Ophthal. Physiol. Opt. Vol. 19, No. 4, pp. 279–285, 1999

0275-5408/99 $20.00 + 0.00

PII: S0275-5408(98)00083-0

Both coloured overlays and coloured lenses can improve reading fluency, but their optimal chromaticities differ

Anita Lightstone,[a] Tamsin Lightstone[b] and Arnold Wilkins[c]

[a]Institute of Optometry, London, UK, [b]4 Fairlight Court, Tonbridge, Kent, UK and [c]Visual Perception Unit, Department of Psychology, University of Essex, Wivenhoe, Colchester, Essex, UK

Summary

Some individuals read more fluently when the text is coloured: i.e., when coloured sheets of plastic (overlays) are placed upon the page, or when coloured lenses are worn. Overlays provide a surface colour whereas lenses mimic a change in the colour of a light source. The neural mechanisms that underlie colour constancy ensure that the chromaticity of overlays and lenses is processed differently by the visual system. We investigated (1) the relationship between the optimal colours of overlays and lenses, and (2) how reading rate is affected by a particular colour in overlays and lenses. In 100 patients we noted (1) the overlay(s) chosen from among the 29 combinations of the 10 IOO Intuitive Overlays® which sample chromaticity systematically and (2) the chromaticity co-ordinates of the lenses subsequently chosen using the Intuitive Colorimeter®, a device providing a light source that can be adjusted in hue, saturation and luminance independently. The relationship between the chromaticities of the overlays and the lenses showed considerable variation. In a second study, patients attending the Specific Learning Difficulties clinic at the Institute of Optometry, London, were given overlays to use for two months. Seventeen who derived benefit were examined using the Intuitive Colorimeter. Patients were asked to read aloud randomly ordered common words (Wilkins Rate of Reading Test): (1) with no colour, (2) with the chosen overlay, (3) with lenses matching the chosen overlay and (4) with lenses matching the Colorimeter setting. The aids increased reading rate significantly only in conditions (2) and (4). There was no significant improvement when lenses matching the overlay colour were used, and under this condition the reading rate was significantly poorer than in conditions (2) and (4). The colour of a lens will improve reading only if it is selected under conditions that mimic a change in the colour of a light source: coloured overlays give no clinically reliable guide to optimal lens colour. © 1999 The College of Optometrists. Published by Elsevier Science Ltd. All rights reserved

There has been considerable controversy concerning the use of coloured overlays and coloured lenses in the treatment of reading difficulty (see Evans and Drasdo, 1991, for review). Many early studies did not appear in peer-reviewed journals and have been "difficult to interpret due to design problems such as selection bias, sample size, heterogeneity of subjects, subjectivity of results, financial interests of investigators, and failure to consider such factors as placebo effects, controls and the ophthalmic status of subjects" (Menacker *et al.*, 1993). The study by Menacker from which the previous quotation is taken was well controlled, but compared the effects of only a few coloured lenses. Wilkins *et al.* (1994) presented evidence suggesting that the effects of colour are idiosyncratic, and that, for optimal effect, the colour had to be selected individually, and with precision, each individual apparently requiring a different colour. This finding was supported by a double-masked placebo-controlled cross-over trial which examined children who had found benefit from

Correspondence and reprint requests to Dr A. Wilkins

Received: 22 December 1997
Revised form: 23 November 1998

coloured overlays (Wilkins *et al.*, 1994). A reduced incidence of headaches and symptoms of eye-strain was found with spectacle lenses that were optimally coloured, but not with those that differed in CIE 1976 UCS chromaticity by a small amount (on average 0.06). No differences between the optimal and sub-optimal lenses were evident in this study when reading skills were assessed using the Neale Analysis of Reading (1966). However, it has since proved possible to obtain a reliable assessment of the effects of colour on reading using a different test. The Rate of Reading Test (Wilkins *et al.*, 1996) measures the speed with which individuals can read aloud a text consisting of randomly ordered common words printed in a small closely spaced typeface. Compared with conventional reading material the text is difficult to see, but easy to read, once seen. There is no contextual cueing, and as a result, perceptual difficulties give rise to errors, often errors of which the reader is unaware. The range of reading speed across the literate population is large (it varies by a factor of more than four), and the test–retest reliability is high. The test shows improved reading fluency when the text is appropriately coloured, and the degree of improvement in reading fluency with a coloured overlay predicts whether the overlay will subsequently be used voluntarily. The increase in speed depends upon the colour, and the optimal colour differs from one individual to another (Wilkins *et al.*, 1994; Jeanes *et al.*, 1997).

