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Computerised screening for visual stress in reading

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Visual stress is the experience of unpleasant visual symptoms when engaged in reading and some other visual tasks. There is currently no objective diagnostic test for this condition, which affects a substantial proportion of the population and which can disrupt development of reading skills. The reliability of subjective reports of symptoms has been questioned, especially where children are concerned. Diagnosis by positive response to the preferred treatment method, either the sustained voluntary use of a coloured overlay or immediate improvement in reading rate when using an overlay, is usually regarded as the best option. Recent research has reported that children who are significantly impaired by a visually stressful pattern during reading-like visual search are more likely to show significant improvement in reading speed when using an overlay. This study was designed to evaluate a prototype computerised visual stress screener that incorporated visual search. The results confirmed that primary and secondary school children who were classified by the screener as having high susceptibility to visual stress had larger percent increases in reading rate with an overlay compared with those with low visual stress. The results also indicated that subjective reports of symptoms may not always be diagnostically effective with younger populations. It was concluded that screening for visual stress in reading using a computerised visual search task is an educationally promising development.

Visual stress is the subjective experience of unpleasant visual symptoms when engaged in reading and some other visual tasks. The symptoms include visual perceptual distortions (illusions of shape, motion and colour; transient instability; diplopia) and asthenopia (sore, tired eyes; headaches; photophobia). Visual stress when reading, sometimes known as Meares–Irlen syndrome, is often defined as a condition that is 'alleviated by using individually prescribed coloured filters' (Kriss & Evans, 2005, p. 300). Visual stress and its remediation with individually prescribed coloured overlays has been supported by randomised double-masked placebo-controlled trials (Evans, Busby, Jeanes & Wilkins, 1995; Evans et al., 1996; Robinson & Foreman, 1999; Wilkins et al., 1994). These studies have shown coloured overlays can reduce symptoms and increase rate of reading (Bouldoukian, Wilkins & Evans, 2002; Wilkins & Lewis, 1999; Wilkins, Lewis, Smith, Rowland & Tweedie, 2001), and sometimes improve reading accuracy and comprehension (Robinson & Foreman, 1999).

There are two principal competing theories regarding the cause of visual stress. Wilkins and colleagues (for reviews see Evans, 2001; Wilkins, 1995, 2003) maintain that visual stress is caused by pattern glare, i.e. a general over-excitation of the visual cortex due to hypersensitivity to contrast. Geometric repetitive patterns that can evoke seizures in people with photosensitive epilepsy or trigger headaches in migraineurs can produce perceptual distortions in normal individuals as a result of neural 'overload' (Wilkins, 1995, 2003). The visual grating created by lines of print, especially where the pattern is glaring, is believed to generate similar physiological effects. Wilkins (1995, 2003) speculates that as the wavelength of light is known to affect neuronal sensitivity (Zeki, 1983) the use of colour could redistribute the cortical hyperexcitability, thus reducing the perceptual distortions and headaches.

The second theoretical explanation is the magnocellular hypothesis. This posits that visual stress is due to a deficit in the magnocellular visual system, which is sensitive to high temporal frequency information and triggered by eye movements (Livingstone, Rosen, Drislane & Calaburda, 1991; Stein, 2001; Stein & Walsh, 1997; Williams, LeCluyse & Rock-Faucheux, 1992). The magnocellular system plays a major role during reading (Edwards, Hogben, Clark & Pratt, 1995), underlying saccadic suppression and facilitating clear perception of text in successive visual fixations (Breitmeyer & Ganz, 1976). Stein (2001) argues that boosting magnocellular performance using yellow filters can improve reading performance.

Symptom questionnaires (e.g. Conlon & Hine, 2000; Irlen, 1991) are frequently used to identify children who are susceptible to visual stress when reading and who may therefore benefit from coloured overlays. However, it is recognised that questioning children about suspected visual perceptual symptoms could result in misleading and subjective responses, and some children may answer unreliably due to a lack of understanding of the questions (Northway, 2003). Children who have always experienced symptoms when reading often accept these as 'normal' and only realise they are abnormal once they have been alleviated (Evans & Joseph, 2002). Given these problems with using symptom questionnaires with children, the currently preferred method of diagnosis for visual stress is based on the favoured treatment method: either the sustained voluntary use of an overlay or immediate improvement in reading speed (typically of $>5\%$) on the Wilkins Rate of Reading Test (WRRT; Wilkins, 2003). However, although overlay testing is rapid, has high test–retest reliability and can be easily used in the classroom (Wilkins, 2003), this approach to diagnosis raises a number of serious problems.

