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Visual stress in adults with and without dyslexia

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The relationship between dyslexia and visual stress (sometimes known as Meares-Irlen syndrome) is uncertain. While some theorists have hypothesised an aetiological link between the two conditions, mediated by the magnocellular visual system, at the present time the predominant theories of dyslexia and visual stress see them as distinct, unrelated conditions, a view that has received some support from studies with children. Studies of visual stress in adults are rare, yet recent reports of a high incidence of this phenomenon amongst university students with diagnosed dyslexia call for further investigation of the issue. This study sought to clarify the relationship between visual stress and dyslexia by comparing the reading performance of dyslexic and non-dyslexic adults with, and without, colour. Degree of susceptibility to visual stress was determined by means of a symptom rating scale. Optimal colour was determined using an Intuitive Colorimeter, which was also employed to assess reading speed under the two experimental conditions. Only the dyslexic students with high visual stress showed significant gains in reading speed when using optimal colour. The use of response to treatment (rather than symptomatology) as a diagnostic criterion for visual stress is questioned, especially when applied to adults, as this may give misleading findings. On the basis of reported symptomatology, students who experience high levels of visual stress are more likely to show improvements in reading rate with optimal colour if they also have dyslexia than if they do not have dyslexia. Although not establishing an aetiological link, these findings imply an interaction between the two conditions with major implications for theory, diagnosis and treatment.

The view that visual factors are involved in dyslexia has a long and controversial history. The current predominant theory – which is so well supported that it could be said to have acquired the status of orthodoxy – is that dyslexia is caused by a genetically-based anomaly in neurological systems sub-serving phonological processing (see Ramus, 2001, 2003; Snowling, 2000; Stanovich, 2000; Vellutino, Fletcher, Snowling & Scanlon, 2004). Since the 1970s, steadily accumulating evidence has enabled the phonological theory to eclipse other theories, many of which saw dyslexia as a deficit in visual processing of some kind. In his comprehensive landmark analysis, Vellutino (1979) observed: ‘Taken together, the impressions derived from the studies attempting both direct and indirect tests of perceptual deficit explanations of reading disability lead to the conclusion that the evidence in support of such explanations is uniformly weak’ (pp. 183–184). Vellutino’s conclusion marked the demise of a variety of classic theories of dyslexia that assumed a fundamental visual-perceptual dysfunction, stretching back to the pioneers Morgan (1896) and Hinshelwood (1917) – both of whom adopted Kussmaul's (1877) term 'word blindness' as a label for the condition – and including luminaries such as Orton (1925, 1937), Bender (1956) and Frostig and Maslow (1973).

A significant shortcoming of early visual-perceptual theories of dyslexia was that remediation addressing the hypothesised root of the problem – visual-perceptual dysfunction – by means of activities such as visual discrimination training and visual-motor practice, was found to have little benefit in comparison with approaches that tackled the dyslexic reading difficulties more directly (see Hammill, Goodman & Wiederholt, 1974; Hartman & Hartman, 1973). However, during the 1980s and 1990s an alternative remediation for visually-based reading problems began to gain currency. Observations by Meares (1980) and Irlen (1983), that the use of coloured acetate overlays and filters can help a large proportion of children and adults who experience symptoms of eye strain and visual perceptual distortions when reading, gave rise to a new syndrome in the literature. Often called 'Meares-Irlen syndrome', this condition has also been known by several other labels (e.g. 'visual discomfort'; 'scotopic sensitivity syndrome'), and for simplicity and consistency it will be referred to here as 'visual stress'.[1] Conlon (Conlon et al., 1998, 1999) has noted the clustering of somatic symptoms (such as sore, tired eyes and eye-strain) and perceptual effects (such as illusions of colour, shape and motion) in some individuals when exposed to bright or flickering light and/or grating patterns (such as may be created by lines of text on a page). Conlon (2000) argues that this symptom cluster, which she calls 'visual discomfort', can be a cause of reading problems. This observation was made earlier by Irlen (1991), who claimed that 12% of the general population experiences these symptoms, but in people with dyslexia the incidence is 65%, suggesting a strong relationship. In a later article, Irlen (1997) stated that 12–14% of the general population suffer from visual stress, a figure that rises to 46% of those diagnosed with dyslexia, attention deficit disorder and other specific learning difficulties. Despite these claims, the exact nature of the relationship between visual stress and dyslexia still remains unclear.

