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Abstract

Visual stress – a condition in which unpleasant visual symptoms are experienced when reading – has been reported to be more prevalent in dyslexic individuals but at the present time the relationship between dyslexia and visual stress remains controversial. ViSS, a computerised visual stress screener that incorporates reading-like visual search, has recently shown promise in studies with unselected samples of primary and secondary school children. This study investigated the use of ViSS with dyslexic children. Dyslexic children identified as having high visual stress showed significantly higher percent increases in reading rate with a coloured overlay and reported significantly higher critical symptoms of visual stress, compared to dyslexic children with low visual stress. The same results were found for reading age controls, indicating that ViSS can be equally effective with normal readers as well as with children with dyslexia. Compared to reading age controls, dyslexic children were found to have significantly higher susceptibility to visual stress, significantly larger percent increases in reading rate with an overlay, and significantly higher critical and non-critical symptoms of visual stress. Extrapolated to unselected population samples, the data also suggest that visual stress is more likely to be found in people with dyslexia than in people who do not have dyslexia. These results, which point to an important link between the two conditions, are discussed in relation to current theories that attribute visual stress to either a magnocellular dysfunction or cortical hyperexcitability.

Computerised screening for visual stress in children with dyslexia

Although most of the literature on the causes of dyslexia supports an underlying deficit in phonological processing (Farmer & Klein, 1995; Ramus, Rosen, Dakin, Day, Castellote, White & Frith 2003; Snowling, 2000; Vellutino, Fletcher, Snowling & Scanlon, 2004), it is now widely accepted that low-level visual processing abnormalities may also be present, (Stein & Walsh, 1997; Livingstone, Rosen, Drislane, & Calaburda 1991), reflecting a selective loss in sensitivity at low spatial and high temporal frequencies, as shown in anatomic (Livingstone et al., 1991), psychophysical (Lovegrove, Heddle & Slaghuis, 1980; Cornelissen, Hansen, Gilchrist, Cormack, Essex & Frankish, 1998a), electrophysical (Livingstone et al., 1991) and brain-imaging studies (Eden, VanMeter, Rumsey, Maisog, Woods & Zeffiro, 1996). People with dyslexia often report subjective experience of unpleasant visual symptoms when reading (Cornelissen, Richardson, Mason, & Stein, 1994; Stein & Walsh, 1997), a condition that is generally known as visual stress (see Wilkins, 2003) but which is also sometimes referred to as Meares-Irlen syndrome (see Evans, 2001). It has been stated that the condition affects up to 20% of children in mainstream education (Jeanes, Busby, Martin, Lewis, Stevenson, Pointon & Wilkins, 1997) and 65% of children with dyslexia (Irlen, 1991). The symptoms can be described in general terms as somatic (asthenopia, sore, tired eyes; headaches; photophobia) and visual perceptual distortions (illusions of shape, motion, and colour; transient instability). Symptoms can be alleviated by coloured filters or placing coloured overlays over text (e.g. Jeanes et al., 1997; Wilkins, Lewis, Smith, Rowland, & Tweedie, 2001). The currently preferred method of diagnosis for visual stress is based on the favoured treatment method, i.e. either the sustained voluntary use of an overlay or immediate improvement in reading speed (typically >5%) on the Wilkins Rate of Reading Test [WRRT] (Wilkins, Jeanes, Pumfrey & Laskier, 1996) when using an overlay. Randomized double-masked placebo-controlled trials support the existence of visual stress and validate remediation with individually prescribed coloured overlays for some individuals

(Evans, Busby, Jeanes & Wilkins, 1995; Evans, Wilkins, Brown, Busby, Wingfield, Jeanes, & Bald, 1996; Robinson & Foreman, 1999; Wilkins, Evans, Brown, Busby, Wingfield, Jeanes & Bald, 1994), and show that coloured overlays can reduce symptoms and improve reading rate (Bouldoukian et al., 2002; Wilkins & Lewis, 1999; Wilkins et al., 2001) and sometimes also reading accuracy and comprehension (Robinson & Foreman, 1999). Symptom questionnaires (e.g. Conlon & Hine, 2000; Irlen, 1991) are also frequently used to identify children who are susceptible to visual stress and who may therefore benefit from coloured overlays.

The exact role of visual anomalies in dyslexic children remains unclear, as does the relationship between visual stress and dyslexia. There are currently two favoured explanations for visual stress, which differ with respect to how they account for the relationship between the conditions. The first emerged 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 et al., 1980; Lovegrove, Martin & Slaghuis, 1986), specifically characterised by impaired processing for low spatial and high temporal frequency visual stimuli (Lovegrove et al., 1980; Martin & Lovegrove, 1984; Talcott, Hansen, Willis-Owen, McKinnell, Richardson & Stein, 1998). The most robust of these findings indicates a particular problem with visual motion processing (Cornelissen et al., 1994; Demb, Boynton, Best, & Heeger, 1998). 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. The two systems coordinate and work in parallel to facilitate detailed visual perception under conditions of almost constant eye movement. If one part of the system is dysfunctional problems will arise in smooth and efficient processing of text. Impairment on visual tasks which require rapid processing of visual information has been reported in dyslexics, implying that the magnocellular cells in the lateral geniculate nucleus – which is important in detecting fast, low-contrast information – may be impaired (Borsting, Ridder, Dudeck, Kelley, Matsui, & Motoyama, 1996; Breitmeyer, Levi, & Harwerth, 1981). Among the most direct evidence of a magnocellular deficit in dyslexia is a functional magnetic resonance imaging study by Eden et al. (1996), in which moving stimuli failed to activate area V5 in the visual cortex (an important motion area inputting into the right posterior parietal cortex) in dyslexic subjects. However, the magnocellular impairment in cases of dyslexia is not found in all dyslexics and has been disputed (see Scheiman, 1994; Skotton, 2000; Stein, Talcott & Walsh, 2000). Indeed, it is still unclear whether these visual deficits represent a correlate or cause of reading problems. Nevertheless, these findings suggested a convenient model for linking dyslexia with anomalies of eye movement control (see Evans et al., 1996; Stein, 2001; Stein & Talcott, 1999; Stein & Walsh, 1997), and hence many researchers have suggested that visual stress could be included within this theoretical framework (e.g. Irlen, 1994; Lehmkule, 1993; Livingstone et al., 1991; Sloman, Cho, & Dain, 1991; Sloman, Dain, Lim, & May, 1995; Williams, LeCluyse, & Roch-Faucheux, 1992).

The second explanation is provided by Wilkins and colleagues and is currently regarded as the predominant theory of visual stress (for reviews see Evans, 2001; Wilkins, 1995, 2003). According to this view, the symptoms of visual stress are attributable to cortical hyperexcitability 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 could generate similar physiological effects. Wilkins 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.

The major difference between the two theories is that Wilkins' regards visual stress as independent of dyslexia. Wilkins (2003) concludes that a diagnosis of dyslexia does not make it more likely that reading will be improved by use of coloured filters. This view is supported in a study by Grounds and Wilkins (unpublished; 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 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 in the proportion who benefited from overlays between these four groups.

