

# Coloured overlays and their benefit for reading

Arnold J. Wilkins

Visual Perception Unit, University of Essex, Colchester, UK

Elizabeth Lewis

Norfolk County Sensory Support Service, Norwich, UK

Fiona Smith

Visual Perception Unit, University of Essex, Colchester, UK

Elizabeth Rowland

Norfolk County Sensory Support Service, Norwich, UK

Wendy Tweedie

MRC Applied Psychology Unit, Cambridge

## *ABSTRACT*

Children in mainstream schools compared text on white paper with identical text covered in turn by each of ten differently-coloured plastic overlays. More than 50% reported improved perception with one or more colours, and were given the best colour to use. About half used the overlays for more than three months and their reading speed increased when the overlays were used. In Study I children were examined twice using different methods and examiners. 47% chose the same colour on both occasions, and showed the greatest improvement in reading fluency, reliable at retest. In Study II children were issued with a random colour, and the greatest improvements in reading speed occurred when the random colour was the same as that previously chosen. Phonological reading strategies were not related to visual symptoms, or the benefit from overlays. Across individuals, reading speed varied by a factor of more than three, for good and poor readers. Study III provided estimates of the prevalence of improvements based on a sample of 426 children from 12 schools: 5% of children read more than 25% faster with a coloured overlay.

## INTRODUCTION

When reading, children sometimes report fewer symptoms of visual fatigue 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 in a mainstream school, showing them text coloured by each overlay in a set of seven. Children who reported benefit from an overlay were relatively poor at reading. After ten minutes 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 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, the overlays can be combined to find a close approximation to this colour: the set of overlays samples chromaticity systematically and efficiently, as shown in Figure 1.

Jeanes et al (1997) used the *Intuitive Overlays* in several small-scale studies in county primary schools. They presented each of the colours in turn and allowed children to choose the one that best improved the clarity of text. About 50% of children reported beneficial perceptual effects with the chosen overlay. These children were all given the selected overlay to use if they wished to do so, and three months later about half the children who were given overlays were still using them; that is, about 20% of the entire sample of normal school children. Again, these children were relatively poor at reading.

Although in the research by Tyrrell et al the effects of overlays on reading fluency were observable only after ten minutes continuous reading when the child had begun to tire, it has subsequently proved possible to demonstrate the benefits of overlays in a one-minute test, the *Rate of Reading Test*. The test consists of a passage of text which is read aloud as quickly as possible for one minute. The score is the number of words correctly read. The passage consists of ten 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 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 *Rate of Reading Test* would appear to provide a sensitive measure of the visual skills involved in reading. The average rate of reading with an overlay compared to that without is greater in the children who will subsequently use an overlay voluntarily in the long term (Wilkins et al, 1996; Jeanes et al, 1997).

## Placebo effects

Children will often seek to please, and are good at picking up cues as to how they are expected to respond, and these can in turn affect motivation, and potentially at least, reading speed. Nevertheless, the increase in reading speed with a coloured overlay is unlikely to be due simply to motivation or other placebo effects. Wilkins and Lewis (1999) used the *Rate of Reading Test* and included a placebo control. Reading rate was compared with no overlay, the chosen overlay, a grey overlay, and a grey overlay

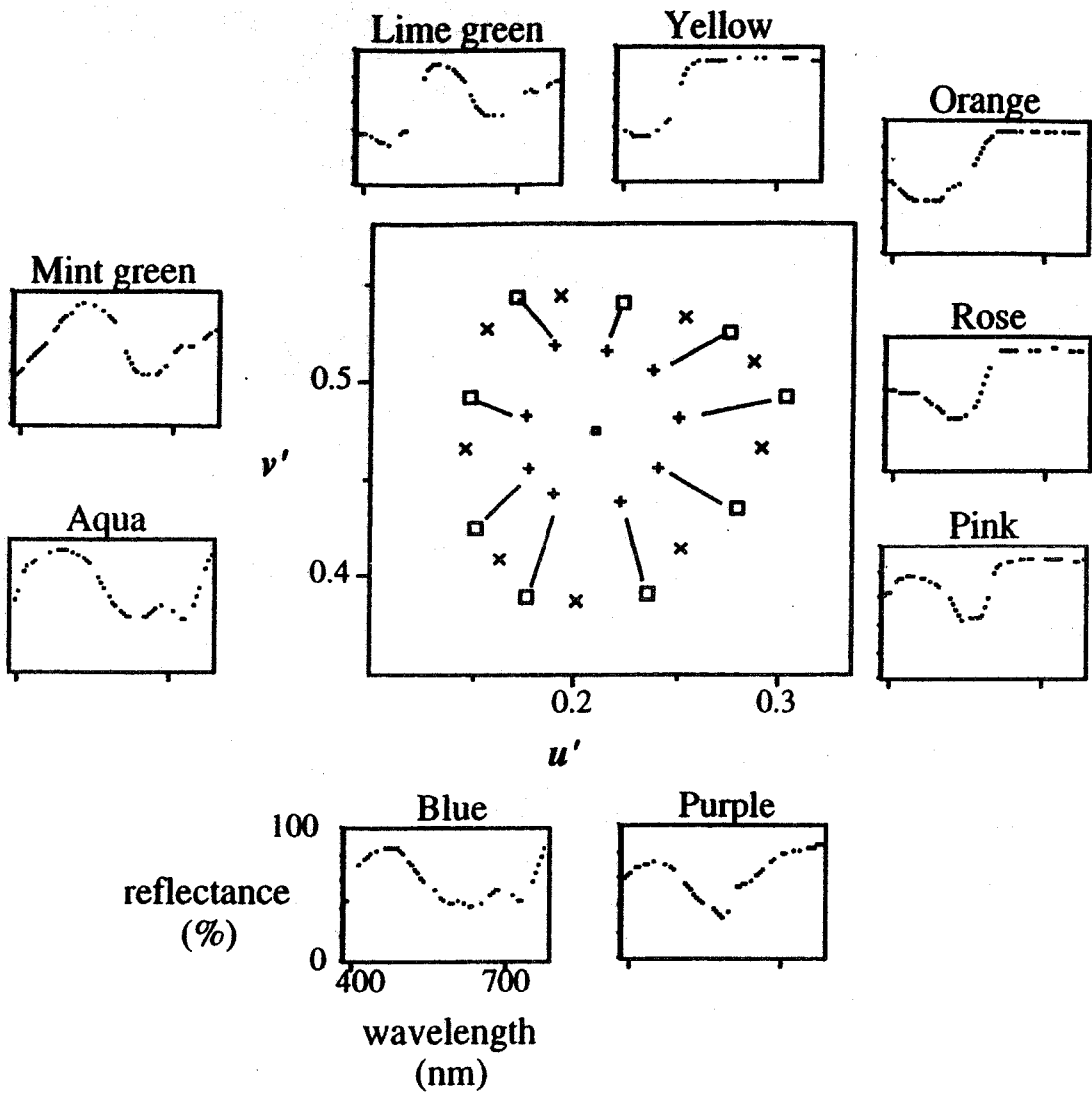


Figure 1. Chromaticities of the Intuitive Overlays.

Notes: The points in the inner circle are the chromaticities of the overlays used singly, and the points in the outer circle are the chromaticities of pairs of overlays, one on top of another of the same or similar colour. The continuous lines join the chromaticities of the single overlays with those of pairs of overlays of the same colour. The broken lines join double overlays with those of the component single overlays.

that was identical except that it carried the label 'scientific prototype'. The children were told that the 'prototype' was new, that it combined all the colours, that they were one of the first children to use it, and that they were expected to do as well as they could. Performance with this grey overlay did not differ from that with the other, although reading rate with the chosen coloured overlay was superior. Bouldoukian (1995) had earlier used a similar design, with similar results.

In a study reported by Jeanes et al, (1997, Study 6), the *Rate of Reading Test* was given without an overlay, with a clear (transparent) overlay, with a grey overlay (the grey overlay from the set of *Intuitive Overlays*), and with two coloured overlays from the same set: one of the chosen colour and one of a colour complementary to that

chosen. The five conditions were presented in random order. With the overlay of the chosen colour the reading rate was superior to the no-overlay, clear-overlay and the grey-overlay conditions. The reading rate with the overlay of complementary colour did not differ significantly from the rate in the other conditions.