Firstly, colour does not work for all individuals with visual stress (Evans & Joseph, 2002). Evans and Joseph (2002) found that 88% of their sample chose a coloured overlay; however 32% of these participants did not read any faster with their chosen overlay, and only one-third demonstrated a significant benefit. Further, of those who experienced a gain in reading rate of $>5\%$ when using an overlay, 76% reported sore or tired eyes when reading, but only 37% reported words blurring when reading, and only 37% had frequent headaches. Hence some adults benefit from using coloured overlays when reading despite failing to report symptoms of visual stress. Using the Intuitive Colorimeter, Singleton and Trotter (2005) found that rate of reading was significantly increased by optimal colour in adults with both dyslexia and visual stress, but not in non-dyslexic adults with visual stress. L. M. Henderson and C. H. Singleton (unpublished data) also found that diagnosis of visual stress based on $>5\%$ increase in rate of reading on WRRT may be limited for some individuals because of an interaction with reading accuracy. They discovered that in children with above average reading accuracy, the mean percent increase in reading rate for participants with high visual stress was $<10\%$, and $<5\%$ for children with moderate visual stress. By contrast, increase in reading rate was $>10\%$ for children with high visual stress and average or below average reading accuracy. According to the criteria suggested as most appropriate by Kriss and Evans (2005) the children with above average reading accuracy in Henderson and Singleton's (unpublished data) study would not have been classified as having visual stress.

Secondly, there are no generally accepted criteria for how much faster an individual should read with an overlay, or how long the person has to use an overlay over a sustained period, in order to receive a diagnosis. This has implications for calculating the incidence of visual stress, which varies according to the criteria adopted. Using the voluntary sustained use criteria (usually taken to be one half to one full school term; Evans & Joseph, 2002), the incidence of visual stress in unselected school populations has been found to be approximately 20% (Kriss & Evans, 2005). However, the diagnostic criterion most commonly used in the literature is the $>5\%$ increase in reading rate with an overlay. Using this, the incidence of visual stress has been reported as approximately 33–34% (Evans & Joseph, 2002; Kriss & Evans, 2005; Wilkins et al., 2001). This is substantially higher than the 20% reported by Wilkins, Jeanes, Pumfrey and Laskier (1996). However, the 5% criteria is very 'easy' to pass, and according to Jeanes et al. (1997) an increase of $>8\%$ in rate of reading with an overlay is a better indicator of prolonged use of an overlay. On the other hand, in some cases having a set criterion may be unreliable as it is likely that visual stress lies on a continuum, ranging from individuals who experience no help from overlays, to the more severe cases who experience improved reading performance and a marked reduction in symptoms (Evans & Joseph, 2002).

Thirdly, Northway (2003) compared the WRRT with the Developmental Eye Movement (DEM) test (used to test horizontal scanning behaviour) to determine whether coloured overlays could enhance reading performance or scanning of dyslexic children. It was revealed that WRRT identified considerably fewer children who would continue to use overlays compared with the DEM test. Improvements to the DEM scores occurred in 88% of children who used overlays for >3 months compared with 60% sensitivity in the WRRT. Despite the fact that the children did not show any increase in reading speed, they continued to prefer to use the overlay than to be without it. This is problematic in that the current clinical recommendations (an increase of reading rate by $>5\%$) would fail to provide objective support for the subjective preference displayed by many of the children using overlays. Alternatively, these children may have suffered perceptual distortions even though their reading rate did not increase significantly with an overlay. Thus it would appear that reading speed may not be the most efficient way to monitor changes in visual perception for some children.

Henderson and Singleton (in press) found that performance on a visual search task predicted visual stress susceptibility in an unselected sample of 9–10-year-olds, to a degree of accuracy that would make such a task suitable as an objective screener. The task required the child to locate a random three-letter word in a matrix of distractor three-letter words where the background was either non-visually stressful (grey) or visually stressful (black/white horizontally striped repetitive pattern). The results indicated that children whose response times were significantly impaired by the visually stressful pattern had significantly higher percent increases in reading rate on WRRT compared with children who were not impaired by the pattern. Conlon et al. (1998) also reported similar results; participants with severe visual stress performed slower than low visual stress groups on reading-like visual search tasks in the presence of low spatial frequency grating pattern backgrounds requiring conscious (Conlon et al., 1998) or automatic visual attention (Conlon & Hine, 2000).

The first objective of the present study was to evaluate the visual search task developed by Henderson and Singleton (in press) when employed for the purpose of screening for visual stress in unselected samples of primary and secondary school children. It was hypothesised that participants who had positive results on the screener would be more likely to show benefit from using an overlay, as measured by improvement in reading rate on WRRT. The second objective was to compare the predictive accuracy of the visual stress screener (VSS) with that of a visual stress symptom questionnaire.

Method

Participants

All participants spoke English as their first language and all reported normal or appropriately corrected vision.[1]

Primary school sample. The participants were an unselected sample of 50 children (23 males, 27 females) attending a primary school in the city of Kingston-upon-Hull. The children were aged 7–11 years; mean age 9.23 years (*SD* = 1.41 years). The British Ability Scales (2nd Edition) Basic Reading Test was administered to all participants to ensure reading accuracy was not a confounding variable and the sample was found to be normally distributed (mean reading age 9.66 [*SD* = 2.67]; mean standard score 99.48 [*SD* = 17.81]).

Secondary school sample. The participants were an unselected sample of 67 students (36 males, 31 females) attending an unselective secondary school in the city of Kingston-upon-Hull. The students were aged 11–17 years; mean age 13.45 years (*SD* = 1.71 years). This sample had a mean reading age of 13.57 (*SD* = 3.43) and a mean standard score of 100.40 (*SD* = 21.44).

Apparatus and materials

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.

*WRRT (*Wilkins et al., 1996). 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 typeface, 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.

