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Coloured overlays in schools: orthoptic and optometric findings

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Abstract

In two studies, the first in a school in Peterborough and the second in a school in Norwich, more than 233 children aged 8–12 years received either an orthoptic examination, or an optometric examination, together with an examination using coloured overlays and a test of reading fluency. In both studies more than one-third of the children reported visual symptoms. More than one-third of the children chose to use an overlay, and they read more quickly with it than without. The colour of the overlay chosen was weakly related to the binocular amplitude of accommodation: overlays reflecting greater energy at long wavelengths were chosen more frequently by children with a higher amplitude of accommodation. Although the visual symptoms were strongly related to the use of an overlay, in neither study was the benefit from an overlay strongly related to the orthoptic or optometric findings. Nevertheless, children who used an overlay had slightly, but significantly, reduced mean binocular amplitude of accommodation and fusional reserves. On average, children with 'sensory' or 'motor' instability of the nonius strips of the Mallett unit read more slowly than others, as did those with poor stereopsis. However, 60% of those demonstrating sustained overlay use gave a normal response on the Mallett aligning prism test, compared with 80% of those who did not use an overlay for a sustained period. Another indicator of decompensated heterophoria, Sheard's criterion, did not differentiate subjects who used overlays from those who did not. Although binocular and accommodative anomalies do not appear to be the underlying mechanism for the benefit from coloured filters in most cases, there may be some individuals who respond to coloured filters and in whom these ocular motor factors require treatment. Children with visually precipitated symptoms and/or reading difficulties need both a careful evaluation of their accommodative and binocular status, and an investigation of the effect of coloured filters.

Keywords: Meares–Irlen syndrome, coloured overlays, reading fluency, binocular vision, orthoptics

Introduction

When reading, children sometimes report symptoms of visual fatigue. They may report fewer such symptoms if the text is coloured by covering the page with a sheet of coloured plastic (an overlay). Tyrrell *et al*. (1995) examined 46 children aged 8–16 years in a mainstream school, showing them text coloured by each overlay in a set of seven. Children who reported benefit from an overlay tended to be poor at reading. After 10 min continuous reading they showed a deterioration in reading fluency not shown by other children, accompanied by symptoms of visual fatigue. The deterioration and fatigue did not appear when the overlay was used. A set of coloured overlays that samples hues systematically

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and comprehensively was subsequently developed by Wilkins (1994). The rationale for the design of these so-called 'Intuitive Overlays'© is that if, indeed, there is a particular colour that can help with reading, it is simple to find a close approximation to the colour using this set of overlays because they sample chromaticity systematically. Jeanes *et al.* (1997) and Wilkins *et al.* (2001) used the Intuitive Overlays in several studies in county primary schools. They showed that when given the opportunity individually to select overlays of an appropriate colour, about 50% of children reported beneficial perceptual effects. These children were all given the overlay of their choice to use if they wished to do so, and several months later about half the children who were given overlays were still using them, that is, about 20% of the entire sample of normal schoolchildren. Again, these children tended to be those who were relatively poor at reading.

In the research by Tyrrell *et al.* (1995) the effects of overlays on reading fluency were observable only after 10 min continuous reading when the child had begun to tire. However, it has subsequently proved possible to demonstrate the benefits of overlays in a 1 min test that was specifically designed for this purpose, the 'Rate of Reading Test'©. The test, described by Wilkins *et al.* (1996), consists of a passage of text that is read aloud as quickly as possible for 1 min. The score is the number of words correctly read. The passage consists of 10 lines each comprising the same 15 common words in a different random order. The words are familiar to poor readers who are therefore prepared to undertake the challenge of reading. The random order ensures that no word can be guessed from the context; each word must be seen in order to be read. The absence of any meaning has the advantage that children are often unaware of their errors of omission and transposition of words. The text is printed in a small typeface, closely spaced, in order to increase the visual difficulty. The test shows improvements in reading speed with an overlay in the children who subsequently use the overlay, and not in others (Wilkins *et al.*, 1996, 2001; Jeanes *et al.*, 1997).

Several studies have used a variety of placebo overlays and motivational controls and have shown that the increase in reading speed with a coloured overlay is unlikely to be simply because of placebo effects (Bouldoukian, 1995; Jeanes *et al.*, 1997; Wilkins & Lewis, 1999). Improvements in symptoms have also been reported in a study that used a double-masked protocol in which children wore coloured lenses without being aware of whether or not the colour was optimum for clarity (Wilkins *et al.*, 1994). These studies are consistent in finding (1) that coloured overlays are superior to grey overlays that reduce the contrast and luminance by a similar amount, and to clear overlays; (2) that quite different colours can be beneficial for different individuals, although (3) the chosen colour gives the greatest benefit; (4) a aversive overlay or one of complementary colour gives relatively little benefit; (5) the rate of reading is little affected by motivational instructions or placebo effects. People who benefit from coloured filters in this way are described as having Meares–Irlen syndrome (Evans, 1997).