A possible theoretical explanation for the beneficial effects of colour in cases of visual stress began to emerge when a number of studies reported evidence of impairment in the magnocellular visual system in people with dyslexia (e.g. Cornelissen et al., 1994; Livingstone et al., 1991; Lovegrove, 1991; Lovegrove, Martin & Slaghuis, 1986). The magnocellular (transient) visual system comprises a fast pathway that processes rapid changes in the visual scene, while its counterpart – the parvocellular (sustained) system – is a slower pathway responsible for more detailed, stable visual perception. In normal vision, the two systems work in parallel in a co-ordinated fashion to facilitate detailed visual perception under conditions of almost constant eye movement that continually alters the image on the retina. If one part of the system is dysfunctional it is not unreasonable to anticipate problems in smooth and efficient processing of text. The magnocellular impairment in cases of dyslexia is slight, not found in all dyslexics, and has been disputed (see Scheiman, 1994; Skotton, 2000; Stein, Talcott & Walsh, 2000). Nevertheless, these findings suggested a convenient model for linking dyslexia with anomalies of eye movement control (see Evans, Drasdo & Richards, 1996; Stein, 2001; Stein & Talcott, 1999; Stein & Walsh, 1997) and hence many researchers have gone further by suggesting that visual stress could be encompassed within this theoretical framework (e.g. Irlen, 1994; Lehmkule, 1993; Livingstone et al., 1991; Sloman, Cho & Dain, 1991; Sloman et al., 1995; Williams, Lecluyse & Rock-Faucheux, 1992). Although the precise mechanisms involved have yet to be elucidated, the magnocellular system remains one of the prime candidates to explain how coloured filters and overlays might affect the reading process (Chase et al., 2003; Edwards et al., 1996; Irlen, 1997; Robinson & Foreman, 1999).

However, until the 1990s, when Wilkins and his colleagues (Evans et al., 1995, 1996; Wilkins et al., 1994) began to investigate visual stress using placebo-controlled studies, both the existence of the syndrome and the credibility of treatment using coloured filters were still regarded with suspicion by members of the medical and educational professions. The lack of a convincing theoretical explanation for the purported benefits of colour further hardened scientific and professional scepticism (see Evans, 1997a; Evans & Drasdo, 1991). The work of Wilkins and his colleagues not only provided scientific evidence for the therapeutic effect of coloured filters but also established an alternative theoretical basis for understanding visual stress (for reviews see Evans, 2001; Wilkins, 1995, 2003). According to this view, the symptoms of visual stress are attributable to cortical hyper-excitability caused by pattern glare. Visual grating patterns that can evoke seizures in people with photosensitive epilepsy and trigger migraine headaches can also produce perceptual distortions in normal individuals (Wilkins, 1995). The visual grating created by moving the eyes across lines of print, especially where the pattern is glaring (i.e. lines of dark black text on a bright white page), could generate similar physiological effects. Associations have also been reported in migraineurs between the location of headaches (left or right hemisphere), visual aura preceding headaches (left or right visual field) and the location of perceptual distortions (Wilkins et al., 1984). Maclachan, Yale and Wilkins (1993) found that children who find colour helpful are twice as likely to have migraine in the family as those who show no benefit. Wilkins (1995, 2003) speculates that since the wavelength of light is known to affect neuronal sensitivity (Zeki, 1983) the use of colour could reduce over-excitation, thus reducing perceptual distortions and headaches when reading.