Kriss & Evans (2005) concluded that visual stress and dyslexia "…are separate conditions, which may be present in isolation or sometimes coexist in the same individual." (p. 15). However, they found a significant improvement in rate of reading with the preferred overlay in the dyslexic group but not in the control group. Grant (2004) reported that over three-quarters of a large sample of university students diagnosed with dyslexia showed significant symptoms of visual stress. Further, Singleton & Trotter (2005) found that, on the basis of reported symptomology, adults 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. If dyslexia and visual stress were entirely independent, one would have predicted that all participants with high visual stress would exhibit a similarly positive benefit of colour (or no effect at all). Although not confirming an aetiological link, these findings imply an interaction between the two conditions. Recent studies by Grounds and Wilkins (unpublished; cited in Wilkins, 2003) provide further support for a relationship between dyslexia and visual processing. They found that the reading rate of dyslexic children aged 12-15 displays greater slowing over time when compared with control groups. This effect was significantly attenuated by the use of coloured overlays and 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. This direct causal link between vision and dyslexia is supported by findings that reading under demanding visual conditions, such as with small print, leads to declines in reading performance by dyslexic individuals (Cornelissen, Bradley, Fowler & Stein, 1991; Skottun, 2001; O'Brien, Mansfield & Legge, 2000). Furthermore, Cornelissen et al (1991) found that reading errors decreased with larger print size for reading disabled children with poor binocular control, suggesting a causal link between a stressed visual system and reading impairment.

Arguably, the debate over whether dyslexia and visual stress are related conditions turns on how visual stress is defined and measured. For example, in the study by Kriss and Evans (2005), visual stress was diagnosed by choice of, and response to, coloured overlays, not by reported symptoms of visual perceptual distortions when reading as advocated by Singleton and Trotter (2005). However, even though symptom questionnaires may be useful with adults, use of symptom questionnaires with children may result in misleading and subjective responses (Henderson & Singleton, submitted; Singleton & Henderson, submitted); for example, children may fail to understand the questions (Northway, 2003) or may accept symptoms as normal until they are alleviated (Evans & Joseph, 2002). Consequently, where children are concerned, diagnosis by positive response to the preferred treatment method may be argued to be the next best thing. However, problems have been highlighted with this practice. For example, not all children with visual stress benefit from overlays and some children without visual stress sometimes benefit from overlays. Further, there are no set criteria for how much faster a child should read with an overlay or how long they should prefer to read with an overlay over a sustained period (see Henderson & Singleton, submitted; Northway, 2003; Singleton & Henderson, submitted). Thus, the condition lacks a completely objective diagnostic test, although a new pattern glare test may be promising (Stevenson & Evans, in preparation; cited in Kriss & Evans, 2005).

Recently a computerized visual stress screener (ViSS) has shown promise as an objective method of screening for visual stress. Two studies using unselected samples of children aged 7–17 have provided empirical support for ViSS in predicting visual stress symptomatology and in predicting immediate increase in reading rate with an overlay on WRRT (Henderson & Singleton, submitted; Singleton & Henderson, submitted). The theoretical underpinnings for ViSS lie in the view that high susceptibility to visual stress causes reading-like visual search to be impaired by visually stressful stimuli (see Conlon & Humphreys, 2000; Conlon, Lovegrove, Hine, Chekaluk, Piatek & Hayes-Williams, 1998; Wilkins, Huang & Cao, 2004). This follows the observation by McConkie & Zola (1987) that interference from the global percept (e.g. lines of text or black and white horizontal stripes) disrupts the more salient local analysis at a word-line level. ViSS requires a child to locate a random three letter word in a matrix of distractor three letter words where the background is either non-visually stressful (grey) or visually stressful (black and white horizontally striped repetitive pattern of equal duty cycle). Results thus far indicate that children whose response times are impaired by the visually stressful pattern are more likely to show significantly higher percent increases in reading rate on WRRT (Henderson & Singleton, submitted), and report significantly higher critical symptoms of visual stress (Singleton & Henderson, submitted) compared to children who are not impaired by the pattern.

No study has yet compared dyslexic children with normal children on ViSS. On the basis of magnocellular theory, it would be expected that dyslexic children with or without visual stress would be relatively impaired on the non-visually stressful search items as well as on the visually-stressful search items, since a magnocellular dysfunction in dyslexic reading has been related to impaired visual search (Casco & Prunetti, 1996; Vidyasagar & Pammer, 1999) and visual attention (Pammer & Wheatley, 2001). Iles, Walsh & Richardson (2000) compared dyslexics with elevated motion coherence thresholds, dyslexics with normal motion coherence thresholds, and normal controls. They found that only dyslexics with elevated motion coherence thresholds are impaired on visual search tasks which require serial search but are unimpaired on parallel search. These results concur with the findings of Williams et al (1987), who used reading-like visual search, and Ruddock (1991). Pammer, Lavis, Hansen & Cornelissen (2004) found evidence that problems with attentional focusing contribute to anomalies in relative position coding in dyslexia. If dyslexic children with possible magnocellular deficits are also impaired on non-visually stressful items it could be that ViSS may not be as useful among dyslexic samples.

The first objective of the present study was to evaluate the accuracy of ViSS in a dyslexic sample. Performance on ViSS was compared against currently used techniques to measure visual stress: percent increase with an overlay on WRRT and a visual stress symptom questionnaire. The studies second objective was to examine the hypothesis that visual stress is more common in dyslexic children compared to reading-age matched controls.

Method

Participants

The participants in this study were 44 children (23 female; 21 male); mean age 10.29 years (range 7.0 – 14.8 years, SD 2.15 years). 22 of the participants (the dyslexic group) had received a formal diagnosis of dyslexia (see Note 1) and were recruited via the Psychological Assessment Unit of Hull University. The other 22 participants were selected from two schools in the city of Kingston upon Hull (the reading-age matched controls). The groups were matched for reading age; the mean reading age of the dyslexic group was 9.29 years (SD 2.78 years) and 9.48 years (SD 2.77 years) for the reading-age controls. There were 13 males and nine females in the dyslexic group, and 10 males and 12 females in the reading-age control group. All participants spoke English as their first language and all reported normal or appropriately corrected vision (see Note 2).

Apparatus and Materials

1. *Intuitive Overlays* (iOO Sales Ltd, London).

This set comprises 11 different coloured acetate overlays. The overlay testing was carried out as specified in the manual.

2. *Wilkins Rate of Reading Test* [WRRT] (Wilkins et al, 1996a)

This test requires speeded oral reading of a 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. In order to increase the degree of difficulty the test is printed in a small type face, closely spaced. The test materials provide a choice of two typefaces of different size and the smaller one was utilised for the secondary sample. However, it was felt neither was appropriate for the primary sample thus the test material was replicated in 10 point Arial bold font. Scores are reported in number of words read correctly per minute minus errors, omitted words and omitted lines.

3. *Visual Stress Screener [ViSS]*

ViSS requires a child to locate a randomly generated three-letter word (selected from a database of 155 words) in a matrix of distractor three-letter words (x axis 18 letters, y axis 16 letters). The location of the target is randomly generated. When the child has located the target word s/he clicks on it with a mouse. Response time and accuracy are measured. Inaccurate responses are recorded, but additional items are administered so that mean response times are always based on the same number of items for which accurate responses were made. The background on which the matrix is superimposed is either (a) non-visually stressful or (b) visually stressful. The non-visually stressful matrix is made up of 10 point Arial normal letters and is set on a grey background display. The visually stressful matrix is made up of 10 point Arial bold letters and is set on an alternated black/white horizontally striped background display. The stripes have an equal duty cycle of 50% and fill the entire screen on which the matrix is superimposed. Two non-visually stressful practice items precede six non-visually stressful items, 15 visually stressful items, and finally four non-visually stressful items. The task was administered on a laptop computer; the screen was positioned 35cm away from the edge of the desk to exert control over the viewing distance. The same instructions were read aloud to each participant.