The colour of an overlay and the colour of a lens worn in front of the eye are likely to be processed differently by the visual system. When an overlay is used the eyes are adapted to white light, as is typical, and the overlay provides but one surface colour among many differently coloured surfaces. When coloured lenses are worn, the eyes are atypically adapted as to a coloured light source. The neural mechanisms that underlie colour constancy enable white surfaces to be seen as white despite the colour of the lens (Land, 1959a,b; Land and McCann, 1971; Zeki, 1983a,b). It is evident that the neural mechanisms involved in the processing of colour in the two contexts above may differ markedly.

In the first of two studies we investigated the relationship between the colours of the optimal overlays selected by multiple choice, and those of optimal lenses, selected using the Intuitive Colorimeter. The Colorimeter is a simple optical device that illuminates a page of text with coloured light in such a way that the hue and saturation of the light can be varied independently without an associated change in luminance. Only surfaces with an even spectral reflectance were visible within the Colorimeter, so the colour of the light source had a physical effect similar to that of a coloured lens. The assessment was undertaken whilst the eyes were colour adapted: the optimization of the Colorimeter setting involved only small changes in hue or saturation, alternately varied.

The second study compared the reading rate of subjects who had been using a coloured overlay for two months or more, and did so under the following conditions: (1) with no colour; (2) with the chosen overlay; (3) with lenses matching the chosen overlay in colour and (4) with lenses of a colour that matched the Colorimeter setting.

Study I

Methods

Patients who attended the Specific Learning Difficulties Clinic at the Institute of Optometry between August 1993 and December 1996 were sampled in alphabetical order of surname, and the first 128 patients who were prescribed tinted lenses were selected. The patients who had not used IOO *Intuitive Overlays* (Wilkins, 1994) were excluded. Those who used two overlays superimposed were also excluded, because double overlays are more saturated, and also necessarily darker. We wished to simplify the data analysis and reduce any effects of luminance variation.

As part of the protocol at the clinic (Lightstone and Evans, 1995) each patient received a full optometric examination and was given refractive or orthoptic correction of any ocular anomaly. Those patients who still had symptoms of asthenopia or perceptual distortion following a minimum of 6 weeks' orthoptic treatment were assessed with coloured overlays according to procedures described elsewhere (Jeanes *et al.*, 1997). Those offered overlays were seen in review a minimum of 8 weeks later and, if the overlays were still being used, were assessed with the Intuitive Colorimeter and associated tinted trial lenses, according to the recommended procedures (Wilkins, 1993). More than 95% patients were prescribed tinted lenses.

Results

The chromaticity co-ordinates of the lenses are plotted in *Figure 1*. The data for patients who had received overlays of the same colour have been grouped, and the average co-ordinates for each of the groups are shown, together with lines representing the variability. The averaged co-ordinates are based on 4–15 observations per point (mean 9.2) and the lines extend from −1 to +1 sd either side of the average. As can be seen, the averaged co-ordinates lie in the appropriate part of the UCS diagram, suggesting that, on average, the chromaticity of the lens is broadly similar to that of the overlay. The difference in colour