In a further study by Wilkins and Lewis (1999), children undertook the *Rate of Reading Test* with no overlay, an overlay that was reported as having *least* benefit, a grey overlay and the chosen overlay. The four conditions were presented in random order. The reading rate increased in the order in which the conditions are listed above, although the only statistical difference was in the performance with the chosen overlay vis à vis the other conditions.

The above studies are consistent in finding (1) that coloured overlays are superior to clear overlays (a placebo control) and to grey overlays that reduce the contrast and luminance by a similar amount; (2) that quite different colours can be beneficial, although (3) the chosen colour appears to give the greatest benefit; (4) a complementary or aversive overlay colour gives relatively little benefit; (5) the rate of reading is unaffected by motivational instructions.

The present series of studies were designed:

- (1) to investigate the reliability of the choice of overlay colour and the reliability of the increase in reading speed with which it was associated;
- (2) to study the relationship between visual difficulties with reading, and scholastic attainment in reading, including phonological and non-phonological reading strategies;
- (3) to replicate the above findings with a larger sample, so that the prevalence of perceptual difficulties could be gauged and the number of children likely to benefit from overlays could be estimated reliably.

## STUDY 1: METHOD

### Participants

All the 47 boys and 42 girls in years 4–6 of a middle school in Norwich, Norfolk UK took part, excluding those for whom parental permission was withheld (about 1%). The mean age was 9 years 4 months, range 8 years 6 months–10 years 6 months.

### Test materials

The overlays used have been described by Wilkins (1994).<sup>1</sup> 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 disposed evenly around the circumference of a circle in the CIE 1976 UCS diagram, centred on white; in other words the saturation ( $s_{uv}$ ) was similar for all colours, averaging 0.52 with a standard deviation of 0.19. The difference in hue angle,  $h_{uv}$ , between neighbouring colours averaged 40 degrees with a standard deviation of 7.7 degrees. The chromaticities are shown in Figure 1. When the overlay was placed upon a halon standard the photopic reflectance with light incident at 45 degrees and reflected normally averaged 65% (sd = 13%). The overlays provided 9 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 ( $s_{uv}$   $m = 1.1$ ,  $sd = 0.13$ ) with difference in hue angle between neighbours averaging 20 degrees ( $sd = 4.8$  degrees). The overlays therefore sampled colours systematically and comprehensively (see Figure 1). 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 degree 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 less than 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.

### Procedure

The testing was undertaken in three sessions: in the first session the children were tested in seven class groups and in the second and third they were tested individually.

#### *Group testing*

The examiner led a brief discussion of what was meant by research and why they were asking questions. The children were then asked to put their glasses on if they had any. They were told that there were no right or wrong answers to the questions that they would be asked, that no one would mind what they said, and they were asked to tell the truth when answering and to keep the answers to themselves. The examiner then led a discussion as to what the word 'blurred' (fuzzy or difficult to see) meant.

The pupils were issued with a questionnaire on which they were invited to place their name and class number, and a page on which was printed a passage of randomly-ordered common words. The passage comprised 20 lines, each with the following fifteen words in a different random order: come, see, the, play, look, up, is, dog, cat, not, my, for, and, you, to. The words were printed in nominal 12 point Arial sans serif font, single-spaced on a 300 dpi laser printer using Microsoft Word 6.0 on a PC.

The examiner then took the class through each of the items in the questionnaire in turn, asking them to circle 'yes' or 'no' as appropriate. The first two questions concerned the use of glasses: 'Do you wear glasses for reading?', 'Do you wear glasses for watching the television or for looking at the blackboard?'. The children were then asked to read the passage aloud as fast as possible for one minute, the purpose being to tire the eyes. They were asked to look at the passage and answer the following questions by circling the appropriate response: 'Do the letters stay still or do they move?', 'Are the letters clear or are they blurred?', 'Is the page too bright, not bright enough or just about right?', 'Does it hurt your eyes to look at the writing or is it ok?' They were then asked to find the middle line of the passage (the 10th line down) and were asked: 'Are the words too close together or far enough apart?'.

Finally they were asked the following general questions: 'Is it easy to see the writing on the board or is it difficult?', 'Is it easy to find your place when copying from the board or is it difficult?', 'Is it easy to see the writing in the book which you

use for literacy or is it difficult?', 'Do you have a headache everyday, most days or less often?'.

### *Individual testing*

After the group tests, the children were tested individually. The interval between the group tests and the first of the individual tests ranged from 3 hours to 2 days. During the individual tests the children were examined in pairs, class by class, in register order, one child in each pair being tested by Examiner EL and one by Examiner ER, both female. First, the child was asked to read aloud the passage of randomly-ordered common words for one minute. Next, each child was asked the same set of questions that had previously been asked of the class, excluding the general questions at the end. The child was then asked to select the overlay that provided for the maximum clarity and comfort of the text. The two examiners used a different method of assessment.

Examiner EL used the method of selection outlined in the *Intuitive Overlays Instruction Book* (IOO Marketing, London) and described in previous studies (Jeanes et al, 1997). In brief, each overlay was placed in turn upon the left or right half of a passage of randomly ordered letters resembling text (*Stimulus Material B*) and the child asked to choose which side was the clearer. Any overlays that improved the clarity were then compared side by side.

Examiner ER used a booklet of overlays in which two stacks of A5-size overlays were available side by side, a passage of text beneath each overlay. Each 'page' in a stack comprised a coloured overlay with a sheet of white paper beneath on which was printed the passage of randomly-ordered common words. Both stacks had the same ten pages, one for each of the ten differently coloured intuitive overlays, in the following order: rose, purple, aqua, lime green, orange, grey, yellow, mint green, blue, pink. At the outset, a white page appeared on one stack and the pages of the other stack were turned so that each coloured page could be compared in turn with the white page. If any colour was reported as clearer than white, that colour was used for subsequent comparison, and the pages of the other stack turned until another colour was reported as clearer or until all the pages in one or other stack had been turned.

The child was then asked to read the passage of text on two further occasions, one with no overlay and one with the overlay just chosen. The order in which these two tests were undertaken was alternated from one child to the next.

At least one and no more than two days later the child was seen again, this time by the other examiner using the alternative overlays-selection procedure. Other aspects of the examination remained the same as those of the earlier examination, except that the examiner told the child to consider the appearance of the text on this occasion and to ignore the results of their previous assessment.

## RESULTS

### **Reliability**

The same number of children, 78 (87%), chose a coloured overlay on both individual test sessions. The rate of reading without the overlay on Session 1 was strongly

correlated with the rate of reading without the overlay on Session 2 ( $r = 0.86$ ;  $p < 0.001$ ), see Figure 2

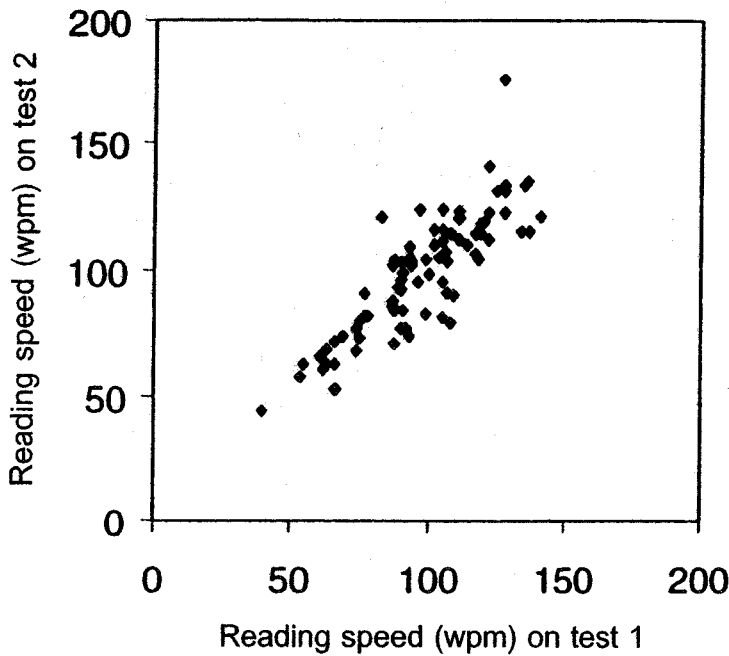


Figure 2. A scatterplot showing the rate of reading measured on one occasion (x-axis) and on a second occasion (y-axis) by a different examiner.