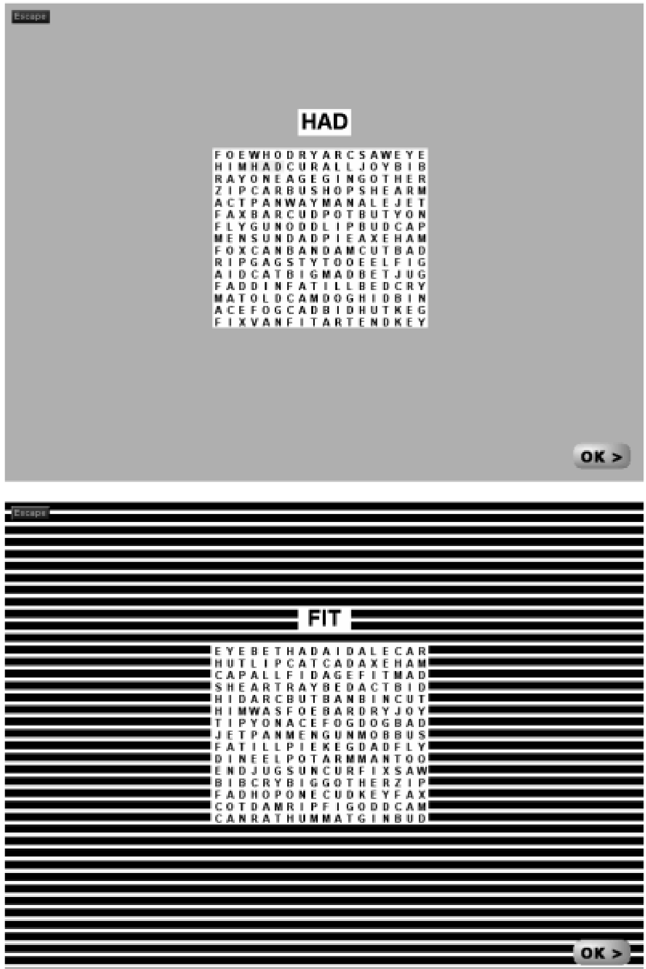

Figure 1. Examples of (top) visually unstressful and (beneath) visually stressful search conditions.

VSS. The VSS is a computerised task that 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 randomly selected from the same database. The size of the matrix was 18×15 letters for primary school children (total 90 words) and 21×16 letters (126 words) for secondary school students, and there were no spaces between words. The location of the target is randomly generated. The target word is signalled by the computer both visually (by appearing on screen above the search matrix) and aurally (digitised speech). 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 (see Figure 1). The non-visually stressful matrix is in 10 point Arial normal font and set on a grey background. The visually stressful matrix is in 10 point Arial bold font and set on an alternated black/white horizontally striped background, the black stripes being horizontally aligned with the adjacent lines of text. (The size of the font was reduced to 9 point for secondary school students for both conditions.) The stripes have an equal duty cycle and fill the entire screen on which the matrix is superimposed. Two non-visually stressful practice items precede 6 non-visually stressful test items, 15 visually stressful test items and finally 4 non-visually stressful test items. The task was administered on a laptop computer; the screen was positioned 35 cm 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 VSS took a mean of 35 minutes for primary-aged children. To reduce possible confounding variables such as boredom, fatigue or motivation three short cartoons were added into the program for the primary-age version only. These were inserted at the end of the non-visually stressful block, at the end of the visually stressful block and at the completion of the task. Second, a recorded voice-over giving 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.

Visual stress symptom questionnaire. The symptom questionnaire 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 A). Each question was read aloud to the participant and is rated on a 5-point scale from 0 (*never*) to 4 (*always*); total score range 0–36; non-critical score range 0–12; critical score range 0–24.

Procedure

Participants were individually tested at school in a quiet, empty room that was illuminated by 50 Hz fluorescent lighting (care was taken to avoid glare from overhead lights and windows). Participants were instructed to wear glasses that were usually worn for reading. The participants completed the following three separate subtests, which were counterbalanced to control for order effects. First, participants were assessed with the Intuitive Overlays to determine the most comfortable colour for reading, and where an individual had no colour preference a grey overlay was used. All participants were then administered the WRRT under two conditions: with their overlay and without. WRRT was used as described in the manual 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 familiarise them with reading randomly ordered text. Second, the symptom questionnaire was administered. Third, all participants completed the appropriate VSS.

Results

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

Children from both samples were put into groups of 'low visual stress' or 'high visual stress' susceptibility based on the outcome of VSS. Where children's search times on visually stressful items were significantly longer than on non-visually stressful items (t test; $p < .05$) they were put into the 'high visual stress' group (primary sample: $N = 12$; secondary sample: $N = 14$); otherwise they were put into the 'low visual stress' group

Table 1. Mean response times (and standard deviations) for the two conditions for both samples, as a function of visual stress group.