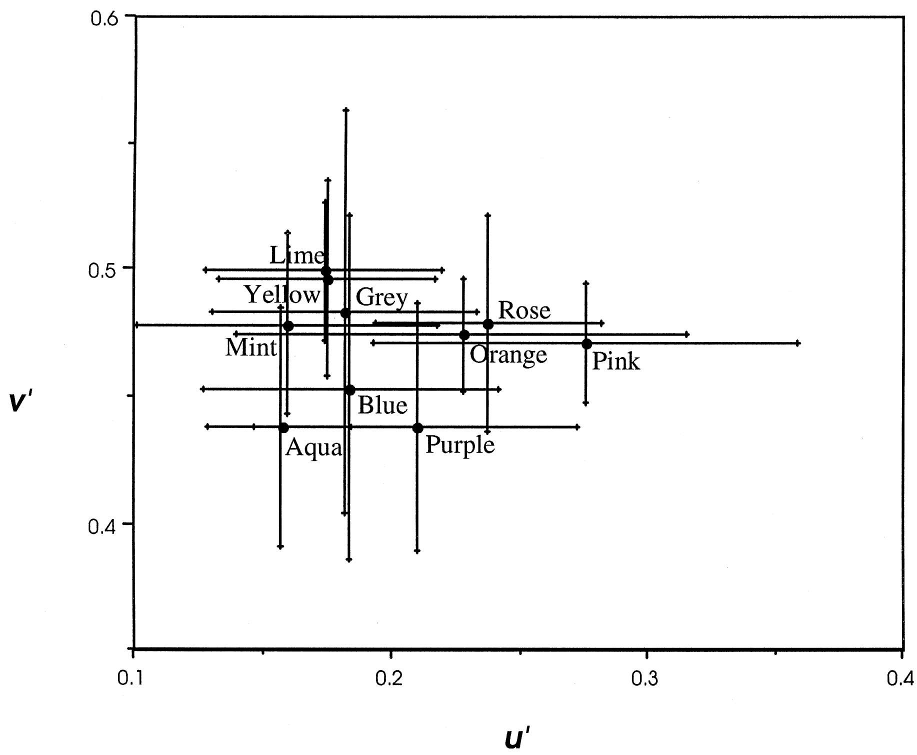

Figure 1. Average chromaticity of lenses associated with each of the 10 overlays. Lines extend from −1 to +1 s.d. either side of the mean

between each lens and its associated overlay was estimated by calculating the CIE colour difference, delta E^*_{ab}. To simplify the analysis, an equal energy illuminant with luminance 100 cd m^{-2} was assumed (although similar results were obtained with other luminances). The average value of delta E^*_{ab} overall was 55.0. In each of 1000 Monte Carlo trials the lenses were randomly reassigned to overlays and the average delta E^*_{ab} re-calculated. The mean of the averages obtained in the Monte Carlo trials was 61.0 with a standard deviation of 1.1. The value of delta E^*_{ab} obtained when the lenses were appropriately assigned to overlays was therefore significantly lower, indicating that on average the similarity between the colour of an overlay and the colour of a lens was greater than might have been expected by chance. The most impressive feature of *Figure 1*, however, is not the similarity between the colour of an overlay and that of the lens, but the variability between the two. The difference in chromaticity between overlays and lenses was 55/61 = 90% of the difference obtained with random allocation.

The average hue angle (h_{uv}) of the overlays (Chronicle and Nimmo-Smith, 1992) was 56.3 degrees whereas that of the lenses was 9.3. The difference was significant ($z = 1.83$, $p = 0.03$) indicating that there was a weak tendency for lenses to have more reddish shades.

The average s_{uv} of the overlays was 0.57 (s.d. 0.06) and that of the lenses 0.94 (s.d. 0.47). The difference was very highly significant by a *t*-test ($p < 0.000$) indicating that on average overlays were less saturated than lenses.

The overlays and lenses differed not only in hue and saturation, but also, of course, in their photopic density (the amount of light they absorbed weighted for the spectral sensitivity of the eye). The lenses were selected using the Intuitive Colorimeter which allows for the selection of a hue and saturation at constant luminance, but the colour was then matched by lenses that varied in density with hue, some pigments such as blue being darker than others such as yellow. The average photopic reflectance of the overlays was 67% (s.d. 15%) and the average transmission of the lenses was 40% (s.d. 20%). The Spearman rank correlation between the density of the lenses and the density of the associated overlay was only 0.27. Given that some pigments are darker than others, the weak correlation in density is again consistent with the weak association in colour between lenses and overlays.

Discussion

Although statistically significant, the relationship between the colour of an overlay and that of the associated lenses was weak, and the variability between overlay and lens colour was large. Although the assessment of optimal colour is known to be of moderate reliability for both overlays (Jeanes *et al.*, 1997) and Colorimetry (Wilkins, 1997), the question arises as to whether the weakness of the relationship is due simply to the errors associated with subjective measurement.

Jeanes *et al.* (1997) showed that in children who persisted in the use of an overlay, the overlay increased their rate of reading both before and after experience of its use. The rate was assessed using a simple Rate of Reading Test in which the children were required to read aloud randomly ordered common words (Wilkins *et al.*, 1996).