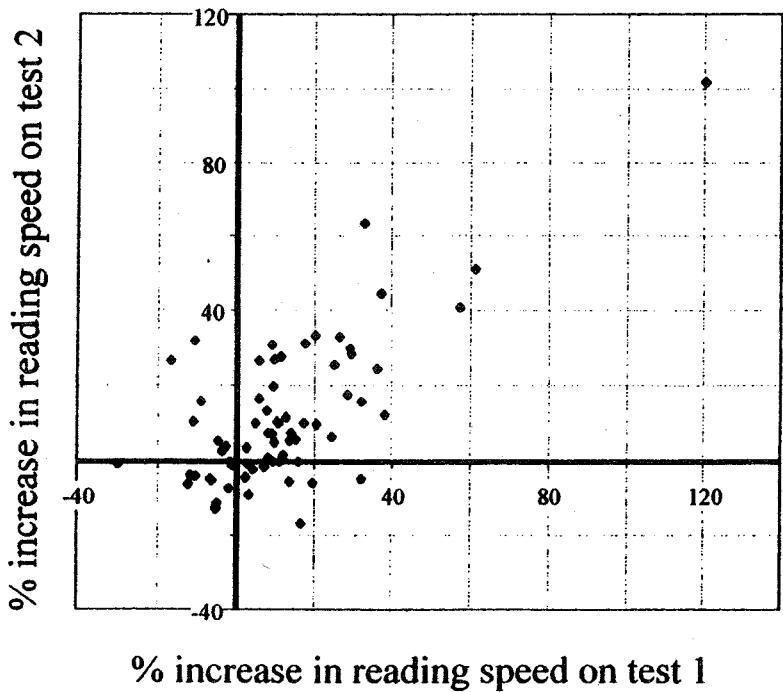


Figure 3. A scatterplot showing the percentage improvement in reading fluency with an overlay recorded on two test sessions.

The improvement in reading fluency due to the overlay was measured as the ratio of reading speed with the overlay, divided by that without. Overall there was an 11% improvement in reading fluency with the chosen overlay ( $t(75) = 2.8$ ;  $p < 0.0001$ ). The ratio obtained in Session 1 was strongly correlated with that obtained in Session 2, notwithstanding the different overlays chosen ( $r = 0.72$ ;  $p < 0.001$ ), see Figure 3. The correlation was also high when the ratio for the method used by Examiner EL (used on half the trials in Session 1 and half in Session 2) was compared with the ratio for the method used by Examiner ER ( $r = 0.72$ ;  $p < 0.001$ ).

Consistency

Notwithstanding the differences in assessment method, 47% of children selected the same colour on both occasions, and a further 21% chose an overlay of similar (neighbouring) chromaticity. The percentage expected by chance to choose an identical overlay on both occasions was estimated to be 8.7%  $\pm$  2.9% by 600 Monte Carlo trials in which children's choice of overlays on the second trial were randomly re-allocated. The consistency demonstrated by the children was therefore more than 13 standard deviations above that expected on the basis of chance alone. The percentage improvement in reading rate is shown as a function of the consistency of the child's choice of colour in Figure 4.

As can be seen, the 47% children who chose the same colour consistently on the two testing sessions showed a greater improvement in reading fluency with the colour than those who chose a colour of neighbouring chromaticity (21%), and these children in turn showed a greater improvement in fluency than those 22% who chose

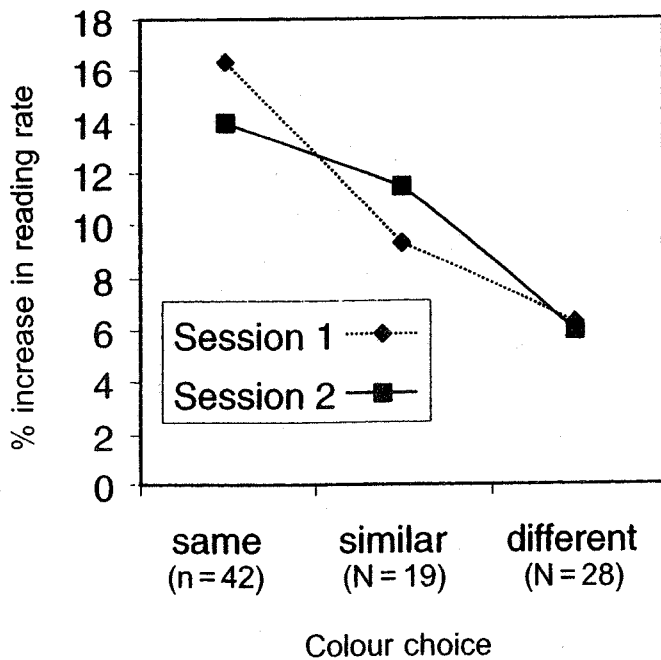


Figure 4. Improvement in reading speed with a chosen overlay in 78 children, shown separately for children who chose the same colour on each of two tests, those who chose a similar colour, and those who chose a different colour.

a different colour on each occasion ( $N = 28$ ). The average increase in reading speed for the children who chose the same or similar colour on Sessions 1 and 2 was greater than that for the children who chose a different colour ( $t(77) = 1.74$ ;  $p < 0.05$ , one-tailed).

### Symptoms: group testing versus individual testing

The percentage of children reporting symptoms in response to each question is shown in Table 1. The symptoms reported during the group testing were similar to those reported when the children were examined individually. The correlation between the total number of symptoms of perceptual distortion reported on the first (group) session and the first individual session was 0.77, and between the two individual sessions, 0.81 ( $p < 0.001$ ).

The 78 children who chose an overlay reported an average of 2.79 symptoms when questioned as a group, whereas the 11 who did not choose an overlay reported only 1.00 on average. The difference was significant ( $t(87) = 3.47$ ;  $p < 0.001$ ). The correlation between the number of symptoms reported on the group session and the rate of reading without an overlay was negligible ( $r = 0.01$ ) although there was a significant positive correlation between the number of symptoms and the rate of reading with a coloured overlay ( $r = 0.26$ ;  $p < 0.05$ ). The correlation between the number of symptoms and the percentage increase in rate of reading with an overlay was similar ( $r = 0.24$ ;  $p < 0.05$ ).

The relationship between the reporting of symptoms and the improvement in reading fluency with an overlay is shown in Table 2. This shows that 56% of children (that is, 9 out of 16) who showed an increase in reading rate of 20% or more reported four or more symptoms on the group test, and 63% (that is, 34 out of 54<sup>2</sup>) of those who reported less than four symptoms showed an increase in reading rate of less than 20%. Note that the specificity of the symptoms did not change with the percentage increase in reading rate adopted as a criterion, although the sensitivity increased and specificity decreased with the number of symptoms.

## DISCUSSION

As in previous studies, a substantial proportion of children reported that one or more overlays improved the clarity and comfort of printed text. The choice of colour was

Table 1. Percentage of children in Study 1 reporting symptoms in response to questions asked of the group or individually.

| Symptom     | Group test | 1st individual session | 2nd individual session |
|-------------|------------|------------------------|------------------------|
| Movement?   | 43         | 52                     | 56                     |
| Blurred?    | 37         | 53                     | 52                     |
| Too bright? | 42         | 37                     | 35                     |
| Hurt eyes?  | 56         | 62                     | 54                     |
| Too close?  | 82         | 69                     | 66                     |

Table 2. The relationship between the number of symptoms reported in Study 1 and the sensitivity and specificity of the number of symptoms in predicting the percentage increase in reading rate with the overlay.

|                                                |             | Percentage increase in reading rate with the overlay |    |     |     |
|------------------------------------------------|-------------|------------------------------------------------------|----|-----|-----|
|                                                |             | 10                                                   | 20 | 30  | 40  |
| Number of children showing increase (Total 70) |             | 32                                                   | 16 | 6   | 5   |
| Symptoms                                       |             |                                                      |    |     |     |
| 2 or more                                      | Sensitivity | 72                                                   | 75 | 100 | 100 |
|                                                | Specificity | 26                                                   | 28 | 30  | 29  |
| 3 or more                                      | Sensitivity | 63                                                   | 69 | 83  | 100 |
|                                                | Specificity | 50                                                   | 48 | 47  | 48  |
| 4 or more                                      | Sensitivity | 53                                                   | 56 | 83  | 100 |
|                                                | Specificity | 68                                                   | 63 | 63  | 63  |

Note: The children have been divided on the basis of the number showing a given percentage increase in reading speed, and in terms of the number of symptoms reported. At each level of symptom susceptibility the *sensitivity* is the percentage of children with more than the criterion number of symptoms whose rate of reading increased by more than the percentage shown and the *specificity* is the percentage of children whose increase in rate of reading was less than that shown. The estimates of sensitivity at the higher increases in reading rate are based on small samples.

highly reliable from one examination to the next, despite different examiners and different techniques. Most children chose the same or similar colour on both examinations and it was these children who demonstrated the greatest increase in reading speed with the chosen overlay. Reading speed showed considerable variation from one individual to another; the range in the population studied exceeding a factor of three. Nevertheless for any given individual the reading speed was a highly reliable measure. The increase in reading speed with the chosen overlay was also highly reliable.