Visual stress group	*N*	Non-visually stressful condition (seconds)	Visually stressful condition (seconds)	Total mean RT (seconds)	Mean percent increase
Primary school sample					
Low VS	38	43.74 (14.36)	53.3 (20.91)	47.67 (15.38)	24.20 (39.85)
High VS	12	37.99 (9.97)	69.31 (16.12)	52.67 (13.27)	78.67 (30.11)
All	50	42.36 (13.57)	56.22 (20.84)	48.88 (14.93)	37.25 (44.19)
Secondary school sample					
Low VS	53	35.53 (16.24)	38.33 (17.31)	35.75 (15.95)	9.04 (37.97)
High VS	14	28.37 (6.48)	59.83 (26.32)	43.00 (11.31)	105.53 (31.71)
All	67	34.05 (16.91)	40.23 (18.43)	37.13 (15.32)	28.32 (50.51)

Note: VS, visual stress.

(primary sample: $N = 38$; secondary sample: $N = 53$). In the primary sample the mean standard reading score for the low visual stress group was 103.39 ($SD = 17.3$) and 87.09 ($SD = 13.60$) for the high visual stress group. In the secondary sample, the mean standard reading score for the low visual stress group was 101.34 ($SD = 21.54$) and 96.92 ($SD = 5.74$) for the high visual stress group. Although there are noticeable differences between the high and low visual stress groups it should also be noted that the *SD*s are relatively large. In fact, neither of these differences was found to be significant.

Primary school data

Table 1 shows the response times for the two conditions as a function of visual stress group. Comparing the two groups using analysis of variance (ANOVA), only the response times for the visually stressful condition, $F(1, 48) = 5.4$; $p < .05$, and the percent increase in response times were found to be significant, $F(1, 48) = 18.83$; $p < .0001$. This is consistent with the finding of Henderson and Singleton (in press) that VSS discriminates between high and low susceptibility to visual stress in visually stressful, but not on non-visually stressful items.

Table 2 shows the number of students in the primary school sample whose reading rate increased by $>5\%$, 8% and 10% with an overlay. Repeated measures ANOVA was carried out, rate of reading with, and without, an overlay being the within-subjects factor and visual stress group as the between-subjects factor. A significant overall main effect of using an overlay on rate of reading was found; rate of reading was significantly faster with ($M = 96.95$; $SD = 28.05$) compared to without ($M = 91.05$; $SD = 28.18$) an overlay, $F(1, 48) = 58.44$, $p < .001$. No significant overall effect was found for visual stress group on rate of reading, despite reading rate being slower in the high visual stress group ($M = 85.33$; $SD = 34.51$) compared with the low visual stress group ($M = 96.7$; $SD = 25.7$), $F(1, 48) = .719$, $p > .05$. However, a significant interaction was found between with/without overlay and visual stress group, $F(1, 48) = 32.76$, $p < .001$; rate of reading was significantly faster with an overlay ($M = 93.66$; $SD = 36.54$) compared to without ($M = 85.33$; $SD = 34.51$) in the high visual stress group compared with the low visual stress group (without overlay $M = 96.78$, $SD = 25.79$; with overlay $M = 97.98$, $SD = 25.32$; $p < .05$; see Figure 2).

Table 2. Number of participants in both samples whose reading rates increased with an overlay according to different criteria.

	Percentage increase in reading rate		
	5%	8%	10%
Primary school sample ($n = 50$)	15 (30%)	9 (18%)	7 (14%)
Secondary school sample ($n = 67$)	29 (43.3%)	19 (28.4%)	15 (22.4%)

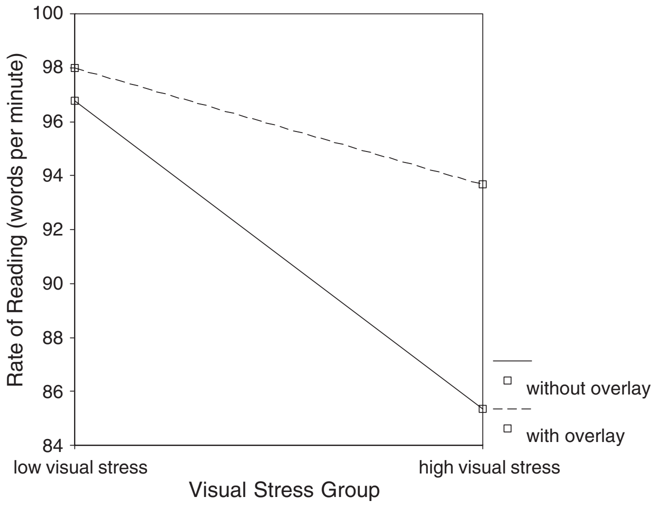

Figure 2. Rate of reading with and without an overlay as a function of visual stress group for primary school children.

Table 3 shows the results of the symptom questionnaire. One-way ANOVA showed a significant main effect of visual stress group on total symptom scores, $F(1, 48) = 38.11$, $p < .001$, the high visual stress group scoring significantly higher than the low visual stress group. One-way ANOVA revealed a significant main effect of visual stress group on critical symptom questionnaire scores, $F(1, 48) = 38.14$, $p < .001$. Total critical scores were significantly higher for the high visual stress group compared with the low visual stress group ($p < .05$). A significant main effect of visual stress group on non-critical symptom questionnaire scores was also found, $F(1, 50) = 11.45$, $p < .001$; total non-critical scores were higher for the high visual stress compared with the low visual stress group.