Pilot testing revealed that primary school children took an average of 30 minutes to complete VSS. To avoid confounding variables such as boredom or fatigue and to help maintain motivation three short cartoons were added into the program at the end of the non-visually stressful block, at the end of the visually stressful block and at the end of the test. Second, a recorded voice of praise (e.g. ‘well done’; ‘ok’; ‘yes’; ‘brilliant’) was added into the program when a child accurately completed an item, and a big tick was also displayed.

4. Visual Stress Symptom Questionaire.

This comprises nine questions relating to symptoms of visual stress, which can be subdivided into six'critical' questions concerning experience of perceptual distortions when reading and three 'non-critical' questions that relate to other symptoms (see Appendix). Each question is rated on a five point scale from 0 ('never') to 4 ('always'), so the total score range is 0–36.

5. British Ability Scales, 2nd Edition *[BAS-II]: Word Reading (nferNelson)*

This is a 90 item test of oral reading of individual words out-of-context.

Procedure

Children in the dyslexic group were individually tested at Hull University in a quiet room. The reading-age controls were individually tested at their schools in a quiet, empty classroom. Both rooms were normally illuminated (care was taken to avoid glare from the windows and overhead lights). All participants were asked to wear glasses that were usually worn for reading. The BAS-II Word Reading Test was administered as directed in the test manual. The symptom questionnaire was administered orally. Participants were assessed with Intuitive Overlays to determine their preferred colour for reading and were tested on WRRT both with and without their chosen colour. Participants who expressed no colour preference were tested on WRRT using a grey overlay. WRRT was used as described in the test instructions with one exception: each child was asked to read the first line of version B or C (alternated at random) as a practice, without an overlay, to familiarize them with reading randomly ordered text. The order in which the tests were administered was counterbalanced to control for order effects.

Results

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

Assessing VSS with a dyslexic sample

Children were assigned to the 'high visual stress' group (N = 14) if a significant difference (t) was found between their non-visually stressful and visually stressful search times ($p<0.05$), and children were put into the 'low visual stress' group (N = 30) when this difference was not significant.

Table 1 shows the ViSS data for the high and low visual stress dyslexic subgroups. Dyslexic children with high visual stress did not have significantly higher response times on the non-visually stressful items compared to the dyslexic children with low visual stress [$F(1, 20) = 0.73$, $p>0.05$]. Dyslexic children with high visual stress had significantly higher response times on the visually stressful items compared to the dyslexic children with low visual stress [$F(1,20) = 4.17$, $p<0.05$]. The dyslexic children with high visual stress had significantly higher percent increases between non-visually stressful and visually stressful items compared to the low visual stress dyslexic group [$F(1,20) =10.05$, $p<0.005$]. The reading-age controls with high visual stress also had significantly higher percent increases between items compared to the low visual stress reading-age controls [$F, (1,20) = 5.47$, $p<0.05$].

TABLE 1 ABOUT HERE

The high visual stress dyslexic group had significantly higher percent increases in reading rate with an overlay (M = 23.01, SD = 23.21) compared to the low visual stress dyslexic group (M = 7.13, SD = 9.49) [$F, (1, 20) = 4.97$, $p<0.05$]. The high visual stress control group did have higher percent increases in reading rate with an overlay (M = 6.96, SD = 5.34) compared to the low visual stress control group (M = 1.82, SD = 5.53), but this difference did not reach significance [$F(1, 20) = 3.37$, $p = 0.08$].

The high visual stress dyslexic group reported significantly higher critical symptoms (M = 9.66, SD = 4.09) compared to the low visual stress dyslexic group (M = 6.76, SD = 2.46) [F(1, 20) = 3.94, p<0.05]. However, there was no significant difference in non-critical symptom scores between high (M = 5.32, SD = 4.02) and low (M = 4.49, SD = 2.20) visual stress dyslexic groups [F, (1, 20) = 2.29, p>0.05]. The high visual stress reading-age control group reported significantly higher critical symptoms (M = 10.80, SD = 3.54) compared to the low visual stress reading-age control group (M = 4.05, SD = 3.50) [F(1, 20) = 14.17, p<0.001], but there was no significant difference in non-critical scores between high (M = 4.28, SD = 3.52) and low (M = 4.34, SD = 4.10) visual stress reading-age control groups [F(1, 20) = 0.78, p>0.05].

Investigating the relationship between dyslexia and visual stress

Table 1 shows the mean non-visually stressful, visually stressful and overall search times for the dyslexic and reading age control groups. Although mean non-visually stressful search time was higher for the dyslexic group than the reading age controls this difference was not significant [F(1.42) = 3.46, p>0.05]. Dyslexic children had significantly longer response times on visually stressful items compared to reading age controls [F(1.42) = 5.57, p<0.05]. No significant difference was found between groups for the overall search times [F(1.42) = 2.94, p>0.05].

Two-way ANOVA revealed that dyslexic children had significantly higher mean percent increase in search time between conditions (non-visually stressful to visually stressful) (M = 67.81, SD = 81.15) compared to reading-age controls (M = 29.04, SD = 38.17) [F, (1,42) = 3.99, p<0.05]. The high visual stress group (both dyslexic and control children combined) also had significantly higher percent increase between conditions (M = 100.78, SD = 77.70) compared to the low visual stress group (M = 23.99, SD = 41.80) [F(1,42) = 13.95, p<0.001]. There was no significant interaction although the dyslexic group with high visual stress had much larger percent increases between items compared to the reading age controls with high visual stress [F, (1,42) = 2.08, p>0.05] (see Figure 1).

FIGURE 1 ABOUT HERE

Overall, children were found to read faster, on average, with their chosen coloured overlay than without. However, the dyslexic group showed considerably greater gains compared to the control group (see Table 2). In fact, the dyslexic children read fewer words per minute than the control group without an overlay but more words per minute than the control group with an overlay.

TABLE 2 ABOUT HERE

Two-way ANOVA revealed that the dyslexic group had significantly higher percent increase in reading rate with an overlay (M = 13.63, SD = 17.09) compared to the reading age controls (M = 2.98, SD = 5.80) [$F(1,42) = 6.82$, $p<0.01$]. There was also a significant effect of visual stress; the high visual stress group showed significantly higher percent increases in reading rate with an overlay (M = 17.28, SD = 20.10) compared to the low visual stress group (M = 4.12, SD = 7.82) [$F(1,42) = 6.59$, $p<0.01$]. There was no significant interaction. However, the dyslexic children with high susceptibility to visual stress had much larger percent increases in reading rate (>20%) compared to the reading age controls with high susceptibility to visual stress (>5%), but the dyslexic children with low susceptibility also benefited from overlays by >5%, more than the reading age controls with low susceptibility (<5%) (see Figure 2).

FIGURE 2 ABOUT HERE

The dyslexic group reported significantly more mean non-critical symptoms (M = 4.54, SD = 2.28) compared to reading-age controls (M = 2.50, SD = 1.26) [$F(1, 42) = 15.417$, $p<0.01$]. Dyslexic children also reported significantly more mean critical symptoms (M =

8.84, SD = 4.22) compared to reading age controls (M = 5.59, SD = 4.48) [$F(1, 42) = 4.62$, $p < 0.05$]. There was also a significant difference between the overall symptom questionnaire scores; the dyslexic group had a higher mean score (M = 12.18, SD = 5.81) compared to the reading age controls (M = 8.00, SD = 4.20) [$F(1, 42) = 8.97$, $p<0.01$].