A substantial proportion of children reported symptoms of visual stress (Wilkins, 1995) and these reports were reliable at three examinations, the first by group, and the second and third by individual. The children who reported many symptoms tended to be those who chose coloured overlays and whose reading speed improved when their overlay was used. The sensitivity and specificity of symptoms in predicting benefit from overlays suggest that group-screening techniques would be sufficient to correctly identify most individuals for whom an overlay improves reading speed by more than 30%, at the expense of incorrectly identifying about 30% of individuals who show relatively little benefit.

The next study used similar techniques but children were issued not with the overlays they had chosen, but with overlays selected at random. In this way the specificity of the effects of colour was investigated. In addition, the children were given a test designed to determine their relative skills in phonological or non-phonological processing strategies in order to see whether such processing was related to visual symptoms or benefit from overlays.

## STUDY 2: METHOD

### Participants

All the 378 children in a middle school in Norwich, Norfolk UK, took part. There were 185 boys and 193 girls aged between 8 years 2 months and 12 years 1 month.

### Test materials

Two stacks of overlays similar to those used in Study 1 were arranged side by side, with a white page of text in a central position below the lower margin of the stacks. As in Study 1 the text was printed in sans serif 10 point Arial Font. Both stacks again had the same ten pages, one for each of the ten differently coloured *Intuitive Overlays*, but the pages were presented in one of 18 different random orders.

A list of 40 phonologically-regular words and a second list of 40 phonologically-irregular words, such as yacht, and meringue were prepared. The words were written individually in a column, in a sans serif typeface (Arial) with an x-height of 3mm, and an interlinear spacing of 14.5mm. The lists were those used by Funnell and Pitchford (personal communication).

### Procedure

All the children were tested individually by one of three examiners. The testing began by asking the child general questions about symptoms when reading. The children were asked 'Do you get headaches when you read?'; 'Do you get sore eyes when you read?'; 'Do you find you lose your place when you read?'; 'Does it make it easier to see words if you look away from the page and look back?'.

Without an overlay the child was then required to read aloud for one minute the passage of randomly ordered common words from the *Rate of Reading Test*. They were then asked to look at the page and answer the following specific questions: 'Do the letters stay still or do they move?'; 'Are the letters clear or are they blurred?'; 'Is the page too bright, not bright enough, or just about right?'. They were then asked to look at the central line of print, and were asked: 'Are the words too close together, or far enough apart?'.

The booklets were placed flat on the table in front of the child, and the top page of the rightmost booklet was turned over to reveal two differently-coloured pages, side by side, with the central white page between these and the child. The child was asked to say which of the three pages (two coloured and one white) was the clearest and most comfortable, and which was the least. This enabled the three pages to be ranked in order of preference.

The least preferred of the two coloured pages was turned to reveal the differently-coloured page beneath. The rank of preference was again obtained for the three pages (one white, and two coloured: one newly revealed, and one shown on the previous occasion). The process continued until all the pages in one or other stack had been turned.

Finally, the child was again asked to read aloud the passage from the *Rate of Reading Test* as quickly and accurately as possible. The passage was read three times: once with a white page, once with a page having the colour of that of the last preferred page, and once with a page of a colour chosen at random. The above three

conditions were presented in random order. At the end of the examination each child was asked to read aloud without an overlay two lists of words graded in difficulty. The first list was the phonologically-regular words and the second the irregular words. All but 25 of the children expressed some perceptual benefit with one or other overlays, and were issued with an overlay. A grey overlay was given to 150 children, and the remaining 100 received a coloured overlay, the colour chosen at random. The children were re-assessed five months later and a note was made of those still using their overlay.

## RESULTS

83% of children chose a coloured page. There was a clear tendency to choose the later overlays in the stack, suggesting that many children found little difference between the colours.

For the children who chose a coloured page the mean rate of reading (words per minute) was as follows – no overlay: 112.7; chosen overlay: 116.8; random overlay: 115.25. The chosen overlay was associated with a significantly greater rate of reading than no overlay ( $t(372) = 5.67$ ,  $p < 0.00001$  one-tailed). There was only a small, though significant, advantage for the chosen overlay compared with the random overlay ( $t(372) = 2.06$ ,  $p < 0.05$  one-tailed). If the children read faster with one coloured overlay but not with the other, they were more likely to do so with the chosen overlay than with the random one ( $X^2(1) = 4.3$ ;  $p < 0.05$ ). Twenty-seven children chose a grey overlay at their first test. The mean reading speed with the grey overlay was 122.2 words per minute, compared with 121.7 words per minute without an overlay, a difference that did not approach significance. Although grey was the chosen colour, it did not benefit reading speed.

The effects of test order were small, after the initial practice. The mean rate of reading on Test 1 was 106.9 words per minute. This test was without an overlay. The remaining three tests were in one of the experimental conditions (no overlay, chosen overlay, random overlay) in random order. The means for these tests were: Test 2: 113.9; Test 3: 116.9; Test 4: 115.8. A single factor repeated measures analysis of variance was used to compare the three means. The effect of test order was not significant ( $F(2,1116) = 0.781$ ,  $p = 0.458$ ).

The children who reported movement of the letters showed a significantly ( $t(161) = 2.32$ , one-tailed  $p < 0.05$ ) larger increase in reading speed with the chosen overlay than those who did not report movement. A similar difference in reading speed was obtained for the children who experienced blurring of the page ( $t(118) = 1.70$ , one-tailed  $p < 0.05$ ), who reported glare from the page ( $t(121) = 2.52$ , one-tailed  $p < 0.05$ ), and who said the page hurt their eyes ( $t(142) = 2.14$ , one-tailed  $p < 0.05$ ). (The above were comparisons *planned* on the basis of the results of Study 1.) Other comparisons were non-significant: there was no significant difference in the improvement in reading speed with the overlay for the children who reported headache when reading, who experienced sore eyes when reading, who thought the word spacing was inadequate, and who reported looking away from text to improve clarity.

The random overlays were divided into those that were grey, those that were of a colour similar to that chosen (neighbouring chromaticity), and those of dissimilar

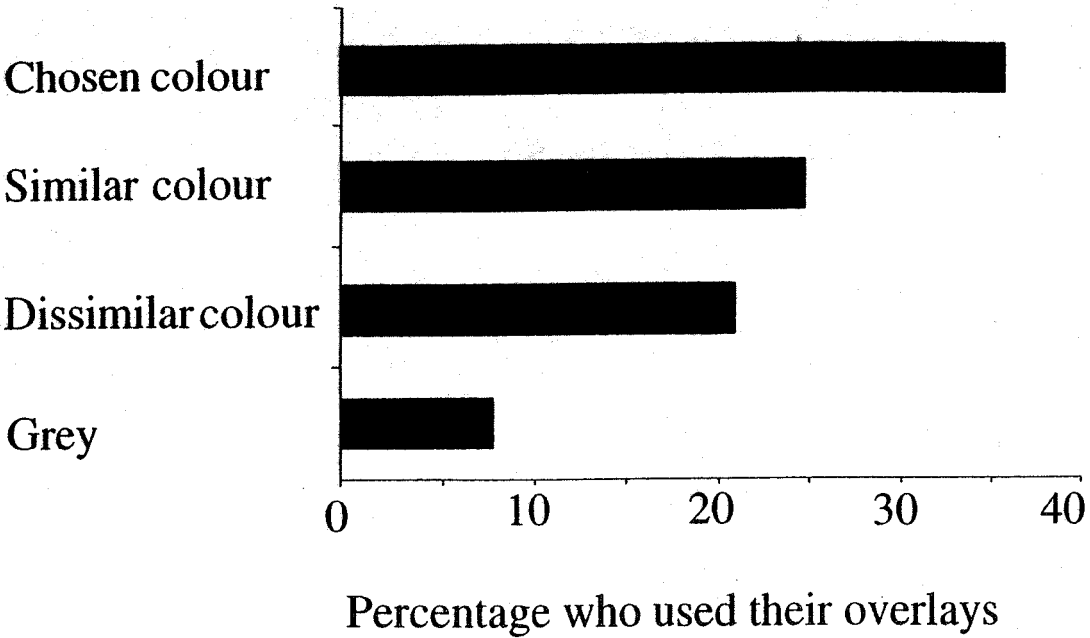


Figure 5. The proportion of children who continued to use their overlays shown as a function of the similarity of colour of the overlay they received to the colour of the overlay chosen as optimal.

colour. In Figure 5 the proportion of children who continued to use their overlays is shown as a function of the similarity of colour to that chosen. The trend towards a decrease in usage with colour difference was significant ( $L = 4700, z = 2.06; p < 0.05$ ).