The question arises as to the relationship between the perceptual difficulties reported by children, the benefits from overlays, and any conventional visual abnormalities. Previous studies have reported optometric findings only in selected groups of children. On the basis of a small sample of Irlen lens wearers, Blaskey *et al.* (1990) argued that the symptoms of Meares–Irlen syndrome reflected impaired binocular function. Evans *et al.* (1996) investigated the optometric findings in 53 children who underwent a double-masked study of Precision Tints, all of whom had earlier reported benefit from coloured overlays and had used them without prompting for a minimum of 3 weeks. The median near point of convergence was slightly ($p = 0.085$) more remote in this group (5.25 cm) than in age and gender matched controls (4.5 cm). The mean amplitude of accommodation was lower (14 cf 17 D; $p = 0.014$); the convergent and divergent reserves were reduced (modal divergent break 14 cf 17 D; convergent break 9 cf 17 D; $p < 0.005$) and stereoacuity was poorer (median 35 cf 20 sec.arc; $p = 0.002$). Although statistically significant, these findings were in most cases of little clinical significance and Evans *et al.* (1996) concluded that these factors appeared to be correlates of Meares–Irlen syndrome rather than the underlying cause (cf. Scheiman *et al.*, 1991).

Psychometric data on a subgroup of 16 of the children with Meares–Irlen syndrome were obtained by Evans *et al.* (1995) who compared this subgroup with 25 control children from the same school who did not have the symptoms or signs of Meares–Irlen syndrome. The two groups were closely matched for age, reading performance and intelligence. The study confirmed the finding of significantly reduced vergence and accommodative amplitudes, and found significantly more pattern glare in the Meares-Irlen group. The two groups did not differ significantly in any other optometric measure, nor in their ability to detect 20Hz flicker.

The present studies were designed to determine the extent to which conventional orthoptic or optometric abnormalities might account for the high proportion of children reporting benefits from overlays. Unlike the previous studies in which the children who took part were selected on the basis of their parents' willingness to participate in an extensive study of coloured filters, the present studies were conducted in mainstream schools with unselected children.

Study I

In the first study, a large sample of children was tested with overlays in order to estimate the prevalence of any perceptual benefits and any resultant improvements in reading fluency. They were then assessed by an orthoptist (authors HM or LS).

Methods

Selection of children

All the 153 children from the first year of a Comprehensive School in Peterborough (aged between 10 and 12) took part if they were present in school, with the exception of two for whom parental consent was not forthcoming.

Test materials and administration

Coloured overlays. The overlays used have been described by Wilkins (1994). When placed over a page of white paper the overlays had a reflectance that varied little with the angles of incident and reflected light (Wilkins 1994; *Figure 3*), provided specular reflection was avoided. They had chromaticities (under the equal energy illuminant) disposed evenly around the circumference of a circle in the CIE 1976 UCS diagram, centred on white. The hue angle, h_{uv}, between neighbours averaged 40° with an S.D. of 7.7°; the saturation, s_{uv}, averaged 0.52 with an S.D. of 0.19. The photopic reflectance, with light incident at 45° and reflected normally when the overlay was placed upon a halon standard, averaged 65% (S.D. 13%). The overlays provided nine colours (and a grey, reflectance 47%) when used singly. They were also used in pairs, one on top of another. The pairs were either of the same colour or of neighbouring chromaticity and provided a further 19 colours having greater saturation (s_{uv} average 1.1, S.D. 0.13) with difference in hue angle (h_{uv}) between neighbours averaging 20°, S.D. 4.8°. The overlays therefore sampled colours systematically and comprehensively (Wilkins 1994; *Figure 2*). The overlays had a matte coating and this reduced the contrast of the text beneath (defined as the difference in luminance of background and letters, divided by the background luminance). With directional lighting normal to the surface and 45° oblique viewing, the reduction in contrast was similar for all colours and about 2%. With diffuse illumination from overhead fluorescent luminaires the reduction in contrast was generally $< 5\%$, unless there was clearly evident specular reflection of the light source, in which case the reduction in contrast could be as much as 80%. Specular reflection of the light source was avoided.

The Intuitive Overlays were supplied in a Teacher's Assessment Pack (I.O.O. Marketing Ltd. London 1994). The pack included two of each of 10 colours, A5 size, together with textual stimulus material and instructions for use.

The *Rate of Reading Test* (I.O.O. Marketing Ltd. London 1996) has been described by Wilkins *et al.* (1996). The child is required to read a series of randomly ordered common words arranged as a paragraph of small closely spaced text (Times 9pt set solid with 4pt interword spacing). The text consists of 10 lines, each with the same 15 high-frequency words in a different random order.

The *London Reading Test* (NFER-Nelson, Windsor, 1992), was administered at the beginning of the school year, as part of the normal school assessment. The test consisted of three sections, the first section comprising a passage with gaps requiring insertion of a contextually appropriate word from the child's own vocabulary, the second section comprising a passage of factual material about which comprehension questions were asked, and the third section requiring the child to give synonyms of a set of words.

The *orthoptic examination* included an assessment of visual acuity, using a Snellen chart at 6 m and Moorfields Bar Reading book (Clement Clarke International, Harlow, 1952) at 0.25 m; cover test at near and distance (initially cover/uncover to differentiate heterophoria from heterotropia, followed by alternate cover with prisms to elicit the maximum angle of deviation, and then cover/uncover to investigate the movement; Mein & Trimble 1991); ocular motility testing in the usual nine positions of gaze (Evans 1997, pp. 22–23); near point of convergence using the RAF rule (target moved at approximately 4 cm s^{-1}), amplitude of accommodation – with each eye and with both eyes, horizontal and vertical fusional reserves to blur point and to break point, measured using a prism bar with 6/60 reduced Snellen letter as near target and 6/60 Snellen letter at 6 m (the rate of change per prism was approximately one step increase on the prism bar per 1.5 s); stereo acuity (Frisby Test). The aligning prism to eliminate any fixation disparity was assessed (Evans 1997, pp. 53–61) using a near Mallett Unit (I.O.O. Marketing Ltd, London 1964). Subjects who usually wore spectacles used them for the above tests at the appropriate viewing distances.

