual differences in response can mask general trends.

People who suffer from visual stress often find that reading or writing on a computer can be visually irritating, leading to headaches and eyestrain. When children or adults are writing using a word processor, they should be encouraged to work in a font size, viewing size and colour that they find most comfortable. There are now several programs available that address this problem and which make using computers less tiring. These products enable an easy choice of colours, fonts, size and spacing to be made (see Singleton, 2008a for further discussion).
Conclusions

The results of the Singleton and Trotter (2005) study suggest that identifying visual stress on the basis of a person’s choice of a coloured overlay (and possible improvements in reading speed when using the overlay) is likely to be unreliable. Similar conclusions can be drawn from the study by Singleton and Henderson (2007a). Objective determination of susceptibility to visual stress would seem to be much more satisfactory (Singleton, 2008b). Unlike the studies by Singleton and Trotter (2005) and Singleton and Henderson (2007b), previous studies of visual stress have not distinguished between participants who have, or do not have, dyslexia. In the light of recent findings, this would seem to be a methodological oversight that may have clouded our understanding of visual stress. We now know that considerably more dyslexics than non-dyslexics suffer from visual stress, and thus it is possible that the presence of (undetected) dyslexics in participant samples in visual stress studies may have contributed disproportionately to the reported effects.

Several important educational conclusions can be drawn from recent research on visual processes in reading (Cornelissen and Singleton, 2007; Singleton, 2008b; Singleton and Henderson, 2006). The efficient organisation of the various components involved in reading – including eye movements, word recognition, working memory, and comprehension – develop and become integrated as an efficient system as a result of the experience of learning to read. This underlines the educational requirement for adequate and appropriate practice in text reading in order to discipline eye movements, attain fluency in decoding and provide a firm basis for competent reading comprehension. Visual factors, such as visual stress, that disrupt the reading process will have detrimental effects on the development of fluency and comprehension. Where individuals also have dyslexia as well as suffering from visual stress there is likely to be a multiplicative detrimental effect on reading. The threshold shift theory (Singleton, 2008b) maintains that, for dyslexics, as a combined result of lack of reading experience and the reading style that they are forced to adopt, the sensitivity threshold for visual stress is shifted, making them more sensitive to the physical characteristics of text (such as contrast, glare, stripedness and font size) and increasing their risk of experiencing the unpleasant symptoms of visual stress. Hence there is a strong case for screening for visual stress in all children, but especially in those who are already known to have dyslexia, since not only is their risk of visual stress much greater than that found in other individuals but, also, if they do suffer from visual stress, the repercussions of remaining untreated are likely to be of much greater educational significance. The availability of objective computer-based screening using VISS [www.visual-stress.com] now makes reliable identification of visual stress in schools a realistic proposition, and the availability of a variety of efficacious treatments using coloured tints provides cost-effective solutions that are easy to use in the classroom and at home.

References


Dyslexia: A handbook for teachers, parents, and professionals

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Stein, J.F. and Walsh, V. (1997) To see but not to read; the magnocellular theory of dyslexia. *Trends in Neuroscience*, 20, 147–152.