The proportion of the 34 children who chose a grey overlay, were given a grey overlay, and continued to use it (44%), did not differ significantly from the proportion who chose a coloured overlay, were given a grey overlay and continued to used it (74%).

**Reading strategy**

As might be expected, children who read many regular or irregular words correctly were generally faster at reading. The correlation between rate of reading (second test on the white page: Session 2) and the number of words correctly read was 0.49 for words in the regular list and 0.54 for the irregular words. The correlation remained similar when age was statistically controlled (the partial correlation between rate of reading and number of regular words correct was 0.44; it was 0.46 for the irregular words). In order to determine whether the predominant reading strategy was related to specific symptoms or overlay efficacy, the number of words correctly read was converted to ranked scores for each list. The partial correlation (controlling for age) between the difference in the ranked scores and the total number of symptoms (data from Session 2) was  $-0.04$ . The corresponding partial correlation with the increase in reading speed due to the overlay was negligible ( $r = -0.06$ ). The correlation between increase in reading speed and difference in ranked scores remained negligible ( $r = -0.03$ ) when the analysis was restricted to children in an age-range of one year (date of birth September 1986–September 1987).

## DISCUSSION

The children read most quickly with their chosen overlay, as in previous studies. The use of the randomly chosen overlays was associated with an increase in reading speed that was almost as great as for the colour the children chose for themselves, but was nevertheless significantly smaller. Those few children who chose a grey overlay differed from the remainder in that they did not show an improvement in reading speed with the chosen overlay.

The improvement in reading rate with the overlay was related to symptoms that the children reported when looking at a page of text, as in Study 1, but not with symptoms that were reported in response to the initial questions about reading in general. Evidently asking questions about the here and now elicited symptoms more reliably. Once children were familiar with the reading task, (i.e. after the first attempt at reading the Rate of Reading Test), the effects of test order (practice/fatigue) were small and non-significant. The children who benefited from an overlay did not differ from the others with respect to their use of a phonological reading strategy.

Studies 1 and 2 have shown that a large number of normal school children read more quickly when the page they were reading was covered by a coloured overlay, particularly if the overlay was of a colour chosen by the individual. The prevalence of visual stress in the school population appears to be high, although the sample size is insufficient for a reliable estimate. In Study 3 the sample size was greatly increased.

## STUDY 3: METHOD

### Participants

Following a lecture to schoolteachers in Norwich, United Kingdom, members of staff in twenty Norfolk schools volunteered to participate in the study. Twelve schools completed the study. The schools included those in urban and rural areas. All the children in each school in Year 3 (aged 6 years 10 months–8 years 6 months, mean 7 years 6 months) took part in the study, except those whose parents refused permission (<1%). The numbers of children tested in each school averaged 35.5, with a standard deviation of 20.6 between schools.

### Testing Materials

The *Intuitive Overlays* were supplied to classroom teachers in a *Teacher's Assessment Pack* (IOO Marketing, London). The pack included two of each of ten colours, A5 size, together with textual stimulus material and instructions for use.

The *Rate of Reading Test* (IOO Marketing, London) was administered. In this case, the published version of the test was used, as described by Wilkins et al, (1996).<sup>3</sup> The typeface was 9pt Times set solid with 4pt inter-word spacing.

The *Young's Group Reading Test* Third Edition (Hodder and Stoughton, 1989) was also administered, but as part of the routine assessment of children by Norfolk Education Department that all children underwent. The test requires children to comprehend short sentences and identify a missing word from among four alternatives.

## Procedure

Testing was undertaken in the autumn term. Teachers were asked to assess whether in their opinion the child's progress in reading was greater or less than that expected from their other skills. They were also asked to say whether the child had difficulty concentrating.

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  $70\text{cd.m}^{-2}$ .

The child was shown *Stimulus Material B* from the *Intuitive Overlays* (random letters arranged in strings 1–7 letters in length to resemble words, and printed single spaced in 12pt Times as a paragraph  $\sim 75$  letters (131mm) wide and 17 lines (70mm) long). The child was asked whether the letters stayed still or moved; whether the letters were 'clear or blurry'; whether they could see the spaces between the groups of letters; whether they saw colours on the page; whether the page was 'too bright, not bright enough or just about right' and finally whether the page hurt their eyes. Each child was then assessed with the overlays following the publisher's recommended procedure. In brief, each overlay was placed over *Stimulus Material B* 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.

Next the *Rate of Reading Test* was administered. The four published versions were used in ascending numerical order, with, without, without and then with the chosen overlay. To save on testing time, only children who chose an overlay were tested.

Children who reported an improvement in the clarity of text with the chosen overlays were given them free of charge to use as and when they wished. Members of school staff were instructed to avoid placing the children under any pressure to use overlays. Nine months later the schools were contacted and the class teachers were asked to list the children who were still using their overlays.

## RESULTS

### Perception

Initially 60% of the 426 children reported improved perception of text (a reduction of visual distortions or improved clarity or comfort) with one or more coloured overlays. These children were issued (free of charge) with their chosen colour (as provided by one overlay or combination of two overlays superimposed).

In the summer term, about eight months later, 52% of these children (i.e. 31% of the total sample) were still using the overlay. The percentage of children using the overlay varied from one school to another with a mean of 30% and standard deviation of 15% between schools.

Table 3 shows the percentage of children who reported various distortions of the page of text. Children who used overlays throughout the school year (63 boys and 73 girls) are shown separately from those who used overlays initially but subsequently ceased to do so (62 boys and 62 girls). (Those who did not report any perceptual benefit from the overlays when first tested were not issued with overlays – 85 boys and 85 girls).

Table 3. The percentage of children reporting distortions of a page of text shown separately for the children in Study 3 who used overlays, and those who subsequently ceased to use them.

| Symptom           | Not given<br>overlay<br>N = 171 | Given overlay            |                 | $\chi^2$ | p       |
|-------------------|---------------------------------|--------------------------|-----------------|----------|---------|
|                   |                                 | Stopped using<br>N = 124 | Used<br>N = 135 |          |         |
| still or moving?  | 4.7%                            | 20.3%                    | 28.7%           | 32.9     | <0.0001 |
| clear or blurred? | 8.2%                            | 22.6%                    | 32.6%           | 28.8     | <0.0001 |
| colours?          | 4.7%                            | 7.3%                     | 8.1%            | 1.6      |         |
| see the spaces?   | 3.5%                            | 8.9%                     | 17.0%           | 16.4     | <0.001  |
| too bright?       | 7.1%                            | 15.3%                    | 18.5%           | 9.0      | <0.01   |
| hurt eyes?        | 7.9%                            | 29.0%                    | 33.6%           | 32.7     | <0.0001 |

The children who used overlays did not differ from those who ceased to use them as regards their response to any of the questions concerning the appearance of print, using chi-square with a conservative criterion for significance ( $p < 0.01$ ) to allow for the number of comparisons involved. However, the children who chose overlays did differ significantly from those who did not choose overlays in their response to *all* the questions except those concerning colour and brightness, using a similar conservative criterion. The children who continued to use their overlays were also more likely to be reported by their teachers to have poor concentration ( $\chi^2(1) = 4.1$ ;  $p < 0.05$ ).