In order to determine the predictive accuracy of VSS, rates for false positives and false negatives were calculated. In this context, false positives are cases where the screener classifies a child as having high susceptibility to visual stress when they actually have a low susceptibility to visual stress. False negatives are cases where the screener classifies a child as having low susceptibility to visual stress when they actually have a high susceptibility to visual stress. In fact, as there is no universally agreed criterion for assessing visual stress against which to compare VSS, false positives and false negatives

Table 3. Mean scores (and standard deviations) on the symptom questionnaire for both samples.

Visual stress group	*N*	Non-critical score (range 0–12)	Critical score (range 0–24)	Total (range 0–36)
Primary school sample				
Low VS	38	2.05 (2.65)	2.94 (2.57)	4.86 (4.00)
High VS	12	4.75 (2.63)	9.66 (4.97)	14.41 (6.43)
All	50	2.7 (2.65)	4.56 (4.35)	7.16 (6.19)
Secondary school sample				
Low VS	53	3.92 (5.35)	4.71 (4.68)	8.40 (6.30)
High VS	14	5.35 (2.40)	9.07 (5.78)	14.42 (6.67)
All	67	4.22 (2.74)	5.62 (5.20)	9.73 (6.78)

Note: VS, visual stress.

calculated here reflect the accuracy of VSS in predicting either improvement in reading rate with an overlay or reported symptoms of visual stress in reading.

The false positive rate for VSS when predicting improvement in reading rate with an overlay for the primary school children was 41.6% when using the $>8\%$ gain in reading rate with an overlay as the criterion (i.e. 5 of the 12 participants who fell into the high visual stress group did not meet this criterion). When the $>5\%$ improvement in reading rate with an overlay was used as the criterion the false positive rate dropped to 8.3% (1 of 12). The equivalent false negative rate on VSS was 5.26% using the $>8\%$ criterion (i.e. 2 of the 38 children in the low visual stress group showed $>8\%$ gain in reading rate with an overlay). This increased to 13.15% (5 of 38) when the $>5\%$ criterion was used. Percent increases between items on VSS and between reading rate without and with an overlay were strongly correlated ($r = .45$; $p < .0001$).

Carrying out the same analysis for the accuracy of the symptom questionnaire in predicting improvement in reading rate with an overlay, 37.5% were found to be false positives (i.e. 3 of the 8 children who had a critical symptom score of >1 *SD* above the mean on the symptom questionnaire did not gain in reading rate by $>5\%$). This figure was unchanged when the $>8\%$ gain in reading rate was used as the criterion. The false negative rate for the symptom questionnaire was 19.04% (i.e. 8 of the 42 children who had a mean critical score of <1 *SD* above the mean *did* gain in reading rate by $>5\%$). The false negative was reduced to 7.1% (3 of 42) when the $>8\%$ criterion was applied. Critical symptom scores and percent increases in reading rate with an overlay were strongly correlated ($r = .59$; $p < .0001$).

When the accuracy of VSS in predicting the results of the symptom questionnaire was assessed, the false positive rate was found to be 41.66% (i.e. 5 of the 12 children who fell into the high visual stress group had a mean critical symptom score that was <1 *SD* above the mean critical score). Nevertheless, two of these children showed $>8\%$ gain in reading rate with an overlay and all showed an increase of $>5\%$ gain in reading rate with an overlay, suggesting that the symptom questionnaire results were misleading in this instance. The false negative rate was 2.6% (i.e. 1 of the 38 children who fell into the low visual stress group had a mean critical score that was >1 *SD* above the mean critical score). However, this single child did not show an increase in reading rate of $>5\%$ with an overlay. Scores on VSS and critical symptom scores were moderately correlated ($r = .34$; $p < .01$).

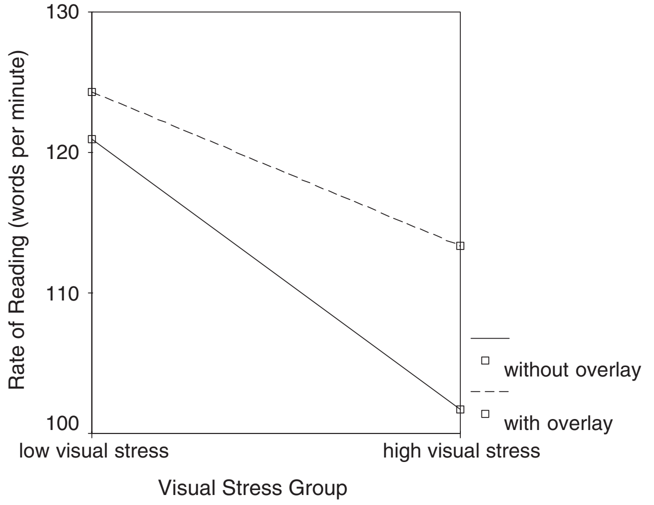

Figure 3. Rate of reading with and without an overlay as a function of visual stress group for secondary school children.

Secondary school data

Table 1 also shows the secondary school students' response times for the two conditions as a function of visual stress group. Comparing the two groups using ANOVA, only the response times for the visually stressful condition, $F(1, 65) = 20.35$; $p < .0001$, and the percent increase in response times were found to be significant, $F = (1, 65) = 86.33$; $p < .0001$. As with the primary school findings, this is consistent with the finding of Henderson and Singleton (in press).