Wilkins (2003) dismisses the competing theory, which holds that visual stress is attributable to deficits in the magnocellular system. First, he points out that this theory is presently unable to account for the large individual differences in colour optimal for reading. Second, he argues that earlier beliefs that visual stress was associated with dyslexia have become doubtful, since just as many individuals who do not have dyslexia have been found to benefit from colour as those who do have dyslexia. Third, children with visual stress show normal flicker perception (Evans, Drasdo & Richards, 1996). Fourth, visual stress sufferers who regularly use coloured lenses have not been found to have deficiencies in visual-motor tasks believed to be sub-served by the magnocellular system (Simmers et al., 2001). A study by Evans et al. (1995) also failed to find convincing evidence that transient system activity (as measured by eye-movement control) was a credible explanation for reported benefits of colour. However, current knowledge does not enable us to rule out with any confidence the possibility of a relationship between magnocellular deficits and pattern glare/cortical hyperexcitability (see Evans, 2001).

One major implication of Wilkins' cortical hyper-excitability theory is that visual stress is regarded as independent of dyslexia, even though in some individuals the two conditions may be seen to have symptoms in common. Wilkins (2003) concludes that a diagnosis of dyslexia does not make it more likely that reading will be improved by use of coloured filters. The evidence for this comes chiefly from a study by Grounds and Wilkins (cited in Wilkins, 2003), in which four different groups were compared: children with dyslexia, a chronological-age matched group without dyslexia, a group of younger children matched on reading-age group to the dyslexic group and a group of children of low general ability who were similar chronological age and reading age to the dyslexic group. No difference was found between these four groups with respect to the proportion who benefited from overlays. However, Kriss and Evans (2005) found the incidence of visual stress was somewhat higher (37.5%) in children with dyslexia than in children with normal reading (25%). Arguably, the problem centres largely on how visual stress is defined and measured, an important issue that will be returned to later in this article.

Most studies of visual stress have focused on children; few have examined this phenomenon in adults. Robinson and Conway (2000) reported on a small-scale study that found benefits of Irlen filters in adults who experienced visual stress. Evans and Joseph (2002) carried out a more extensive study with 113 unselected university students who were assessed using Intuitive Overlays (I.O.O Marketing, London). The Intuitive Overlays assessment pack includes nine different-coloured acetate overlays plus one grey overlay. These are employed successively, in pairs, with the person being assessed required to judge which of each pair is more comfortable for reading text when viewed through the overlays, until a clear preference emerges (or, in some cases, no preference). For further details, see Wilkins (2003). Since there are no standard criteria for classifying visual stress, it is not possible to give an overall incidence figure for Evans and Joseph's sample. However, the following data give an impression. Some visual perceptual distortions of text were found to be much more common than others: 24% blurring; 16% doubling; 12% jumping; 6% changing size; 3.5% fading or disappearing. Other reported symptoms included: sore or tired eyes when reading (13% moderately; 4% often); frequently rubbing eyes 20%; skips, re-reads or omits words or lines 35%. Among the 81 students who experienced headaches, 44% reported that these were associated to some degree with reading. However, Evans and Joseph (2002) note that their study did not include an optometric eye examination and therefore some of their participants' symptoms might be attributable to conventional optometric factors such as refractive errors or orthoptic anomalies.

Evans and Joseph (2002) found that in the Intuitive Overlay assessment, 100 (88%) of their total sample were able to choose a coloured overlay that had an immediately positive effect on their perception of text. In the *Rate of Reading Test*, 68% of these students read faster with their chosen overlay than without it. The overall change in reading speed for the group was only 3.8%, but nevertheless this was still highly significant, and there was considerable individual variation. Two of the students read more than 25% faster with the overlay. When the 13 students who did not choose an overlay were administered the *Rate of Reading Test* using the control overlay (grey), only 38.5% read faster with the overlay than without and over this group as a whole the difference in rate of reading for the two conditions was not significant. Using the criterion advocated by Wilkins et al. (1996) – i.e. more than 5% improvement in rate of reading – Evans and Joseph concluded that more than one-third of the sample showed significant benefits when using coloured overlays. However, the sample used in Evans and Joseph's study might not be regarded as entirely representative because two-fifths of the students had experienced difficulties of some kind at school, most commonly with reading, writing, spelling and/or maths. This might have inflated the number of those who benefited from the overlays, although it should be noted that only two of the 113 had diagnosed dyslexia, an incidence which is a little lower than expected but not outside the range found in universities (see Singleton, 1999). Additionally, 36% did not have English as their first language (although all spoke fluent English).