Procedure

Teaching staff (author PI) or assistants conducted the initial testing with overlays. The child was assessed in a corner of the classroom or in an adjoining room with lighting that was similar to that in the classroom: a mixture of daylight and fluorescent light. The luminance of the page was usually at least 70 cd m^{-2}.

The child was shown *Stimulus Material B* from the *Intuitive Overlays* – random letters arranged in strings one to seven letters in length to resemble words, and printed single spaced in 12pt Times as a paragraph 131 mm (about 75 letters) wide and 70 mm (17 lines) long. Each overlay was placed over the text and the child was invited to say whether the overlay improved the clarity of the text beneath, made it worse, or had no effect. Any overlays reported to improve clarity were then compared side by side on the page and the best overlay chosen by a process of elimination.

Children who reported an improvement in the clarity of text with one or more overlays (86%) were given the best overlay or pair of overlays free of charge to use as and when they wished. Four months later a random sample of 94 of the 153 children (52 boys and 42 girls, then aged 11 years 3 months–12 years 6 months) received the orthoptic examination (administered by a qualified orthoptist, authors LS or HM), and the Rate of Reading Test (administered by research staff, author NS).

A note was made of the ocular history and of whether the child was still using the coloured overlay. The responses to the following questions about symptoms were also recorded: 'Do you feel that the page is too bright to look at?'; 'Do you ever get a headache and/or sore eyes when reading?'; 'Do the words appear to move or jumble?'; 'Are you aware of any other distractions on the page?' Note that the questions were administered at the time of the orthoptic examination and therefore after the children had been examined with the overlays. Those who were still using the overlays had been doing so for about 4 months.

The Rate of Reading test was administered once with and once without the overlay, in random order.

Results

Thirty-one of the 94 children were still using their overlay at the time of the orthoptic examination, i.e. about 4 months after the overlay was issued. The results of the orthoptic tests are shown in *Table 1* separately for the children who were still using their overlay and for those who were no longer using it, or who did not choose to use an overlay in the first instance. The level of significance tabulated for 'significant' comparisons needs to be considered in relation to the total number of comparisons, and the number of tests of similar type showing a significant effect. A Bonferoni correction with 30 comparisons with an average correlation of 0.2 would indicate that only those comparisons significant at the $p < 0.001$ level should be considered, but where all tests of a given type yield significant results, this figure may be rather conservative.

The children who were still using an overlay had a lower amplitude of accommodation (significant only for the binocular test, *t*-tests). They also had poorer distance convergent reserves to break, although in this case the *p*-value is such that the result could well have occurred by chance, given the number of comparisons. The children who were still using overlays also had a higher aligning prism, see *Table 1*. This result could also reasonably have been considered to have occurred by chance, were it not for the replication in Study II.

The ability of subjects to compensate for a heterophoria can be evaluated not only by the aligning prism, but also using Sheard's criterion, which states that the fusional reserve opposing the heterophoria should be at least twice the heterophoria (Evans 1997, pp. 50–70). The proportion of subjects who passed Sheard's criterion was similar for subjects who were still using their overlay (87%) compared with those who were not still using their overlay (84%).

Sixty-seven of the children (68%) reported symptoms from reading: 65 found the page too bright, 63 reported headaches or sore eyes, 37 reported movement of the letters, and 37 other phenomena. Seven children of the 23 who had previously been prescribed glasses were not wearing them. The children who were still using the overlay differed from those who had stopped using it with respect to (1) a greater incidence of reports of 'migraine' (16 cf. 5%, $p < 0.02$), and 'headaches' (58 cf. 39%, $p = 0.002$). Children still using the overlay were also more likely to report the page as 'too bright' (96 vs 52%, $p < 0.00005$) and the words as moving (58 cf. 22%, $p = 0.001$).

The results of the Rate of Reading Test are shown in *Table 2*. The means (and standard deviations) have been tabulated separately for the children who reported frequent use of the overlay over the previous 4 months, and those who reported infrequent or negligible use in this period. The improvement in reading speed with the overlay was highly significant ($p = 0.0002$, repeated-measures *t*-test) for the 31 children who reported frequent use, but not for the remaining 62 children. The reading speed of the former group without an overlay was slightly lower (100 wpm) than the reading speed of the latter (112 wpm; $p = 0.04$ 1-tail *t*-test). The nine children who showed an aligning prism of 1Δ or more read (without the overlay) slightly ($p = 0.06$, 1-tail *t*-test) more slowly than the others (94 wpm cf 110 wpm). There was a Pearson product moment correlation of 0.5 between the scores on the Rate of Reading Test and scholastic attainment in reading, as assessed by the London Reading Test.