Incidence of visual stress

The incidence of high visual stress in the dyslexic group was 40.9% (9/22), while in the reading-age controls the incidence was 22.7% (5/22). This difference was not significant (chi-squared = 1.67; df = 1; p = 0.2]. However, the ratio of dyslexic to control participants in this study was 50:50, which does not represent the situation in the real world where dyslexia is found in only about 5% of the population (Shaywitz, Escobar, Shaywitz, Fletcher & Makugh, 1992). If the data from the present study are used to estimate likely incidence of visual stress in an unselected sample of, say, 1,000 people, the results turn out rather differently. On the basis of a presumed incidence of dyslexia of 5%, 50 of the 1,000 would have dyslexia, and 40.9% (N = 20) of those would be expected to suffer from visual stress and 30 not. Amongst the nondyslexics in the sample (N = 950), 22.7% (N = 216) would be expected to suffer from visual stress and 734 not. If these hypothetical data are analysed using chi-square, the result is chi-squared = 7.85 (df = 1; p = 0.005). In other words, in unselected population samples, visual stress would be expected to be significantly more common amongst people with dyslexia than amongst people who do not have dyslexia.

Discussion

The first aim of this study was to evaluate the effectiveness of ViSS with dyslexic children. The results provide support for ViSS in its ability to identify dyslexic children who suffer perceptual distortions from visually stressful stimuli, and thus who are susceptible to visual stress. Dyslexic children identified by ViSS as having high susceptibility to visual stress had significantly higher percent increases from non-visually stressful to visually stressful ViSS items, had significantly higher percent increases in reading rate with an overlay, and reported significantly more critical symptoms of visual stress compared to the dyslexic children with low susceptibility. The reading age controls identified by ViSS as having high visual stress susceptibility also had significantly higher percent increases from non-visually stressful to visually stressful items and reported significantly more critical symptoms of visual stress compared to the reading age controls with low susceptibility. However, even though the reading age controls with high susceptibility read >5% faster with an overlay, unlike the reading age controls with low susceptibility, this difference did not reach significance. It is likely that this was due to the very low sample size for the high visual stress reading age control group (N = 5).

The present study found that dyslexic children’s response times were significantly more impaired than the control group for the visually stressful items, and their mean percent increase in response time from non-visually stressful to visually stressful items was also significantly higher, thus indicating that, on average, dyslexic children had higher susceptibility to visual stress when compared to reading-age controls. The dyslexic children did not have significantly slower response times on non-visually stressful visual search compared to reading age controls. The failure to find a significant effect for non-visually stressful items, but a significant response time divergence for visually stressful items provides support for the sensitivity of ViSS for use with dyslexic children as well as normal children. Further, it also indicates that ViSS is not simply measuring other cognitive abilities such as working memory ability or attention span, which would be ‘on-line’ during visual search but clearly not affecting the program’s ability to screen for visual stress. However, this finding is surprising given that a number of studies have found dyslexic children to be impaired on tasks that require visual attention without the presence of a visually stressful pattern (Casco & Prunetti, 1996; Iles et al., 2000; Ruddock, 1991; Vidyasagar & Pammer, 1999; Williams, Brannan & Lartigue, 1987) and because a magnocellular dysfunction in dyslexia has been related to deficits in visual attention (Iles et al., 2000; Pammer & Wheatley, 2001). Furthermore, as found in previous studies (Henderson & Singleton, submitted; Singleton & Henderson, submitted), dyslexics and reading-age controls with high visual stress were not impaired on non-visually stressful items. This is again surprising since visual search has been found to be impaired in children with visual stress (Tyrell, Holland, Dennis, & Wilkins, 1995; Conlon & Humphreys, 2000; Conlon et al., 1998). Significant differences may have not been found for non-visually stressful items because the number of test items in ViSS is quite small and variance can be considerable, thus differences in means have to be large to reach significance.

Dyslexic children also showed significantly larger increases in reading rate with an overlay compared to reading-age controls. In fact, the mean reading rate of the dyslexic group was slower than that of the control groups without an overlay, but slightly faster than that of the control group with an overlay. The dyslexic children with high visual stress showed increases in rate of reading with an overlay of more than 20%, compared to reading-age controls with high visual stress, who showed increases of more than 5% but less than 10%. This is consistent with the finding of Singleton & Trotter (2005), who reported that only dyslexic adults with visual stress significantly benefited from overlays compared to non-dyslexic adults with visual stress, dyslexic adults without visual stress and adults without either dyslexia or visual stress. In contrast to Singleton and Trotter (2005), however, the present study found that dyslexics with low visual stress also showed increases in reading rate with an overlay of more than 5% compared to reading age controls with low visual stress who showed increases of less than 5%. This finding could be attributed to demand characteristics; the dyslexic children may have already been made aware of the beneficial effects that coloured overlays can have and thus they may have read faster with an overlay. However, this is unlikely since the low visual stress-dyslexic group also showed slightly higher susceptibility on ViSS (a novel task) than the low visual stress-reading age control group. Wilkins (2003) states that "…sometimes individuals who show dramatic improvements in reading fluency with a coloured overlay report no symptoms and show no signs of visual stress" (p.18). However, it could be inferred that there is a relationship between using colour and dyslexia that is independent of visual stress.

The second aim of the study was to investigate the relationship between dyslexia and visual stress. The incidence of high visual stress in the dyslexic group (41%) was found to be almost twice that found in the reading-age controls (23%). These figures are comparable with those reported by Kriss and Evans (2005), in which 34% of the dyslexic group and 22% of the control group met their criteria for visual stress (i.e. reading rate increased by >8% with chosen overlay). In neither the Kriss and Evans study nor the present study was the difference between the dyslexic and non-dyslexic groups found to be significant, but in both studies samples were selected to give a 50:50 ratio of dyslexics to nondyslexics. However, if these incidence figures are used to estimate likely incidence of visual stress in unselected population samples (in which the incidence of dyslexia is about 5%; Shaywitz et al, 1992), the results suggest that visual stress is significantly more common amongst people with dyslexia than amongst people who do not have dyslexia. The dyslexic children reported significantly higher non-critical symptoms of visual stress compared to the reading-age controls. This was expected since it is likely that dyslexic children often have further visual problems involved with reading that are independent of visual stress. Thus, dyslexic children reported that reading makes them tired, becomes harder the longer they read, and that they often lose their place when reading, significantly more than the reading-age controls. Dyslexic children also reported significantly more critical symptoms of visual stress compared to reading age controls. Even though one must be wary of the reliability of self-reports from children, since they can be subjective and misleading (Northway, 2003), this finding provides further support for a relationship between visual stress and dyslexia. While carrying out the experiment it was noted that a number of the dyslexic children spontaneously reported seeing flashes of colour over the lines of text during ViSS; this did not occur during testing of the reading age controls. While this is an interesting point, it could however be explained by the possibility that the dyslexic children may have been previously asked if they see flashes of colour in print. Nevertheless, perceptual illusions, such as seeing flashes of colour in text, may be explained by cortical hyperexcitability (see Wilkins, 2003).