The results of the study by Evans and Joseph suggest that the prevalence of visual stress in the adult population is similar to that reported in children. Jeanes et al. (1997) found that 53% of a normal sample of 152 primary school children (5–11 years) reported beneficial perceptual effects when using overlays, and three months later more than half of these children (36% of the sample) were still using them (these were mostly the children with relatively poor reading). Ten months later the proportion of children still using the overlays had dropped to 24%. In other words, at least 20% of children may be expected to show long-term benefits of use of coloured overlays. Wilkins et al. (2001) found that out of an unselected sample of 77 children aged 8–11 years, 60% chose an overlay and 31% of all the children in the study were still using it voluntarily after eight months. In a double-blind placebo-controlled study, Robinson and Foreman (1999) examined the effects of using coloured filters on reading speed, accuracy and comprehension with a sample of 113 children with reading difficulties. Over a 20-month period the treatment groups made significantly greater gains in reading accuracy and comprehension, but not speed. The authors suggested that coloured filters can reduce the distracting effect of perceptual distortions allowing greater attention to be given to processing text, rather than concentrating on individual words. However, why this failed to produce an increase in reading speed (which is generally found in other studies) is difficult to explain.

The present study sought to clarify the relationship between visual stress and dyslexia by comparing the reading performance of dyslexic and non-dyslexic adults with, and without, colour. In order to examine visual stress independently of dyslexia and of the benefits of colour on reading, it was essential to have a clear method of measuring susceptibility to visual stress. This was achieved by means of a rating scale called the *Visual Processing Problems Inventory* (VPPI; Singleton, in preparation) which comprises 24 questions relating to symptoms of visual stress when reading. Each question is rated on a 5-point scale from 0 ('never') to 4 ('always'), giving a wide range of possible scores (0 to 96). The VPPI can be subdivided into 14 'critical' questions that relate specifically to the perceptual distortions that characterise visual stress and 10 'non-critical' questions that relate to symptoms that are often reported in cases of visual stress, but which could also be a result of other causes. In the present study, both groups were selected so that half the participants exhibited high susceptibility to visual stress on the VPPI and half had low susceptibility to visual stress.

Method

Participants

The participants in this study were 20 university students (10 male, 10 female); mean age 21.55 years (*SD* 3.93 years). Ten of the participants had received a formal diagnosis of dyslexia by an educational psychologist and were recruited via the disabilities service of their university (the dyslexic group). The other ten participants were selected from several samples of students whose VPPI scores were already known as they had taken part in previous research studies (the non-dyslexic group). Within each group, five had low scores on the critical items of the VPPI ('low visual stress') and five had high scores on the critical items of the VPPI ('high visual stress'). As part of the selection procedure, groups were matched for reading accuracy using the WRAT–3 Reading Test (see below), and there were no significant differences between the groups in age. All participants spoke English as their first language and all reported that their vision was either normal or appropriately corrected.[2]

Apparatus and materials

Intuitive Colorimeter (Wilkins, Nimmo-Smith & Jansons, 1992). This is a box in which text can be placed and illuminated by light of varying colour. The subject views the text through a window while the three determinants of colour (hue, saturation and brightness) can be adjusted independently in order to find the precise location in colour space that is most comfortable for the person when reading.

Visual Processing Problems Inventory [VPPI] (Singleton, unpublished). The VPPI comprises 24 questions relating to symptoms of visual stress, which can be subdivided into 14 'critical' questions concerning experience of perceptual distortions when reading (e.g. 'Does the print seem to move about when you read'; 'Does the print become fuzzy or blurry when you read?') and 10 'non-critical' questions that relate to other symptoms (e.g. 'Do you lose your place when reading?'; 'Are you easily distracted when reading?'). Each question is rated on a 5-point scale from 0 ('never') to 4 ('always'), so the total score range is 0–96. In a previous, unpublished study of the VPPI with 142 unselected university students, the mean score was 25.3 (*SD* 11.9; lowest score 0; highest score 75), with an approximately normal distribution of scores.

Wide Range Achievement Reading Test, 3rd edition [WRAT–3 Reading] (Wilkinson, 1993). This is a 40-item test of oral reading of individual words out-of-context.