### Frequency of choice of different colours

The most frequently chosen colours, rose and aqua, were chosen by less than 10% of the sample of children. Figure 6 is a diagram summarising the frequency with which each colour was chosen. The figure shows the colours provided by single overlays separately from the colours formed by double overlays. The choices of children who ceased to use their overlays are shown separately from those of the children who continued to use the overlays. There was no statistical difference in the frequencies with which the various colours were chosen by these two groups.

### Contrast reduction

Grey overlays reduce the contrast of the text beneath by an amount that is similar to the contrast reduction afforded by coloured overlays. (The contrast reduction was due partly to the matte coating and was generally less than about 5%, provided specular (mirror-like) reflection of the light source was avoided.) Grey overlays were infrequently chosen, suggesting that the effect of colour may be more important than the contrast or luminance reduction. This suggestion is confirmed by other studies that have compared reading rate with grey and coloured overlays and have shown superior reading performance with the coloured overlay (Wilkins and Lewis, 1999).

Table 4 shows the reading rate with and without the overlay in the order in which the tests were administered. Data were available from 273 children who reported a beneficial effect of the overlay.

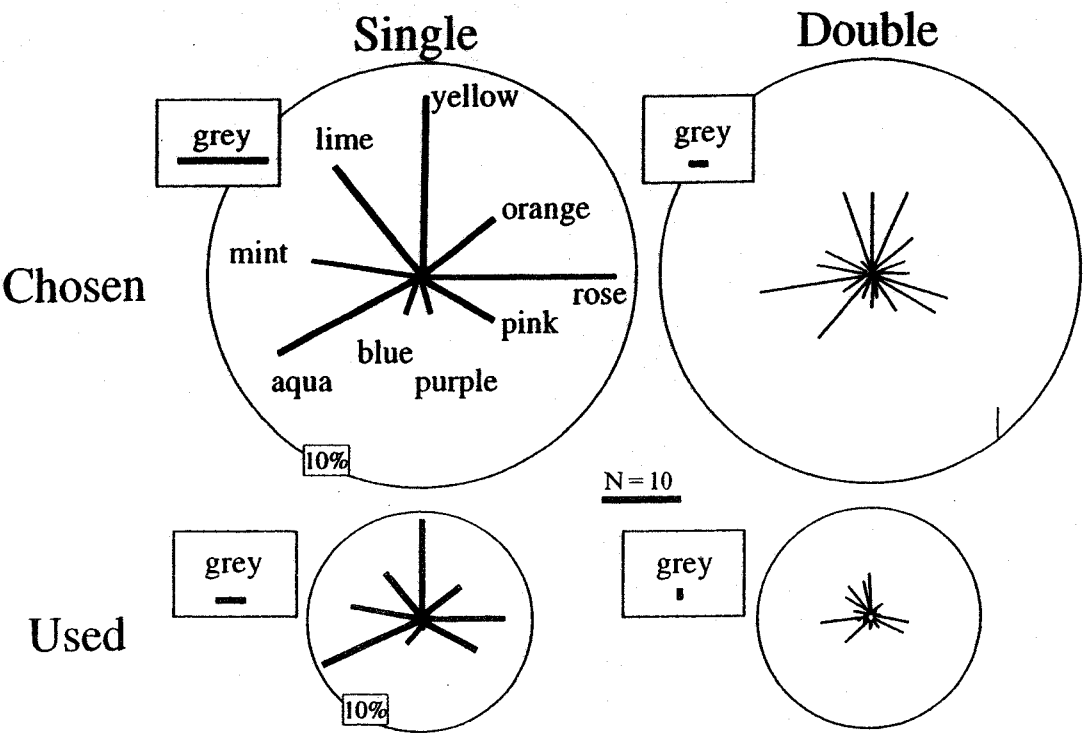


Figure 6. Frequency histogram showing the number of children choosing overlays of each of the ten colours.

Notes: The length of each line is proportional to the number of children, and the orientation of the line represents the hue angle. The circles have a radius equivalent to 10 percent of the sample. The colour choices of children who initially chose an overlay and those who continued to use their overlay are shown separately. The colours derived from combinations of two overlays are shown separately from those for a single overlay. The frequency of choice of hues is similar for children who used single or double overlays and for the subset of children who continued to use the overlay.

A repeated measures analysis of variance with overlay condition (with/without) and practice (1st presentation or 2nd) yielded a significant effect of overlay condition ( $F_{1,272} = 13.6$ ;  $p < 0.001$ ), no significant main effect of test order and a significant interaction term ( $F_{1,272} = 7.91$ ;  $p < 0.01$ ). Given the results of Study 2, the interaction is most easily interpreted as due to non-linear effects of practice, the practice effects being greatest on Test 1 and negligible thereafter. The effect of the overlay on

Table 4. Mean reading rate in words per minute (and standard deviation) with and without an overlay, in the order in which the four tests were administered in Study 3.

| Test 1<br>With  | Test 2<br>Without | Test 3<br>Without | Test 4<br>With  |
|-----------------|-------------------|-------------------|-----------------|
| 73.64<br>(20.5) | 71.63<br>(22.48)  | 71.83<br>(22.3)   | 75.23<br>(21.1) |

Table 5. The mean reading rate in words per minute (and standard deviations) without and with an overlay, averaged over two trials (Study 3).

|                 | Continued to use overlay | Stopped using overlay |
|-----------------|--------------------------|-----------------------|
| Without overlay | 67.7<br>(23.1)           | 76.1<br>(19.7)        |
| With overlay    | 71.7<br>(20.9)           | 77.3<br>(19.5)        |

reading speed, as judged by the difference between the average reading rate with the overlay (Trials 1 and 4) and without (Trials 2 and 3) is therefore conservatively assessed.

The children who were still using their overlays in the summer term were more likely to be those who in the previous autumn term read faster with their overlays on the *Rate of Reading Test*, as shown in Table 5. The average increase in reading speed for the children who used their overlays was 13.3%, ( $t(124) = 4.10$ ;  $p < 0.0001$ ), and for the other children 2.5% ( $t(118) = 2.10$ ;  $p < 0.05$ ), a difference between the groups that was significant on a planned t-comparison ( $t(242) = 2.32$ ;  $p < 0.05$ ). The percentage increase in the rate of reading with the overlay compared to that without was related to subsequent overlay usage, as shown in Table 5. Figure 7 shows how the

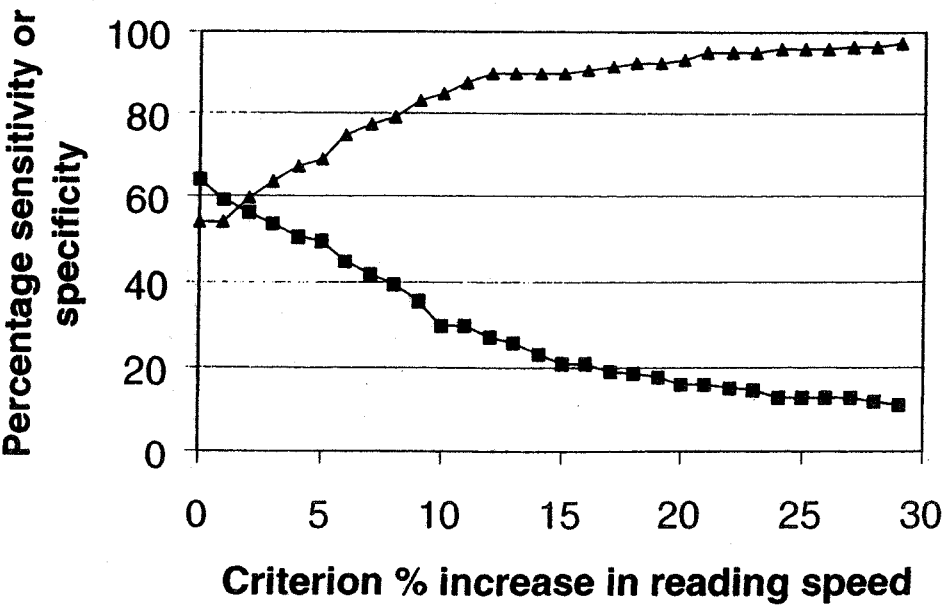


Figure 7. Changes in sensitivity and specificity with the percentage increase in reading speed used as a criterion to divide children who showed an increase in reading speed with their overlay from those that did not.