The Rate of Reading Test was used in Study II to assess the response to coloured overlays and lenses. The test–retest reliability of the test is high when test and retest are months apart (Wilkins *et al.*, 1996). When test and retest are in immediate succession, the reliability is even higher, as is evident in a more recent study. In this recent study (in preparation) 283 children aged 7–8 read with an overlay, then without, again without and then again with the overlay. The average rate of reading on the two trials without the overlay was 81 words per minute, and the difference in reading rate from the first to the second assessment without overlay (i.e., on two immediately successive trials, taking account of sign) averaged 0.20 (standard deviation 14.6 wpm, 18%). The Spearman rank correlation between the children's performance on these two trials was 0.95. The correlation for the two trials with the overlay was 0.93, indicating that the effects of practice did not influence the correlation. The Rate of Reading Test was used to compare reading fluency using lenses that matched the Colorimeter setting with the fluency using lenses that matched the overlay colour.

Study II

Methods

The participants were all patients at the Institute of Optometry who were being investigated according to the clinical protocol described briefly above, and in more detail by Lightstone and Evans (1995). They took part immediately following assessment with the Intuitive Colorimeter and before the patient had had the opportunity to see the trial lenses. (The Colorimeter assessment involved judging the appearance of random letters arranged to resemble text, and the text of the Rate of Reading text was not viewed in the Colorimeter.) Ethical committee approval for the study was obtained. All patients were given the opportunity to opt out, but none did so. The optometric characteristics of the patients are shown in *Table 1*. The criteria for 'normal' binocular vision were (1) near point of convergence of 10 cm or better; (2) associated heterophoria of up to 1 prism dioptre horizontally and stable; (If the associated heterophoria was 1 prism dioptre, this was only regarded as acceptable if the dissociated heterophoria was low, the recovery on cover test was rapid and the fusional reserves were good); (3) fusional reserves met both Sheard's and Percival's criteria. For most subjects, the amplitude of accommodation matched the age-related norms and where this was not the case, the accommodative lag and/or the accommodative facility was in the normal range. All measurements were subjective, except for one subject where readings were judged by observation.

A combination of trial lenses matching the colorimeter setting was selected by the examiner (AL) using established techniques (Wilkins, 1993): the match was made by comparing the appearance of two apertures, one revealing a surface in the Colorimeter illuminated with light of the chosen colour, and the other revealing a surface illuminated with fluorescent light, correlated colour temperature 3500 K. The second aperture was covered by the appropriate combination of coloured trial lenses. The matching was undertaken by AL, a female with normal colour vision and good discrimination (2 errors on the Farnsworth Munsell 100 hue test). The lighting available in the examination cubicle was fluorescent, correlated colour temperature 3500 K, with a contribution from local halogen filament lamps, giving a composite illumination with UCS chromaticity coordinates of $u' = 0.27$, $v' = 0.52$ (measured with a Minolta Colour Analyser). Under this illumination the lenses provided a chromaticity similar to that selected in the Colorimeter (CIE delta $E^*_{ab} = 11.6$ (s.d. 3.54)). The luminance of the white paper on which the Rate of Reading passages were presented was about 70 cd m^{-2}.

A second combination of trial lenses was prepared matching the CIE UCS 1976 chromaticity of the overlay that the participant had been using. The match was such as to allow for the increase in saturation obtained when the overlay was in contact with the page of text, and so the lenses had a saturation approximately twice that of the overlay. The chromaticity match was obtained by direct measurement using the Monolite tele-spectroradiometer and the match of the colour appearance confirmed by eye. The colour difference was small: CIE Delta $E^*_{ab} = 13.42$ (s.d. = 5.86) and was due mainly to differences in L^* (i.e., transmission/reflectance). Nevertheless, the luminance of the text obtained with the overlay and with the

Table 1. Optometric findings for the patients who participated in Study II (the records were not available for 2 patients)