Table 2 also shows the number of students in the secondary school sample whose reading rate increased by $>5\%$, 8% and 10% with an overlay. Repeated measures ANOVA was carried out, rate of reading with, and without, an overlay being the within-subjects factor and visual stress group as the between-subjects factor. A significant main effect of using an overlay on rate of reading was found; rate of reading was significantly faster with ($M = 122.03$; $SD = 35.20$) compared to without ($M = 116.93$; $SD = 33.87$) an overlay, $F(1, 65) = 31.08$, $p > .0001$. No significant effect was found for visual stress group on rate of reading, despite reading rate being lower in the high visual stress group ($M = 101.67$; $SD = 31.34$) compared with the low visual stress group ($M = 120.97$; $SD = 32.91$), $F(1, 65) = 2.207$, $p > .05$. A significant interaction was found between with/without overlay and visual stress group, $F(1, 65) = 9.52$, $p < .01$; rate of reading was significantly higher with an overlay ($M = 113.34$; $SD = 35.99$) compared to without ($M = 101.67$; $SD = 34.31$) in the high visual stress group compared with the low visual stress group (without overlay $M = 120.97$, $SD = 32.91$; with overlay $M = 124.32$, $SD = 34.97$; see Figure 3).

The mean total score for the symptom questionnaire for all participants was 9.73 ($SD = 6.78$; lowest score 0; highest score 27), with an approximately normal distribution of scores (see Table 3). The high visual stress group had significantly higher mean total scores than the low visual stress group, $F(1, 65) = 9.59$, $p < .005$. One-way ANOVA revealed a significant main effect of visual stress group on critical symptom questionnaire scores, $F(1, 65) = 8.66$, $p < .005$. Total critical scores were significantly higher for the high visual stress compared with the low visual stress group. However, the mean non-critical scores for the two groups were not significantly different.

The false positive rate for VSS when predicting improvement in reading rate with an overlay for the secondary school students was 42.9% when using the >8% gain in reading rate with an overlay as the criterion (i.e. 6 of the 14 students who fell into the high visual stress group did not meet this criterion). When the >5% improvement in reading rate with an overlay was used as the criterion the false positive rate dropped to 21.4% (3 of 14). The equivalent false negative rate on VSS was 20.8% using the >8% criterion (i.e. 11 of the 53 students in the low visual stress group showed >8% gain in reading rate with an overlay). This increased to 32.1% (17 of 53) when the >5% criterion was used. Scores on VSS and percent increases in reading rate with an overlay were moderately correlated ($r = .45$; $p < .001$).

When the symptom questionnaire was used to predict improvement in reading rate with an overlay, 22.2% were found to be false positives (i.e. two of the nine secondary school students who had a critical symptom score of >1 *SD* above the mean on the symptom questionnaire did not gain in reading rate by >5%). This figure increased to 33.3% (3 of 9) when the >8% gain in reading rate was used as the criterion. The false negative rate for the symptom questionnaire was 40.4 (i.e. 23 of the 57 students who had a mean critical score of <1 *SD* above the mean *did* gain in reading rate by >5%). The false negative was reduced to 22.8% (13 of 57) when the >8% criterion was applied. Critical symptom questionnaire scores and percent increases in reading rate with an overlay were modestly correlated ($r = .39$; $p < .01$).

Evaluating the accuracy of VSS in predicting the results of the symptom questionnaire, the false positive rate was found to be 71.4% (i.e. 10 of the 14 secondary school students who fell into the high visual stress group had a mean critical symptom score that was <1 *SD* above the mean critical score). Nevertheless, four of these students showed >8% gain in reading rate with an overlay and three showed an increase of >5% gain in reading rate with an overlay, again suggesting that the symptom questionnaire results were misleading in this instance. The false negative rate was 13.2% (i.e. 7 of the 53 participants who fell into the low visual stress group had a mean critical score that was >1 *SD* above the mean critical score); three of these students also showed >5% gain in reading rate with an overlay. Scores on VSS and critical symptom questionnaire scores were weakly correlated ($r = .26$; $p < .05$).

Overall predictive accuracy of the instruments

Combining data from both the primary and secondary school samples, the false positive rate for VSS in predicting improvements in reading rate with an overlay was 42.3% (11 of 26; <8% gain criterion). This reduced to 15.4% (4 of 26) when the <5% gain criterion was applied. False negative rates were 14.3% (13 of 91) using the >8% gain criterion and 24.2% (22 of 91) using the >5% gain criterion.

In calculating the accuracy of the symptom questionnaire in predicting improvement in reading rate with an overlay, false positives were 29.4% (i.e. 5 of the 17 participants who had a mean critical score of >1 *SD* above the mean did not gain in reading rate by >5%). This increased to 35.3 (6 of 17) when the >5% criterion was used. False negatives were 31% (31 of 100), which decreased to 16% (16 of 100) when the >8% criterion was applied.

Finally, when the accuracy of VSS in predicting the results of the symptom questionnaire was assessed, 57.7% (15 of 26) of the high visual stress groups had a mean critical score on the symptom questionnaire that was < 1 *SD* above the mean critical score (false positives). False negatives totalled 13.2% (i.e. 8 out of 91 of the low visual stress group had a mean critical score that was > 1 *SD* above the mean critical score).