The frequency with which each overlay colour was chosen is shown in *Figure 1*. The children who chose overlays with reflectance predominantly of long wavelengths (rose, orange, yellow, lime green, and combinations thereof) were compared with those who chose overlays with predominantly short (mint green, aqua,

Table 1. Results of orthoptic tests in Study I, shown separately for children who used overlays and those who did not. Where applicable the means (and standard deviations in parentheses) are given. Otherwise the Table lists the proportions of each sample satisfying the criteria shown. The final column lists the 1-tailed *p*-value for those tests that showed a significant difference between groups. The fusional reserve data to blur were scored as the blur reading or, if there was no blur reading, the break reading (cf Study II). The vergence amplitudes are the sums of the convergent blur (or if no blur, break) points and the divergent blur (if there was no blur, break) points

	Used overlay $n = 31$	Did not use $n = 63$	
Distance binocular acuity 6/6 or better (%)	90	95	
Near binocular acuity 6/6 or better (%)	97	100	
Convergence to nose (all but one converged to <7.5 cm) (%)	74	87	
Repeat (%)	67	84	
Amplitude of accommodation (D)			
Right eye	12.9 (2.6)	13.7 (2.3)	
Left eye	12.9 (2.8)	13.5 (2.2)	
Both eyes	11.9 (3.4)	13.7 (2.6)	$p = 0.004$
Repeat right	12.7 (2.8)	13.8 (2.2)	
Repeat left	12.7 (2.9)	13.6 (2.1)	
Repeat both eyes	12.0 (3.2)	13.6 (2.6)	$p = 0.008$
Cover test (%)			
Orthophoric at distance	71	78*	
Orthophoric at near	55	56	
Ocular motility normal	93	94	
Dissociation test (prism cover test; horizontal*; Δ)			
Distance (signed; +eso, −exo)	−0.35 (2.3)	0.1 (2.8)	
Distance (unsigned; magnitude only)	0.92 (2.1)	1.0 (2.6)	
Near (signed; +eso, −exo)	−1.1 (4.2)	−0.5 (5.5)	
Near (unsigned; magnitude only)	2.5 (3.4)	2.9 (4.6)	
Fusional reserves (Δ)			
Near convergent reserves to blur	16.0 (5.3)	17.8 (6.6)	
Near convergent to break	24.5 (7.8)	25.4 (8.7)	
Near divergent to blur	7.7 (3.2)	8.4 (3.3)	
Near divergent to break	4.0 (3.0)	10.1 (3.8)	
Near vergence amplitude	22.9 (8.0)	25.7 (8.8)	
Distance convergent to blur	11.6 (6.8)	12.0 (4.8)	
Distance convergent to break	13.5 (3.9)	16.3 (6.6)	$p = 0.020$
Distance divergent to blur	4.5 (2.0)	4.6 (2.1)	
Distance divergent to break	4.9 (2.3)	5.1 (2.9)	
Distance vergence amplitude	15.6 (8.1)	16.4 (5.6)	
Distance vertical to break	3.9 (1.2)	4.1 (4.1)	
Frisby stereo test	34.7 (23.9)	31.8 (27.5)	
Aligning prism (near Mallett unit; Δ)			
Horizontal (signed; +eso, −exo)	−0.32 (1.56)	−0.15 (0.73)	
Horizontal (unsigned)	0.68 (1.35)	0.14 (0.71)	$p = 0.007$
Vertical (unsigned)	0.14 (0.45)	0.02 (0.13)	$p = 0.026$

*2 hyperdeviation, 1 hypertropia, 1 hyperphoria.

Table 2. Mean (and standard deviation) of the reading speed (words per minute) on the Rate of Reading Test for children in Study I who reported frequent vs. infrequent use of the overlay

Usage	*n*	Without overlay	With overlay
Used overlay	31	100 (25)	108 (24)
Did not use	63	112 (30)	111 (29)

blue, and combinations), omitting those who chose purple, pink and grey. The children who chose 'long-wavelength' overlays had a greater ($p < 0.05$ 1-tailed *t*-test) amplitude of accommodation compared with those who chose 'short-wavelength' overlays, consistent with the greater refraction of shorter wavelength light. This relationship was similar for all readings of accommodative amplitude (right, left, both eyes; initial and repeated measurements). Although statistically significant, the effect was small, with the mean amplitudes of accommodation of users of 'long wavelength' overlays approximately 14D compared with approximately 12.5D for users of 'short wavelength' overlays. There was no significant relationship between heterophoria (signed; as measured by prism cover test) and choice of 'long-' or 'short-wavelength' overlay. The subjects who

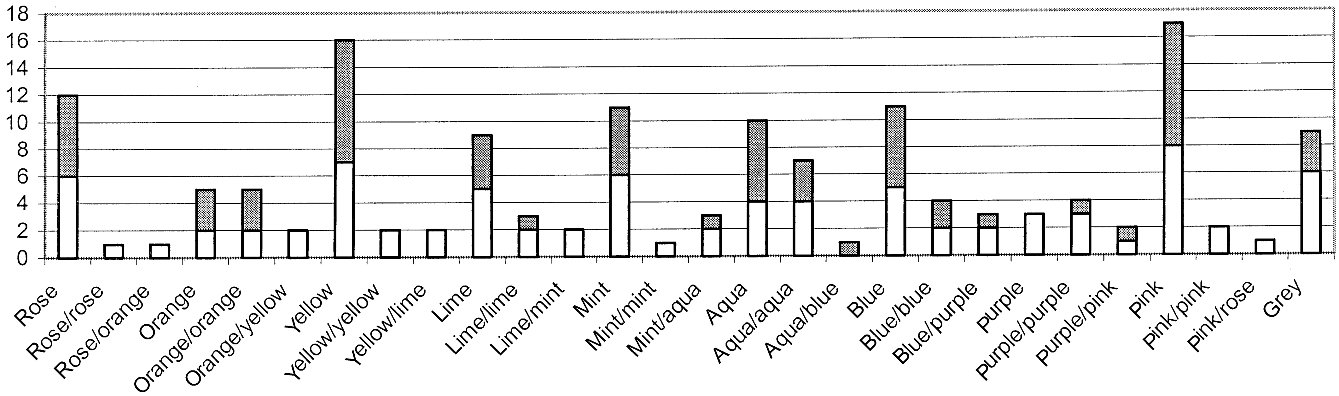

Figure 1. The number of children choosing overlays of each colour in Study I (open bars) and Study II (solid bars).

chose 'short wavelength' overlays reported significantly (Mann–Whitney *U*-test, 2-tailed $p = 0.04$) more headache and/or sore eyes when reading than subjects who chose 'long wavelength' filters.