The findings that dyslexic children showed significantly higher susceptibility to visual stress on ViSS, showed significantly higher increases in reading rate with an overlay, and also reported significantly more critical symptoms of visual stress compared to reading age controls all imply a relationship of some sort between dyslexia and visual stress. The extrapolation of the findings to unselected population samples also suggests that visual stress is significantly more common amongst people with dyslexia than amongst people who do not have dyslexia. The magnocellular deficit hypothesis (see Stein, 2001) offers one explanation for these findings. There is a wide body of evidence to implicate early visual sensory coding difficulties in dyslexia. Differences between poor and normal readers have been demonstrated primarily in their sensitivity to dynamic visual stimuli such as coherent motion (Cornelissen et al., 1994; Hansen, Stein, Prde, Winter, & Talcott, 2001), contrast sensitivity (Evans, Drasdo & Richards, 1994; Martin & Lovegrove, 1984), uniform field flicker (Brannan & Williams, 1988), spatial frequency doubling (Buchholz & McKone, 2004), visual search (Casco & Prunetti, 1996; Vidyasagar & Pammer, 1999), and temporal order judgement (Slaghuis, Twell & Kingstone, 1996). Iles et al (2000) found that dyslexic children who have visual problems related to magnocellular functions also have visual-attentional problems (thus poor visual search performance) related to the functions of areas such as the parietal cortex, which are dominated by inputs originating in the magnocellular lateral geniculate nucleus. Since the reading-like visual search task in ViSS requires such inhibition, especially on the visually stressful items, a weak magnocellular input to the parietal cortex may be implicated in visual stress and dyslexia. Children with high visual stress may be unable to redirect their attention from the presentation of the global repetitive pattern to the salient individual components of the matrix. Reduced processing efficiency during visual search in cases of high visual stress has been explained by an inability to direct attention away from global pattern percepts, using the hierarchical attention allocation system (Conlon et al., 1998; McConkie and Zola, 1987).

Pammer and Vidyasagar (2005) discuss the magnocellular deficit of dyslexia in terms of an early dysfunction in the dorsal visual stream. They argue that adequate early sensory coding is intrinsic to phonological awareness and subsequent reading ability. In this hypothesis, a cortical network is assumed that incorporates the visual, auditory, and phonological skills of reading. The visual sub-component of the network is mediated by the dorsal visual pathway, which is responsible for the accurate spatial encoding of letters, words and text. Pammer and Vidyasagar (2005) argue that the magnocellular-dominated dorsal stream is not working properly in dyslexia and failing to provide adequate feedback to the ventral pathway thus failing to allow detailed examination of a selected location in the visual field, particularly in cluttered visual scenes as in the visually stressful items. A magnocellular deficit has also been proposed to interfere with letter position coding (Cornelissen et al., 1998a; Cornelissen, Hansen, Hutton, Evangelinou, & Stein, 1998b). In this case, it could be that deficient position signals have a bigger impact for letters that are more crowded, as in the bolder letters of the visually stressful matrix and where they are crowded by the pattern (Anstis, 1974; Sloan, 1977).

Other related factors that could have caused dyslexic children to be more impaired during visually stressful search include visual ‘crowding’ (or lateral masking) that may be more prevalent in dyslexic children (Atkinson, 1993; Geiger & Lettvin, 1987), or differences in visual span (Legge, Ahn, Klitz, & Luebaker, 1997; Legge, Mansfield, & Chung, 2001). However, the findings that dyslexic children whose response times were significantly impaired by the visually stressful pattern also had significantly larger percent increases in reading rate with an overlay (> 20%) compared to the dyslexic children whose response times were not significantly impaired, provides support for the accuracy of ViSS in and also for a relationship between dyslexia and visual stress.

There is a problem with the magnocellular theory of visual stress: it cannot account for the idiosyncratic and specific choice of optimal colour for reading. Comparatively, Wilkins’ cortical hyperexcitability hypothesis of visual stress does provide an explanation for this. However, the latter theory does not account for a relationship between dyslexia and visual stress and regards the two conditions as independent (Wilkins, 2003). Neither theory can explain why children with dyslexia and high visual stress showed such dramatic improvements with an overlay in this study compared to non-dyslexic children with visual stress. In fact, one would expect the opposite to be the case: non-dyslexic children with visual stress should show larger improvements in reading speed with a chosen overlay as it is more likely they do not have further reading problems to hinder reading fluency. The theoretical basis for the effects of colour on reading is at present largely a matter for conjecture, and many different mechanisms may be involved. Explanations in terms of magnocellular deficits and cortical hyperexcitability may eventually converge, given that some individuals with migraine exhibit magnocellular deficits (McKendrick & Badcock, 2003). It could be speculated that dyslexic children with high visual stress have a magnocellular deficit as well as cortical hyperexcitability which further impairs on visual search performance and results in larger increases in reading rate with an overlay on WRRT, whereas the reading age controls with high visual stress may have lacked a magnocellular deficit.

In conclusion, the results of this study suggest that a full understanding of visual stress is unlikely to be achieved without an account of its relationship with dyslexia. However, the link between dyslexia and visual stress may not necessarily be causal. It is reasonable to assume that visual stress discourages motivation to practice reading, and this would exacerbate the 'Matthew effect' (progressive widening of the gap between good and poor readers as a function of differences in reading experience) described by Stanovich (1986). It could be that case that the dyslexic person's lack of automaticity in word recognition (caused by underlying phonological deficits, for example) necessitates them adopting a technique for processing text (e.g. detailed scrutiny of individual 'problem' words) that increases their sensitivity to the physical characteristics of the print, which, in turn, will naturally tend to exacerbate any symptoms or effects of visual stress. However, if this hypothesis is correct, one would predict that (a) when reading, non-dyslexic poor readers who lack automaticity in word recognition would also show increased symptoms of visual stress comparable with those found in dyslexic readers, and (b) dyslexics, when compared with non-dyslexics, would not show increased symptoms of visual stress in situations where reading is <u>not</u> involved. The latter prediction implies that dyslexics would not show the increased sensitivity to visual flicker (e.g. from fluorescent lighting or computer monitors) generally reported by persons with high susceptibility to visual stress and would be consistent with widely-reported findings of impaired flicker detection in dyslexics (Buchholz & McKone, 2004; Evans, Drasdo & Richards, 1994; Floyd, Dain & Elliott, 2004; Lovegrove, Martin & Slaghuis, 1986; Martin & Lovegrove, 1987; Mason, Cornelissen, Fowler & Stein, 1993; Talcott et al., 1998).

The literature on reading development and visual stress indicates that on several grounds it is educationally desirable that screening for visual stress should be carried out in schools. The results of this study suggest that visual stress screening and provision of appropriate treatment is especially important where dyslexia is diagnosed or suspected. By providing an objective measure of differences between persons who are significantly affected by stressful visual stimuli when reading, ViSS may also throw light on the complex relationship between dyslexia and visual stress.

Notes

1. The criteria for a diagnosis of dyslexia were as follows: (a) intelligence in the normal range, (b) statistically significant impairments in reading and spelling, and (c) statistically significant impairments in cognitive functioning such as phonological processing, working memory and/or speed of information processing.

2. All participants were asked to wear glasses if they wore them; however it was beyond the capabilities of the authors to carry out an optometric assessment, thus appropriately corrected vision is not ensured.

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References

Anstis, S.M. (1974). A chart demonstrating variations in acuity with retinal position. *Vision Research, 14, 589-592.*

Atkinson, J. (1993) Vision in dyslexics: Letter recognition, acuity, visual crowding, contrast sensitivity, accommodation, convergence and sight reading music. In S.F. Wright and R. Groner (Eds.) *Facets of dyslexia and its remediation.* Amsterdam: Elsevier Science.