Referral source	Status	D.o.B.	Date prescribed	M/F	V.A.R.E.	V.A.L.E.	Binoc. status	Rx
Self	None	30.7.85	18.12.96	F	0.56	1.00	Exotropia	R +1.00/ − 0.50 × 20 L + 0.25DS
Self	"Dyslexia"	28.5.85	27.3.97	F	1.00	1.00	Normal	R plano L +0.50/ − 0.75 × 75
Optom	None	19.9.83	27.3.97	F	1.00	0.80	Esotropia	
Dys. Teach	"SLD"	15.3.85	5.3.97	M	1.00	1.00	Normal	R +0.25DS L +0.25DS
Eye Clinic	"Dyslexia"	5.7.87	20.2.97	M	1.00	1.00	Normal	R +0.50/ − 0.25 × 135 L + 0.25DS
Optom	"Dyslexia"	6.4.85	13.11.96	M	1.00	1.00	Reduced convergence	R + 0.50DS L + 0.50DS
Optom	"Dyslexia"	8.4.85	7.11.96	M	1.00	1.00	Normal	R +0.75DS L +0.75DS
Ed Psych	"Dyscalc"	21.11.83	6.11.96	F	1.33	1.33	Normal	R +0.50DS L +0.50DS
Optom	"SLD"	6.10.86	21.8.96	M	1.00	1.00	Normal	R +1.25DS L +1.25DS
Optom	"Dyslexia"	16.5.81	17.10.96	F	0.80	0.80	Normal	R plano L plano
Optom	None	12.6.78	10.7.96	F	1.00	1.00	Normal	R −0.75/ − 0.25 × 80 L −1.00DS
Optom	None	31.5.84	7.5.97	M	1.00	1.00	Normal	R +0.25DS L +0.50DS
Optom	"Dyslexia"	15.1.80	9.4.97	M	1.33	1.33	Normal	R + 0.50DS L + 0.50DS
Optom	"SLD"	15.4.79	11.6.97	F	1.00	1.00	Reduced convergence	R plano L plano
Optom	"Dyslexia"	24.3.85	21.5.97	M	1.33	1.33	Normal	R plano L plano
Self	"SLD"	22.8.86	7.8.96	M	1.20	1.20	Normal	R +0.75DS L +0.75DS
Ed Psych	"SSS"	26.9.87	19.6.97	M	0.80	0.80	Normal	R + 0.50DS L plano

lenses was similar: the Spearman rank correlation between the photopic reflectance of the overlays and the photopic transmission of the lenses that matched them in chromaticity was 0.93.

The participants read the entire passage from the Rate of Reading test. The passage was presented on white A5 paper (landscape orientation) and the paper lay on the grey surface (reflectance about 50%) of a small desktop (0.36 m wide and 0.30 m deep). The time taken to read the passage was recorded, and errors and omissions noted. The average number of words correctly read per minute was calculated (Wilkins *et al.*, 1996). The test was administered under the following conditions: (1) with no colour, (2) with the chosen overlay, (3) with lenses matching the chosen overlay and (4) with lenses matching the Colorimeter setting. The conditions were presented in random order and participants were not aware of the purpose of the study or the comparisons being made. Although the examiner was aware of the experimental conditions, other studies using this test have shown reading rate to be little affected by explicit motivation from the examiner (in preparation).

The colour difference between the lenses matching the Colorimeter setting and those matching the overlay was delta $E^*_{ab} = 60.8$ (s.d. = 27.7). The former had a mean photopic transmission of 23.8% and the latter 54.9%, with a modest correlation between the two transmissions (Spearman rank correlation, $r = 0.58$).

Results

The number of words per minute read under each of the four conditions is shown in *Table 2*. An analysis of variance with repeated measures revealed a significant main effect of groups ($F(3,54) = 5.4$, $p = 0.003$) which accounted for 23% of the within-subject variance. Post-hoc pairwise comparisons using the Peritz procedure with an experiment-wise alpha rate of 0.05 (Toothaker, 1991) revealed significant comparisons between the nil condition and the chosen overlay and also the nil condition and the lens matching the Colorimeter setting. None of the other comparisons was significant. The planned comparison between the nil condition and the overlay match failed to reach significance ($p = 0.1$, 1-tail t-test), indicating that lenses matching the overlay did not significantly improve reading speed. The planned comparison between the lens matching the overlay and the lens matching the Colorimeter setting was significant ($p = 0.03$, 1-tail t-test) indicating that the lens matching the Colorimeter setting resulted in significantly faster reading than the lens matching the overlay.

There was no consistent correlation between reading speed and lens transmission. For lenses matching the

Table 2. Mean rate of reading (words correctly read per minute) and standard deviation (shown in parentheses) for performance by the 17 subjects in the four conditions of Experiment 2: namely with no colour, with the chosen overlay, with lenses matching the chosen overlay and with lenses matching the Colorimeter setting

	Nil	Chosen overlay	Lens matching chosen overlay	Lens matching Colorimeter setting
Mean rate of reading (s.d.)	85.6 (28.5)	94.3 (27.8)	90.7 (23.8)	96.5 (29.3)

Colorimeter setting Spearman rho was 0.29 and for lenses matching the overlay rho was –0.14). The difference in reading speed in the two conditions was not correlated to the difference in transmission (rho = 0.01).

General Discussion

The findings of Study II confirm those of Wilkins *et al.* (1996) and Jeanes *et al.* (1997) in demonstrating an improvement in reading speed with the appropriate colour, but indicate that this appropriate colour depends critically upon the viewing conditions under which it is selected.