Wilkins Rate of Reading Test [WRRT] (Wilkins et al., 1996a). This test requires speeded oral reading of a passage of text comprising 15 common words which are repeated in random order. In order to increase the degree of difficulty the text is printed in a small typeface, closely spaced. There is a choice of two typefaces of different size and the smallest was used for this study. When carrying out a test–retest study (as in this case), a different order of words is used for the two assessments. Scores are reported in number of words reading correctly per minute. The test is designed to be a sensitive measure of visual skills involved in reading as the words are extremely familiar and no semantic factors are involved (see Wilkins et al., 1996b). Several studies have shown that reading rate of children who show long-term benefits from coloured overlays is significantly greater with an overlay (Wilkins et al., 2001; Jeanes et al., 1997).

Procedure

The participants were first assessed using the Intuitive Colorimeter to determine the most comfortable colour for reading, and an optimal colour was found for all participants. Colour selection showed the usual individual specificity reported by Wilkins and others in the field, and no trend in optimal colour could be discerned other than the fact that the dyslexics with high visual stress tended to choose more highly saturated colours. All participants were then administered the Wilkins Rate of Reading Test in the Intuitive Colorimeter under two conditions: with their optimal colour, and without (white light).

Order effects were controlled for by counterbalancing across the sub-groups. (Note that this design varies from that advocated in the test manual, which is an ABBA design.)

Results

In all analyses, two-tailed tests of probability were used.

In the participant selection process, the groups were matched for reading accuracy using the WRAT–3 Reading Test. The results are shown in Table 1. No significant differences were found between the dyslexic and the non-dyslexic groups, nor between the high visual stress and low visual stress groups, and there was no significant interaction between the variables. Inspection of the standard deviations indicates that the sample was fairly homogeneous with respect to reading accuracy, which was an intentional feature of the design in order to eliminate reading accuracy as a possible confound in the study.

The participants had been selected so that half had high susceptibility to visual stress and half had low susceptibility to visual stress. However, had this selection been made on the basis of overall VPPI scores, there was a risk that causes other than visual stress might have been implicated. Consequently, selection was made on the basis of scores on the critical items of the VPPI, which were more directly connected to the symptoms that characterise the condition. Those in the low visual stress group had VPPI critical items scores of 10 or less, a cut-off that was below the mean score for a sample of 151 non-dyslexic students (12.09; $SD = 8.12$); see Singleton (in preparation) for further details of this study. Those in the high visual stress group had VPPI critical items scores of 20 or greater, a cut-off that was above the mean score for a sample of 50 dyslexic students (16.48; $SD = 9.81$). Hence it was to be expected that both the groups would differ significantly in critical item scores. However, it is of some interest whether the groups also differed significantly in total VPPI scores and in non-critical item scores: in fact, they did.

The means and standard deviations for VPPI scores of the sub-groups are shown in Table 2. It was found that the participants with high visual stress had significantly higher

Table 1. WRAT–3 Reading Test standard scores (and standard deviations).

	All	High visual stress	Low visual stress
Dyslexic	102.6 (10.24)	107.8 (8.20)	97.4 (10.06)
Non-dyslexic	104.4 (6.11)	103.0 (7.38)	105.8 (4.97)
All	103.5 (8.26)	105.4 (7.78)	101.6 (8.69)

Table 2. Mean scores on the Visual Processing Problems Inventory [VPPI] (and standard deviations).

		High visual stress	Low visual stress
Dyslexic	All items (max. score 96)	56.4 (12.70)	25.8 (2.17)
	Critical items (max. score 56)	29.8 (10.23)	5.4 (2.61)
	Non-critical items (max. score 40)	26.6 (5.41)	20.4 (2.60)
Non-dyslexic	All items (max. score 96)	41.8 (5.97)	16.6 (3.91)
	Critical items (max. score 56)	22.2 (5.81)	6.0 (2.55)
	Non-critical items (max. score 40)	19.6 (2.51)	10.6 (2.07)

VPPI scores in all categories than those with low visual stress (Total VPPI: $F = 71.7$; $p < 0.001$. Critical VPPI: $F = 54.3$; $p < 0.001$. Non-critical VPPI: $F = 24.7$; $p < 0.001$). These differences held up when the dyslexic and non-dyslexic groups were analysed separately, with $p < 0.001$ in all cases, except for the dyslexic students on non-critical VPPI items, where the significance level dropped to 0.05. Hence among all the dyslexic students in the sample reading problems that might not be directly connected with visual stress were found to be relatively common, although the incidence in those with high visual stress ($M = 26.6$, $SD = 5.41$) was slightly but significantly higher than those with low visual stress ($M = 20.4$, $SD = 2.60$).