Discussion

The findings are consistent with those of Jeanes *et al.* (1997) and Wilkins *et al.* (2001) in showing that a substantial proportion of children in mainstream education report a benefit from the use of coloured overlays for reading, and show an improvement in reading fluency. The findings are also consistent with those of Evans *et al.* (1995, 1996) in showing poorer amplitude of accommodation in children who benefit from the use of coloured filters.

The correlation of 0.5 between scores on the Rate of Reading Test and the London Reading Test is similar to that obtained with younger children in a previous study comparing the Rate of Reading Test and a different measure of scholastic attainment in reading, the reading quotient of the Young's Reading Test (Wilkins *et al.* 2001).

The findings are the first to show a correlate of children's choice of overlay colour in terms of accommodation, and these findings, together with the poorer amplitude of accommodation in overlay users are consistent with the abnormal fluctuations in accommodation measured objectively in individuals with Meares–Irlen syndrome by Simmers *et al.* (2001). This is investigated further in Study II where data were available on refractive error and accommodative accuracy. The finding in Study I that subjects who chose 'short wavelength' overlays report more headaches and/or sore eyes when reading than those who chose 'long wavelength' filters might suggest that people with more severe Meares–Irlen syndrome tend to choose 'short wavelength' filters, and to have lower amplitudes of accommodation. However, neither the rate of reading without the overlay nor the improvement in rate of reading with the overlay were significantly different in the subjects who chose a 'short wavelength' overlay compared with those who chose a 'long wavelength' overlay.

Study II

A second series of assessments was conducted at a different school, including on this occasion an optometric examination.

Methods

Subjects

All the 199 children from a middle school in Norwich (aged 7–11) who were present in school took part, with the exception of one whose parents refused permission. A random sample of 104 (40 boys and 64 girls) were selected for assessment.

Test materials and procedure

At the beginning of the school year in October 1995 the children were assessed overlays (by authors ME and EL) using coloured overlays and the Wilkins Rate of Reading Test, following the techniques described in Study I, and those reporting beneficial perceptual effects (81 of the 199, 41%) were issued with their chosen overlay either in the autumn term or at the beginning of the spring term.

In the spring term the 104 children were all examined by an optometrist (author LT). The optometrist undertook the following tests: ocular motility; cover test (cover-uncover and alternate cover, with and without refractive correction); near point of convergence (RAF rule); pupillary reflex; distance fixation retinoscopy; visual acuity at 3 m (Snellen) and 0.4 m (Mallett unit), for right eye, left eye and both eyes; subjective refraction; near point of accommodation (RAF rule) for right eye, left eye and both eyes; aligning prism (near Mallett unit) stereopsis (Mallett unit and TNO tests); colour vision (Ishihara, H. K. Lewis & Co. Ltd, London 1970, and City University Colour Vision Test, Keeler Ltd, London 1980); distance dissociated heterophoria (Maddox rod at 6 m); accommodative lag by MEM retinoscopy (Cooper, 1987); fusional reserves (blur, break and recovery point, base in then base out, using a prism bar at near).

The children were then re-examined with the Rate of Reading test towards the end of the summer term and it was noted whether or not they were still using the overlays. Thirty-eight of the 199 (20 of the random sample of 104, 19%) were still using their overlays daily.

Results

The optometric findings are summarised in *Table 3*. The following optometric variables were significantly associated with the voluntary prolonged use of overlays: accommodative amplitude, fusional reserves and aligning prism. The accommodative and fusional reserve findings replicate Evans *et al.* (1995, 1996), who investigated children with reading difficulties who used Precision Tinted spectacles and Evans *et al.* (1994) who investigated children with dyslexia. Reading speed was not significantly correlated with the accommodative amplitude or fusional reserves.

A new finding in the present research is the greater need for an aligning prism in subjects who demonstrated a prolonged use of an overlay. Additional qualitative data were also available in Study II on the aligning prism test result, for example whether there was a 'motor' instability (transient apparent movement of the strips) or 'sensory' instability (flashing appearance of the strips). The data were therefore re-coded taking note of any abnormality (Evans 1997, pp. 54–57) on the Mallett aligning prism test (aligning prism of 1Δ or more horizontally or vertically, and/or movement and/or flashing of the strips). Using these criteria, 60% of those demonstrating sustained overlay use were normal, as were 80% of those who did not use an overlay for a sustained period. These ratios are not significantly different (chi-square test). The 31 children with an abnormal Mallett test had a significantly lower reading speed (91 wpm) than those with a normal test (103 wpm; $p = 0.02$, 1-tailed t-test). They also showed a greater improvement in reading speed with the overlay (9.5 vs 3.3%; $p = 0.05$, 1-tailed t-test). Although 'sensory' instability, was associated with a lower average reading speed than 'motor', the difference was not significant.