Discussion

The critical issue in this study is: can VSS be a valid method of screening for visual stress in primary and secondary schools? In a previous study using a smaller sample with a more restricted age range the visual search task was found significantly to predict whether or not an individual will benefit from an overlay on WRRT (Henderson & Singleton, in press). The results from the present study show that children from both samples who were significantly impaired by a visually stressful pattern during reading-like visual search had significantly higher percent increases in reading rate with an overlay on WRRT compared with children who were not impaired by the pattern.

Henderson and Singleton (in press) did not find any difference in non-visually stressful search response time for the high and low visual stress groups. This finding was attributed to task difficulty as Conlon et al. (1998) had previously reported that when task difficulty is increased a significant difference is found between high and low visual stress groups for non-visually stressful visual search. However, the present study also found that for both primary and secondary samples the high visual stress groups did not have significantly higher non-visually stressful visual search response times compared with the low visual stress groups; this was the case even in the secondary school sample where the matrix of three-letter words was increased in size, thus increasing task difficulty. This finding is at variance with previous research that has reported children with visual stress to be generally impaired on visual search (e.g. Conlon et al., 1998; Tyrrell, Holland, Dennis & Wilkins, 1995) and does not provide support for the magnocellular hypothesis. The magnocellular system plays a key role in visual search (Steinman, Steinman & Lehmkuhle, 1997; Vidyasagar, 1998; Vidyasagar & Pammer, 1999), thus if it was deficient in individuals with high susceptibility to visual stress one would also expect impaired visual search. However, this inconsistency in research findings could be due to the different tasks used in different studies.

Processing of the salient components of text is thought to occur automatically for most readers, but for the children in the high visual stress group in the present study interference effects from the global percept formed by the whole screen produced difficulty with reading-like visual search efficiency (McConkie & Zola, 1987). Individuals experiencing eyestrain and headache when reading report a substantial reduction in these symptoms when a reading mask reduces the field of view of three text lines (Wilkins & Nimmo-Smith, 1987). Thus it is reasonable to assume that the visually stressful pattern produced performance difficulties on VSS for children with visual stress because of the interference from the global level of the whole screen of letters and stripes to the local level of individual letters and words in the grid (Evans et al., 1996). Further, the patterned background of the visually stressful visual search items may have had characteristics within a critical range for which a variety of adverse visual perceptual distortions were possible: illusions of motion, shape and colour (Chronicle & Wilkins, 1996; Wilkins, 2003).

Additionally, the finding of the present study could also be attributed to a crowding effect from closely spaced letters (Anstis, 1974; Sloan, 1977) as the letters in the visually stressful items were in bold font compared with normal font in the non-visually stressful items. Hence, impaired performance of children with high visual stress cannot necessarily be solely attributed to an increased level of global interference due to presence of the visually stressful pattern. Therefore, visual stress may extend beyond cortical hyperexcitability to patterns as proposed by Wilkins (2003). In fact, studies have shown that response time on serial search tasks is longer in poor readers with low visual motion sensitivity, particularly if items are closely crowded (Facoetti, Paganoni & Lorusso, 2000). Thus, in line with the magnocellular hypothesis, children with visual stress may have performed poorly on the visually stressful items compared with the non-visually stressful items because of impaired processing of closely spaced bold letters due to low visual motion sensitivity. As some individuals with migraine have also been found to exhibit magnocellular deficits (McKendrick & Badcock, 2003), these effects are probably independent from or, more likely, in addition to the hyperneuronal response to high contrast that results from a hyperexcitability of the cortex, which Meldrum and Wilkins (1984) attribute to a failure of inhibitory mechanisms shared by interneurons under conditions of strong physiological stimulation.

The high visual stress groups from both samples had significantly higher percent increases with an overlay on WRRT compared with the low visual stress groups. In fact, 18% of the primary school sample read $>8\%$ faster with an overlay, and only two of these children were not predicted as having visual stress by VSS. Of the secondary school sample 28.4% read $>8\%$ faster with an overlay, but 11 of these students were not predicted as having visual stress by VSS. The incidence rates in the primary group are similar to those reported by Evans and Joseph (2002) but the secondary school sample incidence rates are substantially higher than those previously reported (Evans & Joseph, 2002; Kriss & Evans, 2005; Wilkins et al., 1996, 2001), and may have contributed to the higher false negatives calculated for VSS and overlay response compared with the primary group. It is notable that of the 11 secondary students classed as false negatives, only four had critical symptom scores of >1 *SD* above the mean critical score. Thus, it is reasonable to argue that the increase in reading rate of the remaining seven was due to reasons other than a reduction in perceptual distortions (e.g. the novelty of having an overlay, or simply because they believed they should read faster).

The effectiveness of VSS as a screening tool was also supported by the findings that the high visual stress groups in both samples reported significantly more symptoms on the symptom questionnaire. However, the questionnaire was more sensitive at picking up critical symptoms of visual stress in the secondary sample as in this case significant group differences were only found for critical and total scores. This suggests that symptom questionnaires may not be such effective tools for identification of visual stress amongst younger children, a conclusion that is consistent with previous research that has found low correlations between visual stress symptom questionnaires and reading speed without an overlay (Conway, unpublished data, cited in Wilkins, Huang & Cao, 2004).