Comparing the dyslexic and non-dyslexic groups overall, significant differences in visual stress were found in the VPPI total score ($F = 13.05$; $p = 0.002$) and VPPI non-critical item score ($F = 30.2$; $p < 0.001$), but no significant difference in critical item score. These effects held up when inter-group differences were analysed. Comparing the two high visual stress sub-groups, the dyslexic sub-group had significantly higher VPPI total ($t = 2.33$; $p < 0.05$) and VPPI non-critical scores ($t(8) = 2.63$; $p = 0.03$), but not significantly higher critical scores. Comparing the two low visual stress sub-groups, the dyslexic sub-group also had significantly higher VPPI total ($t = 4.60$; $p = 0.002$) and VPPI non-critical scores ($t = 6.58$; $p < 0.001$), but not significantly higher critical scores. The findings indicate that a good match of groups had been achieved on visual stress indicators but that the dyslexic students experienced significantly more reading problems that were not necessarily directly related to visual stress. There was no significant interaction between the dyslexic and visual stress variables in any of the three VPPI categories.

All groups were found to read faster with optimal colour (see Table 3). However, in all groups except the dyslexic high visual stress group, the mean gains in reading speed were relatively modest at around 3–4%, and non-significant. In the dyslexic high visual stress group there was a mean 16% increase in reading speed when using optimal colour, which was significant ($t = 2.85$; $p = 0.046$). Further analysis of individual results indicates that in the dyslexic high visual stress group all participants showed increases in reading speed, ranging from 5% to 27%, while in the other groups the changes ranged from +14% to −10%. In fact, two participants showed no change at all in reading speed and two had slightly slower speed in the optimal colour condition. It is also particularly notable that the mean reading speed of the dyslexic high visual stress group in the optimal colour condition (137.7 wpm) was essentially the same as that of the dyslexic low visual stress group when reading without colour (137.0 wpm). 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, they did bring them up to the same level as other dyslexic students who do not suffer from visual stress.

Table 3. Wilkins Rate of Reading Test scores in words per minute (and standard deviations) under optimal colour condition and without colour (white light) condition.

	Condition	High visual stress	Low visual stress
Dyslexic	Without colour	119.1 (11.59)	137.0 (45.67)
	With optimal colour	137.70 (15.04)	141.1 (52.66)
Non-dyslexic	Without colour	149.3 (37.56)	158.2 (24.76)
	With optimal colour	155.5 (32.78)	164.7 (22.61)

Discussion

The critical issue in this study is: What is the relationship between visual stress and dyslexia? As outlined in the introduction, this question is complicated by the fact that there at least four different concepts of visual stress: (1) a condition in which unpleasant visual symptoms experienced when reading are reported to be alleviated by use of coloured overlays and filters (also sometimes known as Meares-Irlen Syndrome); (2) a clustering of somatic and perceptual symptoms triggered by bright or flickering light and/or grating patterns (also sometimes known as visual discomfort); (3) cases where an increase in reading speed may be observed when using a coloured overlay for reading, compared with no overlay; and (4) a condition characterised by cortical hyper-excitability, and as such, related to photosensitive epilepsy and migraine. Whilst acknowledging that the statistical relationship between visual stress symptoms and increase in reading speed when using an overlay is relatively weak, a degree of commonality between these different concepts of visual stress is nevertheless apparent. Consequently it is appropriate to treat them as relating to the same underlying condition, at least on the basis of current knowledge, whilst recognising that not all sufferers may experience exactly the same set of symptoms to the same degree or show identical responses to treatment.