The frequency with which each overlay colour was chosen is shown in *Figure 1*. The overlays were categorised as in Study I into those with predominantly long wavelength reflectance and those with predominantly short. As in Study 1, the children who chose 'long-wavelength' overlays had a greater ($p = 0.037$, 1-tailed t-test) binocular amplitude of accommodation (16.1 D) compared with those who chose 'short' (12.5 D), consistent with the greater refraction of shorter wavelength light. However, this did not reach significance for monocular amplitudes of accommodation ($p > 0.2$). It should be noted that a mean amplitude of accommodation of 12.5 D should be more than adequate to allow normal reading. Study II allowed a more detailed assessment because data on accommodative accuracy (lag) and refractive error were available. The mean accommodative lag of the subjects choosing a long wavelength filter was 0.54 D compared with 0.71 D for those choosing a short wavelength. Although in the anticipated direction, this difference does not approach significance ($p = 0.2$, 1-tailed Mann–Whitney U-test).

The spherical component of the refractive errors for each eye, both subjective and objective (retinoscopy), were not significantly different for the long and short wavelength overlays and were not consistently in the anticipated direction. There was no significant relationship between the use of long vs. short wavelength overlays and the dissociated heterophoria (Maddox rod, signed or unsigned) or the aligning prism (signed or unsigned).

General discussion

The above studies show consistency with regard to the proportion of children in mainstream education who report beneficial perceptual effects with coloured overlays (about 50%), who persist in using overlays (about 20%) and who demonstrate improvements in reading fluency both before and after using them (again, about 20%). The studies are also consistent in supporting the findings of Evans *et al.* (1995, 1996) obtained in smaller and less representative samples. The children who benefit from the use of coloured overlays are those who tend to have slightly lower accommodative amplitude and lower fusional reserves.

Decompensating heterophoria can cause photophobia (Eustace *et al.*, 1973) and this might be related, in some cases, to the benefit from coloured filters. A review by Evans (1997, pp. 53–70) found that the two orthoptic measures that correlate most strongly with symptomatic heterophoria are the Mallett aligning prism and Sheard's criterion. In Study I, the former, but not the latter, was correlated with overlay use. Sheard's criterion could not be calculated for near vision in Study II, but the aligning prism was again found to be associated with overlay use. However, Study II also demonstrates that 60% of subjects with sustained voluntary use of an overlay have a normal response

Table 3. Summary of optometric findings of Study II. The findings are shown separately for the 20 subjects who used their overlay for more than one school term and the remainder who either did not choose an overlay, or who ceased to use one. The final column lists the 1-tailed *p*-value for those tests that showed a significant difference between groups. The refractive error by retinoscopy: mean spherical error in dioptres, both with respect to sign and without regard to sign (standard deviation in parentheses); the binocular visual acuity at distance and near (expressed as a percentage of each sample with less than 6/6 vision); the percentage of each sample with exo- or esophoria (assessed by cover test of right, then left eyes at distance and confirmed by prism and cover test, ignoring exophorias of less than 4 dioptres); the mean accommodative lag expressed in dioptres (the right and left eye's readings were the same in all except one case, an overlay user, whose lower reading – from the least hypermetropic eye – was used); fusional reserves (blur, break, recovery, for convergent and divergent; the blur point was only scored where the patient was able to detect this; cf Study 1); vergence amplitude, calculated as the sum of the convergent blur (or if no blur, break) point and the divergent blur (if there was no blur, break) point; the near point of convergence in cm; the geometric mean stereopsis (min arc) on the near Mallett unit, and the TNO test; and the percentage of each sample passing the Ishihara and City University tests of colour vision

	Used overlay ($n = 20$)	**Did not use overlay ($n = 98$)**	***p*-value (if $p \leq 0.05$)**
Refractive error (subjective refraction; signed, negative cylinder format; Δ)			
Right eye sphere	+0.90 (0.86)	+0.82 (0.61)	
Right eye cylinder	−0.02 (0.11)	−0.08 (0.48)	
Left eye sphere	+0.99 (0.78)	+0.89 (0.57)	
Left eye cylinder	−0.00 (0.00)	−0.08 (0.44)	
Distance Binocular VA worse than 6/6 (%)	0	5	
Near Binocular VA worse than 6/6 (%)	0	5.4	
Amplitude of accommodation (D)			
Right eye	11.3 (4.9)	14.4 (5.0)	0.0044
Left eye	11.8 (5.6)	14.7 (5.1)	0.0090
Both eyes	12.8 (6.3)	15.4 (5.3)	0.022
Accommodative lag	0.60 (0.41)	0.59 (0.48)	
Cover test (%)			
Orthophoric at distance*	95.5	98.0	
Orthophoric at near	86.4	84.7	
Ocular motility normal:	95.5	98.0	
Dissociation test (distance Maddox rod; Δ)			
Vertical (unsigned)	0.00 (0.00)	0.03 (0.33)	
Horizontal (signed; +eso, −exo)	+0.14 (0.48)	+0.07 (0.38)	
Horizontal (unsigned)	0.18 (0.47)	0.14 (0.37)	
Fusional reserves (near vision; Δ)			
Convergent to blur (Δ)	17.4 (12.5)	22.7 (11.1)	0.051
Convergent to break (Δ)	26.0 (11.1)	30.4 (10.0)	0.037
Convergent to recovery (Δ)	19.3 (12.9)	23.4 (13.6)	
Divergent to blur (Δ)	6.2 (1.8)	7.2 (3.4)	
Divergent to break (Δ)	9.1 (3.8)	10.5 (4.3)	
Divergent to recovery (Δ)	4.6 (2.3)	5.9 (2.8)	0.021
Vergence amplitude (Δ)	25.7 (13.3)	32.0 (13.4)	0.027
Near point of convergence (cm)	6.1 (3.7)	5.2 (2.9)	
Aligning prism (near Mallett unit; Δ)			
Vertical (unsigned)	0.048 (0.150)	0.016 (0.115)	
Horizontal (signed, +eso, −exo)	0.190 (0.487)	−0.016 (0.260)	0.0036
Horizontal (unsigned)	0.286 (0.435)	0.081 (0.248)	0.0021
Stereopsis, Near Mallett unit (geometric mean)	66.9	58.9	
Stereopsis, TNO (geometric mean)	131.8	95.2	
Ishihara pass (%)	92.3	86.9	
City University pass (%)	81	87	