Notes: Sensitivity (ascending curve) is here defined as the percentage of children continuing to use their overlays who read more quickly with their overlay than without by the criterion shown in the abscissa. Specificity (descending curve) here refers to the percentage of children who did not use their overlays and who did not read more quickly with their overlay by the same criterion.

sensitivity and specificity of the prediction changed with the percentage increase in reading rate chosen as the criterion.

**Placebo effects?**

Thirty-three children chose a grey overlay. As in Study 2, these children did not show a significant increase in reading rate with the overlay, suggesting that motivation is not a sufficient explanation for the improvement in reading speed with coloured overlays, as also indicated by the studies reviewed in the introduction.

**Reading ability and use of overlays**

Standardised Young's-test scores (average 100, standard deviation 15) were available for 427 children. The 133 children who used overlays had an average reading quotient of 98.7, compared with 102.2 for the remaining 294 who did not use overlays or did not choose them ( $t(558) = 2.51$ ;  $p < 0.02$ , two-tailed). The average reading speed (without overlays) for the children who used overlays was 67.7 words per minute compared with 76.0 for the remaining 119 children tested (those who stopped using their overlays;  $t(243) = 3.04$ ;  $p < 0.01$ ). Figure 8 shows a scatter plot relating the reading quotient on the Young's test of reading attainment to the scores on the Rate of Reading Test, both measured before the overlays were issued. The correlation was 0.60 ( $p < 0.001$ ) for the children who subsequently used their overlay and 0.54 ( $p < 0.001$ ) for the children who subsequently stopped using it.

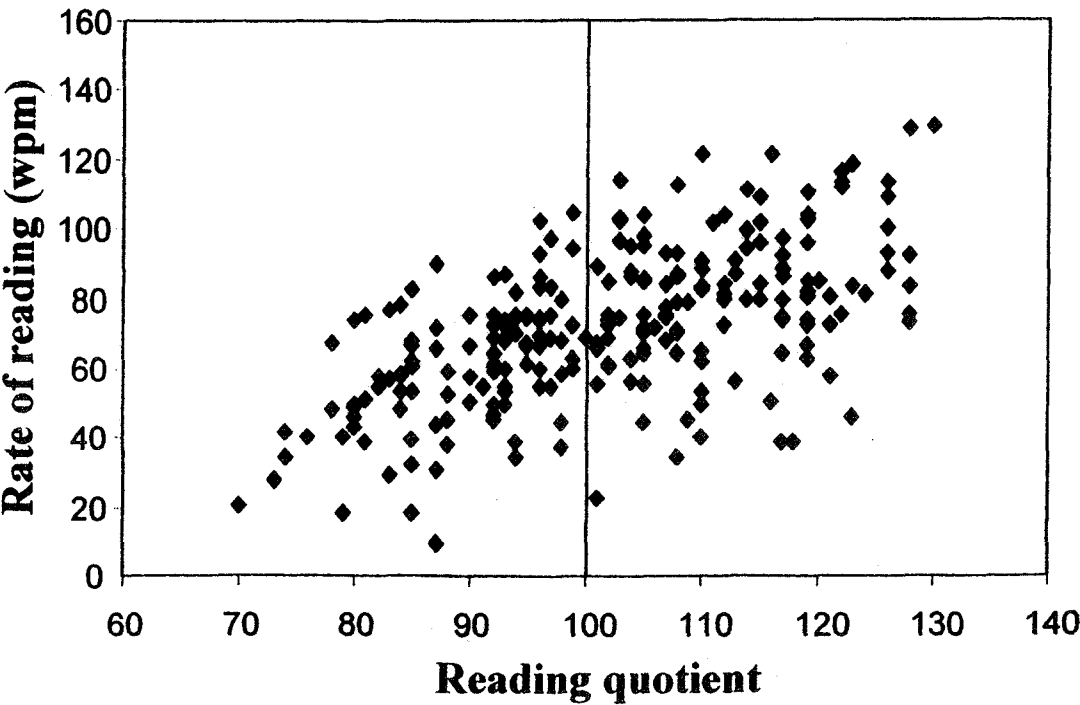


Figure 8. A scatterplot showing the relationship between rate of reading and scholastic attainment in reading as assessed by the reading quotient from the Young's Reading test.

## DISCUSSION

Study 3 showed that about 50% of mainstream school children (boys and girls in similar proportion) report that one or more coloured overlays improve the clarity of text. About half of these children used the overlay and half stopped using it over the ensuing eight months; there were no gender differences in this respect. The children who continued to use their overlay differed from the others in showing an improvement in reading speed with the overlay when first tested. In the above respects the findings replicate those of Jeanes et al (1997) and Wilkins et al (1996) with a larger sample.

### Reading attainment and reading fluency

The range of reading speeds shown in Figure 8 is remarkable. Note that there are good readers (reading quotient > 120) who are reading only 40 words per minute and others with similar reading attainment who are reading more than three times as fast. This range is not due to variability in the rate at which a person can read from one time to the next because the *Rate of Reading Test* has a very high test-retest reliability. With immediate retest the correlation between first and second tests is high (see Study 1) and remains high even when tests are separated by three months (Jeanes et al, 1997). Clearly the *Rate of Reading Test* scores reflect large and stable individual differences. Some of these differences may be attributable to visual skills given that (1) reading rate can show improvements with coloured overlays within participants and (2) it is difficult to attribute the individual differences to linguistic skill because the differences exist when reading attainment is controlled. The immediate increase in reading rate when overlays are used is consistent with such a viewpoint. Further, the improvements in reading speed have predictive utility with respect to the usage of overlays.

## 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, who persist in using overlays and who demonstrate improvements in reading fluency both before and after using them. The choice of colour is individual, yet reliable at re-test in so far as more than half the children choose the same or similar colour. No one colour clearly predominates. The chosen overlay gives greater improvements in reading fluency than others of similar colour. If the choice of overlay colour is consistent at re-test, greater benefits in fluency are demonstrable. A simple questionnaire about symptoms experienced when viewing text can be administered to a class of children and will correctly identify about 80% of those who will demonstrate an improvement in reading fluency of 30% or more with an overlay, but at the cost of a false positive rate of more than 40%.

The present findings and those reviewed above are consistent in pointing to a visual or visuo-perceptual benefit from colour. Indeed, Scheiman et al (1991) have argued that Meares-Irlen Syndrome (the benefit from colour and symptoms of perceptual distortion) is a reflection of binocular dysfunction. Evans et al (1996a,

1996b) have investigated binocular vision of individuals who benefit from using coloured lenses. In general the findings are within normal limits in most individuals. There is a tendency for slightly poorer (but not necessary abnormal) performance on certain clinical tests of vision (near point of accommodation and prism vergences). Direct measurements of accommodation using a modified optometer have failed to show any steady-state accommodative deficits (Simmers, Grey and Wilkins, 1999). It is an open question as to how far the relatively poor performance is due to perceptual effort rather than optometric difficulties, given that both tasks (near point of accommodation and prism vergences) require the report of maintained clear vision of targets that are difficult to focus on (near point of accommodation) or to fuse binocularly (prism vergences). Benefits are common in children whose binocular vision is quite normal.

There remains the possibility that colour may be affecting accommodation. Evans et al (1996a, 1996b) studied children who benefited from coloured glasses and noted that the beneficial colour was not such as to reduce any residual refractive error. Simmers, Grey and Wilkins, (1999) measured the accommodative dynamics and found them normal; i.e. the power of the lens was altered appropriately in order to focus the image on the retina. However, in the steady-state response they found an abnormally high power of accommodative fluctuations at low frequencies: the power of the lenses was fluctuating more than it usually does. These fluctuations were reduced by the prescribed coloured lenses, but also by spectrally neutral lenses absorbing an equivalent amount of light (i.e. of similar photopic absorbance). These findings are preliminary, but important in that they reliably demonstrate for the first time a physiological abnormality in these children. The abnormality may be a correlate of visual stress, rather than a component of a causal mechanism for the benefits of coloured glasses. Lightstone, Lightstone and Wilkins, (1999) noted that the optimal colour for use in lenses was not the same as that optimal in overlays, which suggests that any accommodative mechanism is unlikely to be a sufficient explanation.

As yet, no retinal deficit has been demonstrated in individuals with Meares-Irlen Syndrome. Deficits of colour vision on clinical tests are no more prevalent than would be expected on the basis of age and gender (Evans et al, 1996a). There are no obvious optometric or orthoptic deficits on clinical testing (manuscript in preparation).