In another study (Singleton, in preparation), VPPI scores were found to be significantly higher for a sample of 50 dyslexic compared with 151 non-dyslexic students suggesting that students with dyslexia were more likely to report symptoms of visual stress. However, the difference between the two groups was considerably greater for non-critical items than for critical items, suggesting that the dyslexic and non-dyslexic groups differed more dramatically on factors that were not necessarily related to visual stress than they did on factors that were directly connected with visual stress. Nevertheless, rather than leading to the conclusion that visual stress and dyslexia are completely independent, as preferred by Wilkins (2003), these findings imply a greater likelihood of individuals with dyslexia having visual stress. This conclusion is consistent with recent claims by Grant (2004), who has cited data which indicate that visual stress is much more common in cases of dyslexia amongst university students than previously imagined. Grant, who is a psychologist with many years' experience of assessing students for dyslexia in the UK and who is well known in his field, reported that over the period 2001–2003, of 377 students diagnosed by him as having dyslexia, evidence of visual stress was strongly present in 42% of cases and weakly present in another 34% of cases.

In the present study, the finding that only the dyslexic students with high visual stress showed significant improvements in reading speed when using optimal colour implies a relationship of some sort between dyslexia and visual stress. Had the two factors (dyslexia and visual stress) been entirely independent, one would have predicted that all participants with high visual stress would exhibit a similarly positive benefit of colour (or, alternatively, no effect at all). Visual stress seems to have a particularly pronounced effect on the reading speed of dyslexic students: reading rate without colour for the high visual stress dyslexic group was significantly slower than that of the low visual stress dyslexic group. This effect was not found amongst the non-dyslexic students: reading rate without colour for the high visual stress non-dyslexic group was a little slower than that of the low visual stress non-dyslexic group, but not significantly so. It therefore appears that the combination of dyslexia and high visual stress is particularly detrimental to reading speed, independent of ability to recognise real words. A consequence of this is that untimed tests of reading accuracy will be less helpful in identifying dyslexia in bright, well-educated adults, whereas reading tests that take speed and fluency into account (such as the *Test of Word Reading Efficiency*; Torgeson, Wagner & Rashotte, 1999) are more likely to reveal serious processing difficulties.

Can the present findings be explained simply by differential severity of reading problems across the sub-groups? This is unlikely since the sub-groups did not differ significantly in reading accuracy on WRAT–3, and the high visual stress non-dyslexic sub-group had a similar non-critical VPPI score (19.6) to that of the low visual stress dyslexic sub-group (20.4). In other words, where problems in reading that were not necessarily directly connected to visual stress are concerned, the high visual stress non-dyslexic and the low visual stress dyslexic sub-groups were alike, suggesting that they experienced a similar range of (perceptually unrelated) literacy difficulties to a comparable degree. The only difference between these sub-groups was in degree of visual stress, yet neither showed significant effects of optimal colour on reading rate.

It has frequently been observed that colour is not a universal panacea for visual stress (see Evans, 2001). In the study by Evans and Joseph (2002), 32% 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% of the sample having chosen overlays. Looking at particular symptoms of visual stress in the Evans and Joseph study, of those who experienced a gain in reading rate of greater than 5% when using an overlay, 76% reported sore or tired eyes when reading, 37% reported words blurring when reading and 37% had frequent headaches. Hence although colour is frequently a beneficial treatment for visual stress, it does not seem to work for all sufferers. It is also clear from the Evans and Joseph study that many adults benefit from using coloured overlays when reading, despite lacking reported symptoms of visual stress. These findings call into question the common practice of defining visual stress as a condition that is 'alleviated by the use of individually prescribed coloured filters' (Evans, 1997b, 1997c; Evans & Joseph, 2002; Kriss & Evans, 2005), and which is diagnosed by means of either an immediate improvement on the Wilkins Rate of Reading Test when using a coloured overlay, or sustained voluntary use of an overlay for reading. In the present study, only two of the five students in the high visual stress non-dyslexic group showed increases in reading rate of greater than 5%. Clearly, therefore, relying solely on response to an overlay in order to judge whether or not a person suffered from visual stress would be a questionable practice, as some individuals can experience a range of visual perceptual distortions while reading and yet derive little, if any, benefit from use of a coloured overlay. In this context it is interesting that Wilkins also notes the opposite situation: 'Sometimes individuals who show dramatic improvements in reading fluency with a coloured overlay report no symptoms and show no signs of visual stress . . . Whether these individuals have Meares-Irlen syndrome is a question of definition' (2003, p. 18).