Borsting, E., Ridder, W.H., Dudeck, K., Kelley, C., Matsui, L. & Motoyama, J. (1996) The presence of a magnocellular defect depends on the type of dyslexia. *Vision Research,* 36, 1047-1053.

Bouldoukian, J., Wilkins, A. J. and Evans, B. J. W. (2002). Randomized controlled trial of the effect of coloured overlays on the rate of reading of people with specific learning difficulties. *Ophthalmic & Physiological. Optics,* 22, 55–60.

Brannan, J. & Williams, M. (1987). Allocation of visual attention in good and poor readers. *Perception and Psychophysics,* 41, 23-28.

Breitmeyer, B.G., & Ganz, L. (1976). Implications of sustained and transient channels for theories of visual pattern masking, saccadic suppression, and information processing. *Psychological Review,* 83, 1-36.

Breitmeyer, B., Levi, D. M., & Harwerth, R. S. (1981). Flicker masking in spatial vision. *Vision Research*, 21, 1377-1385.

Buchholz, J. & McKone, E. (2004) Adults with dyslexia show deficits on spatial frequency doubling and visual attention tasks. *Dyslexia*, 10, 24-43.

Casco, C. & Prunetti, E. (1996). Visual search of good and poor readers: Effects with targets having single and combined features. *Perceptual and Motor skills*, 82, 1155-1167.

Conlon, E., & Hine, T. (2000). The influence of pattern interference on performance in migraine and visual discomfort groups. *Cephalagia,* 20, 708-713.

Conlon, E., & Humphreys, L. (2000). Visual search in migraine and visual discomfort groups. *Vision Research,* 41, 3063-3068.

Conlon, E., Lovegrove, W., Hine, T., Chekaluk, E., Piatek, K., & Hayes-Williams, K. (1998). The effect of visual discomfort and pattern structure on visual search. *Perception,* 27, 21-33.

Cornelissen, P.L., Bradley, L., Fowler, M.S. & Stein J.F., (1991). What children see affects how they read. *Developmental Medicine and Child Neurology*, 33, 755-762

Cornelissen, P.L., Hansen, P., Gilchrist, I. Cormack, F., Essex, J. & Frankish, C. (1998a). Coherent motion detection and letter position encoding, *Vision Research,* 38, 2181-2191.

Cornelissen, P.L., Hansen, P., Hutton, J., Evangelinou, V. & Stein, J. (1998b). Magnocellular visual function and children's single word reading. *Vision Research,* 38, 471-482.

Cornelissen, P.L., Richardson, A.R., Mason, A., & Stein, J.F. (1994) Contrast sensitivity and coherent motion detection measured at photopic luminance levels in dyslexics and controls. *Vision Research,* 35, 1483-94.

Demb, J.B., Boynton, G.M., Best, M. & Heeger, D.J. (1998) Psychophysical evidence for a magnocellular deficit in dyslexics. *Vision Research*, 38, 1555-1559.

Eden, G.F., VanMeter, J.W., Rumsey, J.M., Maisog, J.M., Woods, R.P. & Zeffiro, T.A. (1996) Abnormal processing of visual motion in dyslexia revealed by functional brain imaging. *Nature,* 382, 66-69.

Evans, B. J. W. (2001). *Dyslexia and Vision*. London: Whurr.

Evans, B. J. W., Busby, A., Jeanes, R. & Wilkins, A. J. (1995). Optometric correlates of Meares–Irlen Syndrome: a matched group study. *Ophthalmic & Physiological Optics*, 15, 481–487.

Evans, B.J.W., Drasdo, N. & Richards, I. (1994) An investigation of some sensory and refractive visual factors in dyslexia. *Vision Research*, 34, 1913-1926.

Evans, B.J.W., & Joseph, R. (2002). The effect of coloured filters on the rate of reading in an adult student population. *Ophthalmic & Physiological Optics*, 22, 535-545.

Evans, B. J. W., Wilkins, A. J., Brown, J., Busby, A., Wingfield,A. E., Jeanes, R. and Bald, J. (1996). A preliminary investigation into the aetiology of Meares–Irlen Syndrome. *Ophthalmic & Physiological Optics,* 16, 286–296.

Farmer, M., & Klein, R. (1995). The evidence for a temporal processing deficit linked to dyslexia: A review. *Psychonomic Bulletin and Review,* 2, 460-493.

Fischer, B. & Hartnegg, K. (2000). Effects of visual training on saccade control in dyslexia. *Perception,* 29, 531-543

Floyd, R.A., Dain, S.J., & Ellliott, R. T. (2004) Is the perception of brightness different in poor readers? *Vision Research*, 44, 221-227.

Frith, C. & Frith, U. (1996) A biological marker for dyslexia. *Nature*, 382, 19-20.

Geiger, G. & Lettvin, J.Y. (1987). Peripheral vision in persons with dyslexia. *New England Journal of Medicine*, 316, 1238-1243.

Grant, D. (2004) *From myths to realities: Lessons to be drawn from over 600 student assessments.* Paper presented at the 6th International Conference of the British Dyslexia Association, University of Warwick, March 2004.

Grounds, A.R. & Wilkins, A.J. (unpublished) Separating the visual and semantic factors that affect reading speed in dyslexic children (cited in Wilkins, 2003).

Hansen, P., Stein, J., Orde, S., Winter, J, & Talcott, J. (2001) Are dyslexics' visual deficits limited to measures of dorsal stream function? *Neuroreport*, 12, 1527-1530.

Henderson, L.M., & Singleton, C.H. (submitted). Visual search as a predictor of visual stress in reading.

Iles, J., Walsh, V. & Richardson, A. (2000) Visual search performance in dyslexia. *Dyslexia*, 6, 163-177.

Irlen, H. (1991). *Reading by the colours*. New York: Avery.

Irlen, H. (1994) Scotopic sensitivity/Irlen Synrome: hypothesis and explanation of the syndrome. *Journal of Behavioural Optometry*, 5, 62 & 65-6.

Jeanes, R., Busby, A., Martin, J., Lewis, E., Stevenson, N., Pointon, D., & Wilkins, A. (1997). Prolonged use of coloured overlays for classroom reading. *British Journal of Psychology*, 88, 531-548.

Kriss, I. & Evans, B.J.W. (2005). The relationship between dyslexia and Meares-Irlen syndrome. *Journal of Research in Reading,* 28, 350-364.

Legge, G.E., Ahn, S.J., Klitz, T.S. & Luebaker, A. (1997) Psychophysics of reading – XVI. The visual span in normal and low vision. *Vision Research*, 37, 1999-2010.

Legge, G.E., Mansfield, J.S. & Chung, S.T.L. (2001) Psychophysics of reading – XX. Linking letter recognition to reading speed in central and peripheral vision. *Vision Research*, 41, 725-743.

Lehmkule, S. (1993) Neurological basis of visual processes in reading. In D. Willows, R. Kruk & E. Corcos (Eds.) Visual Processes in Reading and Reading Disabilities. New Jersey: pp. 77-94.

Livingstone, M., Rosen, G.D., Drislane, F. & Calaburda, A. (1991). Physiological evidence for a magnocellular deficit in developmental dyslexia. *Proceedings of the New York Academy of Science*, 88, 7943-7.