The increase in reading speed with the lens matching the colorimeter setting cannot easily be attributed to a placebo effect because the participants were unaware of the purpose of the study and, in particular, they were not informed that one lens matched their overlay and one matched the Colorimeter setting.

The weakness of the relationship between the colour chosen for use as an overlay and that chosen for a lens cannot now be attributed simply to the variability inherent in the techniques for subjective measurement. This is because of the findings of the second study which showed improvements in reading fluency contingent upon colour, but only when the colour was selected appropriately for the viewing conditions in which it was used. The average difference between the colour of lens matching the Colorimeter and the colour of the lens matching the overlay was small. Nevertheless it was only the former lens that resulted in a significant increase in reading fluency. This finding confirms the findings of the double-blind study (Wilkins *et al.*, 1994) in showing just how precise must be the selection of colour for optimal benefit.

The present findings have important implications for theories that seek to explain the effects of colour on reading. The findings make it more difficult to attribute the beneficial effects of colour to peripheral ocular factors such as variations in accommodation: these factors cannot easily explain the importance of viewing conditions. The individual differences in optimal colour remain difficult to explain, particularly since these differences appear to depend on viewing conditions, but not in any easily interpretable way: the overlay colour does not appear to be strongly related to the lens colour. Perhaps some of the individual differences in beneficial colour reflect differences in susceptibility to perceptual distortion across the visual field. Obviously, were the size of an overlay to be increased progressively there would come a point at which the entire field was coloured and the effect of the overlay was equivalent to that of lenses. When relatively small overlays are used, the part of the visual field that is coloured may or may not include all those parts that are susceptible to perceptual distortion. The relationship between the colour chosen for use in overlays and in lenses may perhaps reflect individual differences with respect to which parts of the visual field are susceptible to distortion, and the extent to which these are coloured by the overlay. Such a possibility will shortly be explored.

One important practical conclusion from the present studies is that the colour of the overlay may give only misleading guidance as to the colour optimal for use in lenses. Practitioners should be warned that it is not acceptable practice to offer lenses tinted to match the colour of a selected overlay. Lenses tinted in this way may offer relatively little benefit.

Acknowledgements

The authors thank the patients who took part in the study and they are also grateful for the helpful comments from two anonymous referees.

References

Chronicle, E. and Nimmo-Smith, I. (1992) Application of some statistical methods for comparing hue-angle data. *Colour Research and Application* **17,** 375–378.

Evans, B. J. W. and Drasdo, N. (1991) Tinted lenses and related therapies for learning disabilities: a review: *Ophthalmic and Physiological Optics* **11,** 206–217.

Jeanes, R., 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.

Land, E. H. (1959a). Colour vision and the natural image. Part I. *Proceedings of the National Academy of Sciences, USA* **45,** 115–129.

Land, E. H. (1959b). Colour vision and the natural image. Part II. *Proceedings of the National Academy of Sciences, USA* **45,** 636–644.

Land, E. H. and McCann, J. J. (1971). Lightness and retinex theory. *Journal of the Optical Society of America* **61,** 1–11.

Lightstone, A. and Evans, B. J. W. (1995). A new protocol for the optometric management of patients with reading difficulties. *Ophthalmic and Physiological Optics* **15** (5), 507–512.

Menacker, S. J., Breton, M. E., Breton, M. L., Radcliffe, J. and Gole, G. A. (1993). Do tinted lenses improve the reading performance of dyslexic children? *Archives of Ophthalmology* **111,** 213–218.

Neale, M. D. 1996. *The Neale Analysis of Reading Ability*. 2nd edn. Macmillan Education, London.

Toothaker, L. (1991). *Multiple Comparisons for Researchers*. Sage, California.

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** (1), 10–23.

Wilkins, A. J. (1993). *A System for Precision Ophthalmic Tinting*, Cerium Visual Technologies, Tenterden, Kent.

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

Wilkins, A. J. (1997). A system for precision ophthalmic tinting and its role in the treatment of visual stress. ed. C. Dickinson, I. Murray and D. Carden. In: *John Dalton's Colour Vision Legacy*, Taylor Francis, London.

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** (4), 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.

Zeki, 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.

Zeki, S. (1983b). Colour coding in the cerebral cortex: the reaction of cells in monkey visual cortex to wavelengths and colours. *Neuroscience* **9,** 741–765.