*Most subjects were orthophoric or had a heterophobia; only one subject in each group had a manifest strabismus.

on testing with the near Mallett unit, supporting the conclusions of Evans *et al*. (1995, 1996) that vergence anomalies are not the explanation for the benefit from coloured filters in the majority of cases.

Although the amplitude of accommodation is lower in overlay users, the difference in mean amplitude is unlikely to be of clinical significance in the vast majority of children. This conclusion is supported by the finding in Study II of almost identical mean accommodative lag in the two groups. The finding in both studies that children who choose filters with predominantly short wavelength reflectance have significantly lower amplitudes of accommodation is intriguing and does suggest that for some subjects accommodative factors might influence their choice of overlay. However, this did not reach significance for monocular amplitudes of accommodation in Study II and the data on accommodative lag and refractive error do not support the hypothesis that subjects were choosing the colour of filters on the basis of a focusing error.

The data seem to suggest that accommodative and vergence dysfunction are in most cases correlates of Meares–Irlen syndrome rather than causes of the condition. However, there will inevitably be cases where the symptoms of Meares–Irlen syndrome might at least partly result from accommodative insufficiency and/or decompensated heterophoria. Both these conditions can be treated refractively (Evans, 2000a) or orthoptically (Evans, 2000a,b). Lightstone and Evans (1995) recommended that if a patient with suspected Meares–Irlen syndrome has the clinical signs of a decompensated heterophoria or of accommodative dysfunction then these ocular motor factors should be treated in the first instance. If symptoms remain once the ocular motor status is normalised, then the patient may benefit further from coloured filters (Evans *et al*., 1999; Evans, 2001).

It might be argued that clinical tests of accommodation and of vergence require an effort after good perception, and that in children who report perceptual distortion, such effort may be more difficult than in others. Nevertheless there are obvious mechanisms by means of which coloured filters might indeed be expected to affect accommodation. First coloured filters will change the distribution of blur and its relation to wavelength. Evans *et al*. (1996) studied children who benefited from coloured glasses and noted that the beneficial colour was not such as to reduce any residual refractive error, and this is supported by Study II. Simmers *et al*. (2001) made direct measurements of accommodation in individuals with Meares–Irlen syndrome and noted normal accommodative lag. However these individuals did show an abnormally high power of accommodative fluctuations at low frequencies.

Coloured filters might be expected to reduce the degree of blur, and with it the effect of any accommodative fluctuation. Simmers *et al*. (2001) noted a reduction in accommodative fluctuation with coloured filters, but also with neutral density filters of similar photopic transmission. The neutral filters are unlikely to have affected blur in the same way as coloured filters, suggesting that accommodative blur is not a causal mechanism. This viewpoint is consistent with several studies demonstrating that the required tint in Meares–Irlen Syndrome needs to be individually prescribed (Wilkins *et al*., 1994; Lightstone *et al*., 1999; Robinson and Foreman, 1999). Accommodative mechanisms are unlikely to be a sufficient explanation for the individual choice of colour and its effect on reading fluency. Instead, the fluctuations may be a correlate of visual stress (Wilkins, 1995). Correlate or cause, the fluctuations may nevertheless have been responsible for the present clinical findings of reduced accommodative amplitude and fusional reserves, the latter via a link between accommodation and vergence. Poor vergence control, or binocular instability (Evans *et al*., 1994) might account for the finding that it appeared to be the absolute magnitude of the aligning prism that was associated with overlay use, with the mean direction of required prism differing in Study I and Study II.

An alternative hypothesis is that the key feature of Meares–Irlen syndrome is a sensory anomaly in the visual cortex causing visual perceptual distortions, particularly when viewing certain 'striped' stimuli including text (Wilkins, 1995). The unstable visual percept might impair the feedback loops (Ciuffreda and Tannen, 1995, pp. 144–147) that are responsible for the fine control of accommodation and vergence. This could account for the correlates identified in this paper. It is interesting that some aspects of the data suggest that binocular accommodative amplitude is more strongly associated with overlay use, especially 'short wavelength' overlay use, than monocular amplitudes. It is possible that there may be an interaction between pattern glare and accommodation, as the predominant spatial frequency of the accommodative target will decrease as it approaches, possibly causing more pattern glare. Pattern glare is greater for binocular viewing than monocular (Wilkins, 1995) and blue light has been found to be more successful at ameliorating pattern glare than red light, at least in individuals with migraine (Chronicle and Wilkins, 1991; Chronicle, 1993).