Lovegrove, W.J., Heddle, M. & Slaghuis, W. (1980) Reading disability: spatial frequency specific deficits in visual information store. *Neuropsychologia*, 18, 111-115.

Lovegrove, W.J., Martin, F. & Slaghuis, W. (1986) A theoretical and experimental case for a visual deficit in specific reading disability. *Cognitive Neuropsychology*, 3, 225-67.

Martin, F. & Lovegrove, W. (1984) The effects of filed size and luminance control on contrast sensitivity differences between specifically reading disabled and normal children. *Neuropsychologia*, 22, 73-77.

Martin, F. & Lovegrove, W. (1987) Flicker contrast sensitivity in normal and specifically disabled readers. *Perception*, 16, 215-221.

Mason, A. J. Cornelissen, P. L., Fowler, M. S., & Stein, J. F. (1993) Static and flicker contrast sensitivity in children with unstable visual direction sense. *Clinical Vision Science*, 8, 345-353.

McConkie, G.W., & Zola, D. (1987). *Visual attention during eye-fixations while reading*. In M. Colheart, (Ed) *Attention and performance XII* (pp. 385-401). Hillsdale, NJ: Lawrence Earlbaum.

McKendrick, A., & Badcock, D. (2003) Contrast-processing dysfunction in both magnocellular and parvocellular pathways in migraineurs with or without aura. Investigative *Ophthalmology and Vision Science*, 44, 442-448

Northway, N. (2003). Predicting the continued use of overlays in school children - a comparison of the Developmental Eye Movement test and the Rate of Reading test. *Ophthalmic & Physiological Optics*, 23, 457-464.

O'Brien, B.A., Mansfield, J.S. & Legge, G.E. (2000). The effect of contrast on reading speed in dyslexia. *Vision Research*, 40, 1921-1935.

Pammer, K., Lavis, R., Hansen, P. & Cornelissen, P. (2004). Symbol-string sensitivity and children's reading. *Brain and Language*, 89, 601-610.

Pammer, K. & Vidyasagar, T.R. (2005) Integration of the visual and auditory networks in dyslexia: a theoretical perspective. *Journal of Research in Reading*, 28, 320-331.

Pammer, K. & Wheatley, C. (2001). Isolating the M(y)-cell response in dyslexia using the spatial frequency doubling illusion. *Vision Research*, 41, 2139-2147.

Ramus, F., Rosen, S., Dakin, S.C., Day, B.L., Castellote, J.M., White, S., and Frith, U. 2003. Theories of developmental dyslexia: Insights from a multiple case study of dyslexic adults. *Brain*, 126, 1-25.

Robinson, G.L. & Foreman, P.J. (1999). Scotopic sensitivity/Irlen Syndrome and the use of coloured filters: a long-term placebo-controlled and masked study of reading achievement and perception of ability. *Perceptual & Motor Skills,* 88, 35-52.

Ruddock, K.H. (1991) Visual search in dyslexia. In J. Stein (Ed.) *Vision and Visual Dyslexia.* London: MacMillian.

Scheiman, M. (1994) Scotopic sensitivity syndrome, reading disability and vision disorders. *Journal of Behavioural Optometry*, 5, 63-7.

Shaywitz, S.E., Escobar, M.D., Shaywitz, B.A., Fletcher, J.M. & Makugh, R. (1992). Evidence that dyslexia may represent the lower tail of a normal distribution of reading ability. *New England Journal of Medicine*, 326, 145-50.

Singleton, C.H. & Henderson, L.M. (submitted) Computerised screening for visual stress in reading.

Singleton, C.H. & Trotter, S. (2005). Visual stress in adults with and without dyslexia. *Journal of Research in Reading*, 28, 365-378.

Skottun, B. C. (2001). On the use of metacontrast to assess magnocellular function in dyslexic readers. *Perception & Psychophysics*, 63, 1271-1274.

Skotton, B.C. (2000) The magnocellular deficit theory of dyslexia: evidence from contrast sensitivity. *Visual Research*, 40, 111-27.

Slaghuis, W., Twell, A. & Kingstone, K. (1996) Visual and language processing disorders are concurrent in dyslexia and continue into adulthood. *Cortex*, 32, 413-438.

Sloan, I.L. (1977). *Reading aids of the partially sighted: a systematic classification procedure for prescribing* .Baltimore, MD: Williams and Wilkins.

Sloman, R.T., Cho, H. & Dain, S.J. (1991) Colour-mediated grouping effects in good and disabled readers. *Ophthalmic & Physiological Optics*, 11, 320-7.

Sloman, R.T., Dain, S.J., Lim, H. & May, J.G. (1995) Reading-related wavelength and spatial frequency effects in visual spatial location. *Ophthalmic and Physiological Optics*. 15, 125-32.

Stanovich, K. E. (1986) Matthew effects in reading: Some consequences of individual differences in the acquisition of reading. *Reading Research Quarterly,* 21, 360-407.

Stein, J.F. (2001). The magnocellular theory of dyslexia. *Dyslexia,* 7, 12-36.

Stein, J.F., Talcott, J.B., & Walsh, V. (2000) Controversy about the visual magnocellular deficit in developmental dyslexics. *Trends in Cognitive Science*, 4, 209-11.

Stein, J.F. & Talcott, J.B. (1999) Impaired neuronal timing in developmental dyslexia – The magnocellular hypothesis. *Dyslexia*, 5, 59-77.

Stein, J.F. & Walsh, V. (1997). To see but not to read: the magnocellular theory of dyslexia. *Trends in Neuroscience*, 20, 147-52.

Stevenson, S.J. and Evans, B.J.W. (in preparation) A normative study of the pattern glare test (cited in Kriss & Evans, 2005).

Talcott, J.B., Hansen, P.C., Willis-Owen, C., McKinnell, I.W., Richardson, A.J., & Stein, J.F. (1998). Visual magnocellular in adult developmental dyslexics. *Neuro-ophthalmology*, 20, 187-201.

Tyrrell, R., Holland, K., Dennis, D., Wilkins, A.J. (1995). Coloured overlays, visual discomfort, visual search and classroom reading. *Journal of Research in Reading,* 18(1), 10-23.

Vidyasagar, T.R. & Pammer, K. (1999). Impaired visual search in dyslexia relates to the role of the magnocellular pathway in attention. *NeuroReport,* 10, 1283-1287.

Wilkins, A.J. (1995). *Visual Stress*. Oxford: Oxford University Press, pp.194.

Wilkins, A.J. (2003). *Reading Through Colour*. Chichester, Sussex: Wiley.

Wilkins, A.J., Evans, B.J.W., Brown, J., Busby, A., Winfield, A.E., Jeanes, R. & Bald, J. (1994). Double masked placebo controlled trials of precision spectral filters in children who use coloured overlays. *Ophthalmic & Physiological Optics*, 14, 365-70.

Wilkins, A.J., Jeanes, R.J., Pumfrey, P.D., & Laskier, M. (1996) Rate of Reading Test: its reliability, and its validity in the assessment of the effects of coloured overlays. *Ophthalmic and Physiological Optics*, 16, 491-497.

Wilkins, A.J., Huag, J. & Cao, Y. (2004) Visual stress theory and its application to reading and reading tests. *Journal of Research in Reading,27, 152-162.*

Wilkins, A.J. & Lewis, E. (1999). Coloured overlays, text and texture. *Perception,* 28, 641-650.