Livingstone et al (1991) and Lovegrove, Martin and Slaghuis (1986) have demonstrated that, in individuals with dyslexia, transient visual function can be impaired. Transient visual function refers to those aspects of vision that provide information about rapid changes in the visual scene, and it is thought to be subserved by the magnocellular division of the visual pathways. In the parvocellular division the cells have different characteristics and are thought to support the detection of stable detail. The impairment has been widely proposed as providing a basis for the benefits from colour, partly on the basis of the suppression of transient cell activity in the presence of red light, first noted by Wiesel and Hubel in 1968 and subsequently confirmed (see Wilkins, 1995). For example, Lehmkuhle (1993) asserts that 'a blue overlay would be most effective in reducing the relative contribution of the (parvocellular) pathway' and that 'the balance of the magno- and parvocellular pathways is thereby restored'. Notwithstanding this assertion, there is no way of explaining the large individual differences in optimal therapeutic colours (demonstrated in these studies and under double-masked conditions by Wilkins et al in 1994.)

Wilkins (1995) has proposed an alternative explanation which draws together aspects of visual stress in epilepsy, migraine and discomfort when reading. The children who benefit from coloured filters are twice as likely to have migraine in the family as those who show no benefit (MacLachlan, Yale and Wilkins 1993). Individuals with migraine are thought to have a hyperexcitable visual cortex (Aurora and Welch, 1998) and this may explain their susceptibility to photophobia, given that the visual stimuli that provoke photophobia are very similar to those that trigger seizures in patients with photosensitive epilepsy (Wilkins, 1995). Patterns of stripes that provoke photosensitive seizures interfere with normal vision (Chronicle and Wilkins, 1996), provoking perceptual distortions (Wilkins et al, 1984) to which individuals with migraine are particularly susceptible (Marcus and Soso, 1989), the more so with certain colours (Chronicle and Wilkins, 1991). Depending upon its layout, text can resemble a pattern of stripes with epileptogenic characteristics, and when it does it can provoke distortions similar to those provoked by such stripes (Wilkins and Nimmo-Smith, 1987; Wilkins, 1995).

Changing the colour of a visual stimulus must inevitably alter the distribution of normal neuronal activity within the visual cortex. Zeki (1983a, 1983b) has measured the spectral sensitivity functions of neurons in visual areas V3 and V5, areas that code for space and movement. The functions show large differences between neurons, particularly in the short-wavelength end of the visible spectrum. Similar differences are likely to exist for neurons in other visual areas. Perhaps comfortable colours reduce strong excitation in hyperexcitable regions, reducing an inappropriate spread of excitation and with it the illusory percepts. Such an explanation would predict that coloured filters will have benefit not only in reading but also in reducing headaches and seizures, and there are initial indications that this is indeed the case (Wilkins et al, 1994; Wilkins et al, 1999). Whatever basis for the benefits in symptom relief and improvements in reading fluency, the present studies join those of Robinson (e.g. Robinson and Foreman, 1999) in providing additional support for the anecdotal but insightful reports of Meares (1980) and Irlen (1991).

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## NOTES

1. Available as the *Intuitive Overlays* from IOO Marketing Ltd., 56-62 Newington Causeway, London SE1 6DS, UK.
2. 70-16
3. Available as the *Wilkins Rate of Reading Test* from IOO Marketing Ltd, 56-62 Newington Causeway, London SE1 6DS, UK.

## REFERENCES

- AURORA, S. K. and WELCH, K. M. (1998) Brain excitability in migraine: evidence from transcranial magnetic stimulation studies. *Current Opinion in Neurology*, 11, 205–209.
- BOULDOUKIAN, J. (1995) *Evaluation de l'effet de filtre colorés 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. P. and WILKINS, A. J. (1991) Colour and visual discomfort in migraineurs. *Lancet*, 338, 890.
- CHRONICLE, E. P. and WILKINS, A. J. (1996) Gratings that induce distortions mask superimposed targets. *Perception*, 25, 661–668.
- EVANS, B. J. W., WILKINS, A. J., BROWN, J., BUSBY, A., WINGFIELD, A., JEANES R. and BALD, J. (1996a) A preliminary investigation into the aetiology of Meares-Irlen syndrome. *Ophthalmic and Physiological Optics*, 16, 286–296.
- EVANS, B. J. W., WILKINS, A. J., BUSBY, A. and JEANES, R., (1996b) Optometric characteristics of children with reading difficulties who report a benefit from coloured filters. In: C. M. Dickinson, I. J. Murray, and D. Garden (eds.), *John Dalton's Colour Vision Legacy*. London; Taylor and Francis, 709–715.
- IRLEN, H. (1991) *Reading by the colors: Overcoming dyslexia and other reading disabilities through the Irlen method*. New York: Avery Publishing Group.
- 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. *British Journal of Psychology*, 88, 531–548.
- LEHMKUHLE, S. (1993) Neurological basis of visual processes in reading. In D. Willows, R. Kruk and E. Corcos (eds.), *Visual Processes in Reading and Reading Disabilities*, New Jersey: Erlbaum Associates.
- 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 and Physiological Optics*, 91, 279–285.
- LIVINGSTONE, M. S., ROSEN, G. D., DRISLANE, F. W. and GALABURDA, A. M. (1991) Physiological and anatomical evidence for a magnocellular defect in developmental dyslexia. *Proceedings of the National Academy of Sciences*, 88, 7943–7947.
- LOVEGROVE, W., MARTIN, F. and SLAGHUIS, W. (1986) A theoretical and experimental case for a residual deficit in specific reading disability. *Cognitive Neuropsychology*, 3, 225–267.
- MACLACHLAN, A., YALE, S. and WILKINS, A. J. (1993) Open trials of precision ophthalmic tinting: 1-year follow-up of 55 patients. *Ophthalmic and Physiological Optics*, 13, 175–178.
- MARCUS, D. A. and SOSO, M. J. (1989) Migraine and stripe-induced visual discomfort. *Archives of Neurology*, 46, 1129–1132.
- MEARES, O. (1980) Figure/ground brightness contrast, and reading disabilities. *Visible Language* 14, 13–29.
- ROBINSON, G. L. and 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*, 89, 83–113.
- 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. *Journal of the American Optometric Association*, 61, 600–605.
- SIMMERS, A. J., GREY, L. S. and WILKINS, A. J. (1999) The influence of Precision Tinted lenses upon ocular accommodation. *Investigative Ophthalmology and Vision Science (SUPPL.)* 40, 361.
- TYRRELL, R., HOLLAND, K., DENNIS, D. and WILKINS, A. J. (1995) Coloured overlays, visual discomfort, visual search and classroom reading. *Journal of Research in Reading*, 18, 10–23.
- WILKINS, A. J. (1994) Overlays for classroom and optometric use. *Ophthalmic and Physiological Optics*, 14, 97–99.
- WILKINS, A. J. (1995) *Visual Stress*. Oxford: Oxford University Press.
- WILKINS, A. J., BAKER, A., AMIN, D. SMITH, S., BRADFORD, J. BONIFACE, S., ZAIWALLA, Z., BESAG, F. M. C., BINNIE, C. D. and FISH, D. (1999) Treatment of photosensitive epilepsy using coloured filters. *Seizure*, 8, 444–449.
- 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 and Physiological 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 and Physiological Optics*, 16, 491–497.
- WILKINS, A. J. and LEWIS, E. (1999) Coloured overlays, text and texture. *Perception*, 28, 641–650.
- WILKINS, A. J. and NIMMO-SMITH, M. I. (1987) The clarity and comfort of printed text. *Ergonomics*, 30, 1705–1720.

- WILKINS, A. J., NIMMO-SMITH, M. I., TAIT, A., MCMANUS, C., DELLA SALA, S., TILLEY, A., ARNOLD, K., BARRIE, M. and SCOTT, S. (1984) A neurological basis for visual discomfort. *Brain*, 107, 989–1017.
- ZEK, S. (1983a) 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.
- ZEK, S. (1983b) Colour coding in the cerebral cortex: the reaction of cells in monkey visual cortex to wavelengths and colours. *Neuroscience*, 9, 741–765.

**Address for correspondence:** PROFESSOR ARNOLD WILKINS, Visual Perception Unit,  
Department of Psychology, University of Essex, Colchester CO4 3SQ, UK.  
E-mail: [arnold@essex.ac.uk](mailto:arnold@essex.ac.uk)