It is recommended that children should have a full optometric assessment at the earliest possible stage of the investigation of any visual factors that may be contributing to reading difficulties (Evans, 2001). Even though children were instructed to wear glasses normally used for reading, the present study did not include an optometric assessment and thus some children may have had uncorrected errors of refraction, accommodation or binocular coordination. Nevertheless, even though these problems affect a significant number of unselected school children and are often undetected (Thomson, 2002) it seems unlikely that these could account fully for the results of this study, as the only differences between the two conditions (visually unstressful and visually stressful) were the emboldened font and the presence of a striped pattern on the screen. Both conditions required the same visual search and any uncorrected errors of refraction, accommodation, or binocular coordination would be expected to affect both conditions more or less equally. However, the possibility that some of the children classified as having high visual stress by VSS may not have had visual stress but other visual anomalies may to some extent have contributed to the high false positive rates between VSS with overlay response and the symptom questionnaire.

In conclusion, the results of this study suggest that VSS is a very promising diagnostic tool for identifying susceptibility to visual stress. VSS could easily be used by teachers in schools and by educational professionals involved in the diagnosis of children with reading disabilities. VSS has advantages in that it is not heavily influenced by either different levels of reading ability (as the distractor and target words are all simple three-letter words and the child is not required to read the word aloud), comprehension demands or emotional stress generated by a 'forced' reading task. Coloured overlays provide an effective low-cost treatment option that has scientific support; they increase reading speed substantially in at least 5% of the school population (Wilkins, 2003). However, their use as the sole basis for the diagnosis of visual stress is questionable because the condition is not invariably alleviated by colour.

Future studies are required to assess the effectiveness of VSS at predicting sustained voluntary use of an overlay, to ascertain its retest reliability and to endeavour to reduce the incidence of misclassifications. VSS could also be useful as a research tool to assess the relationships between visual stress, dyslexia and eye movements during visual search.

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Note

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

References

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

Bouldoukian, J., Wilkins, A.J. & 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 and Physiological Optics*, 22, 55–60.

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.

Chronicle, E.P. & Wilkins, A.J. (1996). Gratings that induce distortions mask superimposed targets. *Perception*, 25, 661–668.

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

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.

Edwards, V.T., Hogben, J.H., Clark, C.D. & Pratt, C. (1995). Effects of a red background on magnocellular functioning in average and specifically disabled readers. *Vision Research*, 36, 1037–1045.

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 and Physiological Optics*, 15, 481–487.

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

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

Facoetti, A., Paganoni, P. & Lorusso, M.L. (2000). The spatial distribution of visual attention in developmental dyslexia. *Experimental Brain Research*, 132, 531–538.

Henderson, L.M. & Singleton, C.H. (in press). Visual search as a predictor of susceptibility to visual stress in reading. *Ophthalmic and Physiological Optics*.

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

Jeanes, R., Busby, A., Martin, J., Lewis, E., Stevenson, N., Pointon, D. et al. (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.

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, 7943–7947.

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 Erlbaum.

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.

Meldrum, B.S. & Wilkins, A.J. (1984). Photosensitive epilepsy: Integration of pharmacological and psychophysical evidence. In P. Schwatzkroin & H.V. Wheal (Eds.), *Electrophysiology of Epilepsy*. (pp. 51–77). London: Academic Press.

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 and Physiological Optics*, 23, 457–464.

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 and Motor Skills*, 88, 35–52.

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

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

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

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

Steinman, B., Steinman, S. & Lehmkuhle, S. (1997). Transient visual attention is dominated by the magnocellular stream. *Vision Research*, 37, 17–23.

Thomson, D. (2002). Child vision screening survey. *Optician*, 224, 16–20.

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, 10–23.

Vidyasagar, T.R. (1998). Gating of neuronal responses in macaque primary visual cortex by an attentional spotlight. *NeuroReport*, 9, 1947–1952.
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.
Wilkins, A.J. (2003). *Reading through colour*. Chichester: Wiley.
Wilkins, A.J., Evans, B.J.W., Brown, J., Busby, A., Winfield, A.E., Jeanes, R. et al. (1994). Double masked placebo controlled trials of precision spectral filters in children who use coloured overlays. *Ophthalmic and Physiological Optics*, 14, 365–370.
Wilkins, A.J., Huang, 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., 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. & 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.
Wilkins, A.J. & Nimmo-Smith, M.I. (1987). The clarity and comfort of printed text. *Ergonomics*, 3012, 1705–1720.
Williams, M.C., LeCluyse, K. & Rock-Faucheux, A. (1992). Effective interventions for reading disability. *Journal of the American Optometric Association*, 63, 411–417.
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.

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Appendix A

Visual stress symptom questionnaire

Note: Each item is scored on a 5-point scale from 0 (*never*) to 4 (*always*).

Section A: Non-critical items

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

Section B: Critical items

4. Does the print seem to move about when you read?
5. Does the print become fuzzy or blurry when you read?
6. Does the white page between the words seem to form patterns like rivers?
7. Does white paper seem to glare?
8. Do your eyes become sore when you read?
9. Do you get headaches when you read?