The present studies have shown small but consistent relationships between the use of overlays and orthoptic findings. Small but significant relationships have emerged between the colour of overlay and amplitude of accommodation. Coloured overlays improve reading speed in children who show no signs of binocular anomaly, but in the few who do, reading speed is generally poorer.

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References

Blaskey, P., Scheiman, M., Parisi, M., Ciner, E. B., Gallaway, M. and Selznick, R. (1990) The effectiveness of Irlen filters for improving reading performance: a pilot study. *J. Learn. Disab*. **23**, 604–612.

Bouldoukian, J. (1995) Evaluation de l'effet de filtre colourés sur la performance à la lecture d'enfants supectés d'avoir le syndrome d'Irlen. Thesis supervised by BJW Evans and presented to Université de Paris-Sud, 134 Route de Chartres 91440 Bures-sur-Yvette, France.

Chronicle, E. (1993) The influence of colour on visual discomfort in migraineurs and controls. In: *Headache and Migraine* (eds T. J. Steiner and L. A. H. Hogenhuis) Utrecht, Bunge, pp. 10–15.

Chronicle, E. and Wilkins, A. J. (1991) Colour and visual discomfort in migraineurs. *Lancet* **338**, 890.

Ciuffreda, K. J. and Tannen, B. (1995) *Eye Movement Basics for the Clinician*. Mosby, St Louis.

Cooper, J. (1987) Accommodative dysfunction. In: *Diagnosis and Management in Vision Care* (ed. J. F. Amos), Butterworths, London, pp. 431–459.

Eustace, P., Weston, E. and Druby, D. J. (1973) The effect of illumination intermittent divergent squint of the divergence excess type. *Transact. Ophthalmolog. Soc. Gr. Br*. **93**, 559–590.

Evans, B. J. W. (1997) *Pickwell's Binocular Vision Anomalies*, 3rd edn. Butterworth-Heinemann, Oxford.

Evans, B. J. W. (2001) Case studies. In: *Binocular Vision and Orthoptics* (eds B. Evans & S. Doshi) Butterworth-Heinemann, Oxford, pp. 116–126.

Evans, B. J. W. (2000a) Decompensated exophoria at near and binocular instability: diagnosis and the development of a new treatment regimen. *Optician* **291**, 20–28.

Evans, B. J. W. (2000b) An open trial of the Institute Freespace Stereogram (IFS) exercises. *Br. J. Optometry Dispensing* **8**, 5–14.

Evans, B. J. W., Drasdo, N. and Richards, I. L. (1994) Investigation of accommodative and binocular function in dyslexia. *Ophthal. Physiol. Opt*. **14**, 5–19.

Evans, B. J. W., Busby, A., Jeanes, R. and Wilkins, A. J. (1995) Optometric correlates of Meares–Irlen syndrome: a matched group study. *Ophthal. Physiol. Optics* **15**, 481–487.

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

Evans, B. J. W., Patel, R., Wilkins, A. J., Lightstone, A., Eperjesi, F., Speedwell, L. and Duffy, J. (1999) A review of the management of 323 consecutive patients seen in a specific learning difficulties clinic. *Ophthal. Physiol. Opt*. **19**, 454–466.

Jeanes, R., Busby, A., Martin, J., Lewis, E., Stevenson, N., Pointon, D. and Wilkins, A. J. (1997) Prolonged use of coloured overlays for classroom reading. *Br. J. Psychol* **88**, 531–548.

Lightstone, A. and Evans, B. J. W. (1995) A new protocol for the optometric management of patients with reading difficulties. *Ophthal. Physiol. Opt*. **15**, 507–512.

Lightstone, A., Lightstone, T. and Wilkins, A. J. (1999) Both coloured overlays and coloured lenses can improve reading fluency, but their optimal chromaticities differ. *Ophthalmic Physiol. Optics* **19**, 279–285.

Mein, J. and Trimble, R. (1991) *Diagnosis and Management of Ocular Motility Disorders*, 2nd edn. Blackwell Science, Oxford.

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

Scheiman, M., Blaskey, P., Ciner, E. B., Gallaway, M., Parisi, M., Pollack, K. and Selznick, R. (1991) Vision characteristics of individuals identified as Irlen filter candidates. *J. Am. Optometric Assoc* **61**, 600–605.

Simmers, A. J., Gray, L. S. and Wilkins, A. J. (2001) The influence of tinted lenses upon ocular accommodation. *Vision Res*. **41**, 1229–1238.

Tyrrell, R., Holland, K., Dennis, D. and Wilkins, A. J. (1995) Coloured overlays, visual discomfort, visual search and classroom reading. *J. Res. Reading* **18**, 10–23.

Wilkins, A. J. (1994) Overlays for classroom and optometric use. *Ophthalmic Physiol. Optics* **14**, 97–99.

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

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

Wilkins, A. J., Evans, B. J. W., Brown, J. A., Busby, A. E., Wingfield, A. E., Jeanes, R. J. and Bald, J. (1994) Double-masked placebo-controlled trial of precision spectral filters in children who use coloured overlays. *Ophthalmic Physiol. Optics* **14**, 365–370.

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

Wilkins, A. J., Lewis, E., Smith, F. and Rowland, E. (2001) Coloured overlays and their benefits for reading. *J. Res. Reading* **24**, 41–64.