By contrast with Grant's (2004) report that over three-quarters of university students with diagnosed dyslexia show significant symptoms of visual stress, Kriss and Evans (2005) report that the prevalence of visual stress in dyslexia is only about 10% higher than its prevalence in non-dyslexic children. On the basis of these results, Kriss and Evans conclude that visual stress and dyslexia 'are separate conditions, which may be present in isolation or sometimes coexist in the same individual' (2005, p. 362). However, in that study visual stress was diagnosed by choice of, and response to, coloured overlays, not by reported symptoms of visual perceptual distortions when reading. Furthermore, Kriss and Evans note that a surprisingly large number of the children in the study chose the mint green overlay, which may indicate that in this particular study factors other than alleviation of visual stress may have played a part in the children's selection. The present study used the Intuitive Colorimeter, which is able to determine optimal colour, rather than coloured overlays, a relatively coarse method that can only approximate optimal colour (Wilkins, 2003).

Recent studies by Grounds and Wilkins (in preparation) have yielded evidence to support a closer relationship between dyslexia and visual processing than was previously suspected. These authors found that the reading rate of dyslexic children aged 12–15 years displays greater slowing over time when compared with control groups. This effect, which seems to be independent of errors in reading, is significantly attenuated by the use of coloured overlays, and also by manipulation of perceptual characteristics of text, such as letter size and spacing. These results suggest that individuals with dyslexia are more sensitive to the visual features of text, and consequently have greater susceptibility to reading-induced fatigue.

At the present time there is no completely objective diagnostic test for visual stress and, certainly, when assessing children, it is recognised that questioning them about suspected visual perceptual symptoms could result in misleading responses. Hence in such cases diagnosis by positive response to the preferred treatment method may be argued to be the next best thing. When assessing adults, however, there is no reason why symptomatology should not be the fundamental basis for initial diagnosis, as is the norm in medical practice. When doing so, however, it should be recognised that the symptoms of visual stress are non-specific, i.e. they can result from a variety of other conditions, including ocular pathology, refractive error, binocular vision anomalies and accommodative anomalies (see Evans, 2001). Many people who have symptoms of visual stress regard them as 'normal' and they may only realise they actually had a problem when they experience the benefits of treatment. Hence not only would it be prudent to refer all cases of suspected visual stress to an eye-care practitioner who can check for undiagnosed conventional visual problems, but also to administer coloured overlay screening to any child or adult who shows signs of dyslexia.

The present study shows that on the basis of reported symptomatology, university students who experience high levels of visual stress are more likely to show improvements in reading rate with optimal colour if they also have dyslexia than if they do not have dyslexia. While that does not demonstrate an aetiological connection between the two conditions, it suggests an interaction that has major implications for diagnosis and treatment, and indicates a need for further research on possible mechanisms of linkage between dyslexia and visual stress, including the magnocelluar system as well as processes involved in visual fatigue. However, it is possible that it is only when reading is difficult (for whatever reason) that the task of reading benefits from treatment of visual stress, facilitating improvements in reading speed. The reading task used in this study was quite brief; longer and more challenging reading tasks, investigated under conditions of optimal colour and without, might yield different outcomes to that reported here, and in such circumstances non-dyslexic participants who report high levels of visual stress might also experience benefits of colour.

Notes

1. The term 'visual stress' has occasionally been used to refer to visual discomfort caused by decompensated heterophoria (latent squints/strabismus); e.g. see Pickwell, Jenkins & Yetka (1987); Yetka, Pickwell & Jenkins (1989). It is not being used in this sense here.

2. It is acknowledged that undetected visual problems may have existed in this sample (see Evans, 2001; Evans & Rowlands, 2004), but it was beyond the scope of the authors to investigate this. The extent to which VPPI results might be confounded by such problems has yet to be assessed.

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