Wilkins, A.J., Lewis, E., Smith, F., Rowland, E., Tweedie, W. (2001). Coloured overlays and their benefit for reading. *Journal of Research in Reading*, 24, 41-64.

Williams, M.C., Brannan, J.R. & Lartigue, E.K. (1987) Visual search in good and poor readers. *Clinical Vision Sciences*, 1, 367-371.

Williams, M.C., LeCluyse, K., & Rock-Faucheux, A. (1992). Effective interventions for reading disability. *Journal of the American Optometric Association,* 63(6), 411-417.

Yule, W., Rutter, M., Berger, M. & Thompson, J. (1974) Over and under achievement in reading: distribution in the general population. *British Journal of Educational Psychology*, 44, 1-12.

Zeki, S. (1983). Colour coding in the cerebral cortex: The responses of wavelength-selective and colour-coded cells in monkey visual cortex to changes in wavelength composition. *Neuroscience*, 9, 767-781.

Appendix

1. *Visual Stress Symptom Questionnaire*

Non-critical Questions:

1. Does reading make you tired?
2. Does reading become harder the longer you read?
3. Do you lose your place when reading?

Critical Questions:

1. Does print move about when you read?
2. Does print become fuzzy or blurry when you read?
3. Does the white page between the lines of print form patterns like rivers?
4. Does the white page glare against the black letters?
5. Do you get sore or tired eyes when reading for a long time?
6. Do you get headaches when reading for a long time?

Table 1. Mean (and SD) visual search time (in seconds) for individual and combined items for the dyslexic and reading-age control groups divided by high and low visual stress.

	Dyslexic group			Reading-age controls		
	All	**High visual stress**	**Low visual stress**	**All**	**High visual stress**	**Low visual stress**
N	22	9	13	22	5	17
Non-visually stressful search	43.06 (25.00)	38.67 (12.72)	46.10 (23.57)	30.39 (19.82)	28.82 (24.81)	30.86 (25.78)
Visually stressful search	68.93 (34.65)	83.57 (31.06)	56.49 (30.21)	47.69 (24.08)	56.99 (37.65)	44.96 (19.29)
Overall search time)	56.00 (24.70)	60.56 (20.50)	52.84 (27.58)	44.92 (17.53)	55.33 (15.71)	41.87 (17.26)
Percent increase between items	67.81 (81.15)	122.9 (88.48)	29.65 (49.50)	29.04 (38.17)	60.92 (29.53)	19.67 (35.82)

Table 2. Wilkins Rate of Reading Test mean scores in words per minute (and SDs) with and without a chosen coloured overlay.

	Without coloured overlay	**With coloured overlay**
Dyslexic group	81.32 (34.99)	93.08 (33.11)
Reading-age controls	90.54 (27.42)	91.40 (26.88)
Overall	85.93 (31.28)	92.24 (29.81)

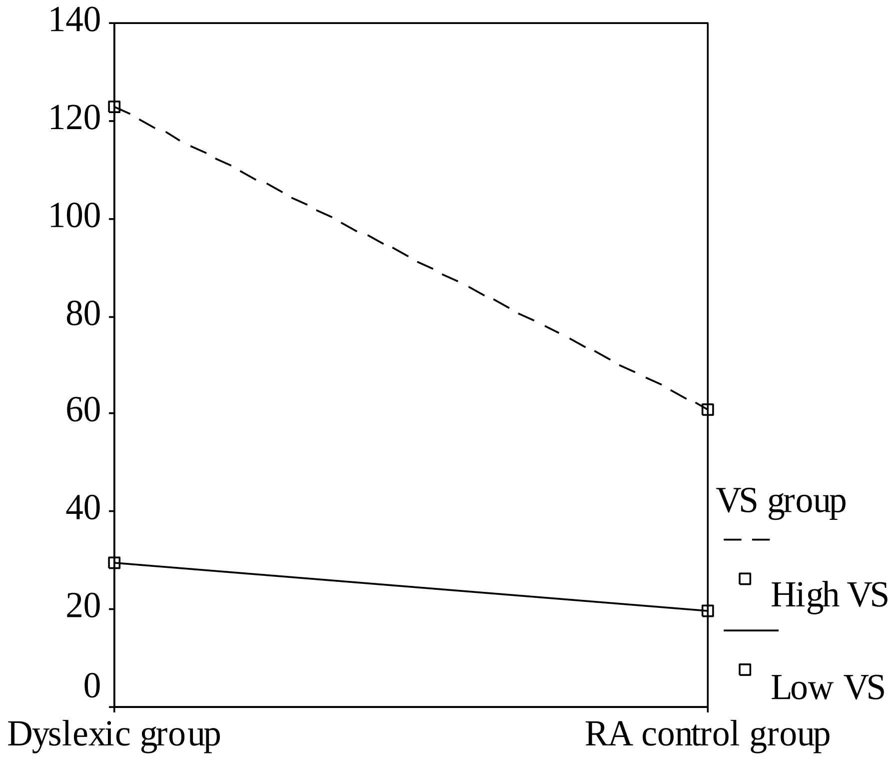

Figure 1. Mean percent increase from non-visually stressful to visually stressful ViSS items for dyslexic and reading age (RA) control groups and high and low visual stress (VS) groups.

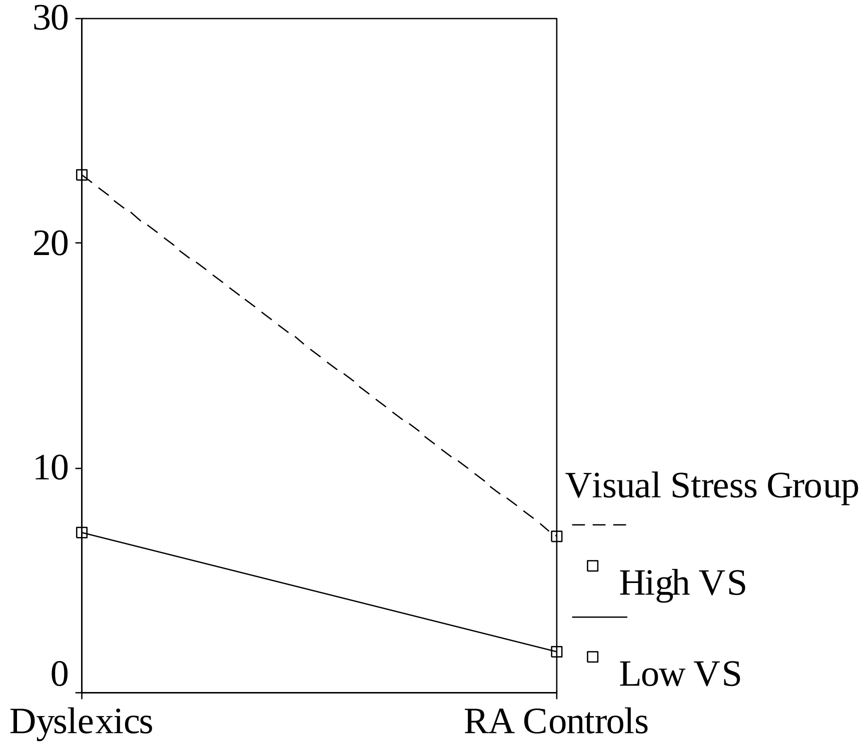

Figure 2. Mean percent increase in reading rate with an overlay for dyslexic and reading age (RA) control groups and high and low visual stress (VS) groups.