SPECTRAL FILTERS CAN IMPROVE READING AND VISUAL SEARCH IN PATIENTS WITH MULTIPLE SCLEROSIS

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Column title: Spectral filters and multiple sclerosis

ABSTRACT

We investigated the possible benefit for 26 patients with multiple sclerosis of placing *Intuitive Overlays* (spectral filters) over the page during reading and visual search. Initially all patients were allowed to select an overlay of a colour that reduced perceptual distortion and were tested with and without that overlay. With the coloured overlay, 25/26 patients reported fewer symptoms of visual stress, 50% read at least 20% more quickly and 50% omitted at least 57% fewer targets during visual search. Subsequently, under double-masked conditions 13 randomly-selected patients were given grey overlays, while the remaining 13 gender- and age-matched patients were each given an overlay of their individually selected colour. Patients were permitted to use their overlays as and when they wished during the next 2 weeks. The reading and visual search performance of those patients who had received a grey overlay did not change, whereas the performance of those who received an overlay of their selected colour subsequently improved, both when using the overlays and also when not. After testing, the 13 patients who had received a grey overlay returned it prior to subsequent testing. The 13 patients were then each given an overlay of their selected colour and their performance subsequently improved. A large proportion of patients with multiple sclerosis may benefit from the use of spectral overlays.

Keywords: multiple sclerosis, visual stress, reading speed, visual search, spectral filters

INTRODUCTION

The symptoms collectively referred to as 'visual stress' consist of asthenopia, and perceptual distortion, most noticeably distortion of text (e.g. blurring, doubling, moving or flickering letters or lines sometimes accompanied by shadows that may be coloured). Some patients with photosensitive epilepsy, migraine, autism and dyslexia have revealed these symptoms [8,18,19,22]. The symptoms can frequently be reduced using spectral filters [8,19].

The proportion of patients with multiple sclerosis reported to have visual deficits varies with study from 38-85% [1]. Following optic neuritis, colours may appear darker or washed out [11], colour matching is often anomalous [12,16], patients may reveal deficits when tested using random luminance-contrast masking [4,5] and temporal discrimination of visual stimuli may be impaired [6].

Patients with multiple sclerosis also experience symptoms of visual discomfort and perceptual distortion, but, to our knowledge, there are no published studies that have investigated visual stress in these patients. In patients with optic neuritis, tinted lenses can, however, be used to reduce visual fatigue, and progressively deteriorating grating acuity under typical levels of illumination [15].

Wilkins has proposed cortical hyperexcitability as a generic explanation for visual stress [18]. Cortical hyperexcitability has been reported in patients with various neurological conditions and is consistent with three observations in patients with multiple sclerosis: (1) Moreau et al. demonstrated that 17/402 (4%) of their patients with multiple sclerosis experienced at least one epileptic seizure [10]; (2) Gee et al. demonstrated that 61.7% of their sample of 70 male and 207 female patients with multiple sclerosis had experienced migraines [7]; (3) patients with multiple sclerosis may reveal hyperexcitability of the motor cortex [2,14]. Spectral filters may help to redirect the visual activation to less hyperexcitable cortical cells [8]. Spectral filters have been shown not only to reduce symptoms of visual stress but also to increase reading speed [20] and improve visual search [19]. We developed a new test of visual search that can be easily and quickly administered, making it suitable for use in a clinical environment [Wilkins and Wright, in preparation].

Following initial testing sessions in which the reading speed and visual search tests were administered, patients were given an overlay to use as and when they wished. We wanted to see whether the visual performance of patients would improve once they had regular access to an overlay of the appropriate colour.

METHODS AND MATERIALS

Participants

INSERT TABLE 1 ABOUT HERE

All 26 patients who participated in this study were recruited from a therapy centre in Springfield, Chelmsford, UK, run by 'Charity action for the relief of multiple sclerosis and other neurological disorders' (CHARMS), a CHAI-registered Independent

Healthcare Provider. All of the patients were categorised as having 'definite' multiple sclerosis based on the Poser [13] and McDonald [9] criteria. All of the patients reported that they had received an optometric examination within the previous 2 years and all participants were tested with their habitual corrections. See Table 1 for patient data.

Each patient gave signed consent to participation. Patients were randomly assigned to 1 of 2 groups, as described in the procedure. The Coloured Overlay group comprised 9 females (mean age: 52; range: 33-69) and 4 males (mean age: 51; range: 37-63). The Grey Overlay group comprised 9 females (mean age: 57; range: 47-66) and 4 males (mean age: 40; range: 33-47). The experimenter remained unaware of the group to which patients had been assigned. An additional group of normal controls comprised 13 males (mean age: 54; range: 33-65) and 13 females (mean age: 51; range: 30-64) recruited from patients' carers, staff and colleagues.

Materials

The *Intuitive Overlays* were supplied by iOO sales Ltd. The spectral properties of these overlays have been described elsewhere [17].

A version of the 'Rate of Reading test' [20] was prepared in Times New Roman font, with a x-height of 2.6mm, readable by all patients, apart from 1 who was not included in the study.

INSERT FIGURE 1 ABOUT HERE

The 'Circles Search test' comprised 4 A4 sheets on which were printed 15 rows of ellipses, each with a major axis of 12mm and a minor axis of 10mm. The shapes were laser printed in outline, each row being 90.5mm wide and comprising 7 shapes. The orientation of each major axis was chosen at random from the following angles to the vertical: 0, 45, 90 or 135 degrees, with the constraint that neighbouring ellipses had different orientations. Among the ellipses were distributed 15 circles, each of 11mm diameter, randomly positioned, with the constraint that no more than 2 could appear in each row.

Procedure

INSERT TABLE 2 ABOUT HERE

The tests were administered between June and August 2005, according to the sequence reported in Table 2. During Session 1 each patient completed a symptom questionnaire, as described by Wilkins [19]. Five questions were printed under a paragraph comprising randomly positioned common words. The questions asked about print stability, clarity and spacing, glare from the page, and eye pain.

Participants were individually tested, seated at a desk in a quiet daylit room. At the outset of Sessions 2 and 3, each participant was first shown 'Visual Material 2' from the 1997 version of the overlays testing pack (iOO sales Ltd, UK), which consists of strings of randomly selected letters arranged to resemble words in a 17 row

paragraph. The overlay optimal for improving the perceptual clarity of the text was chosen by successive elimination, following the procedure described by Wilkins [19]. This set of overlays did not include a grey overlay. During Session 5 the patients were randomly allocated to one of two groups. The Coloured Overlay group received a coloured overlay to use for reading over the subsequent two weeks. The Grey Overlay group received a grey overlay. Two patients wished to use the coloured overlay instead of the grey and were permitted to do so. The grey overlays transmitted 50% of the light and, in this respect, were similar to the coloured overlays. Nevertheless, in previous studies with other patient groups grey overlays have been shown to be of little benefit in improving visual performance [19]. The experimenter was unaware of the group to which any patient had been assigned.

The 'Rate of Reading test' was administered during Sessions 2, 6 and 7. Participants were required to read aloud the 4 paragraphs of the 'Rate of Reading test' as quickly and as accurately as possible, first with the overlay, then without, then again without and finally again with the overlay. Each paragraph consisted of the same 15 common words in a different random order on each line, and all four passages differed.

The 'Circles Search test' was administered during Sessions 3, 6 and 7. Participants were required to point to circles while working through each sheet of the Circles Search test. The 4 versions of the test were presented with, without, without and with an overlay, as before.

Between Sessions 5 and 6 a post-box was provided into which each patient was asked to post his/her overlay if it ceased to be of any benefit, concealing the number and type of overlays that were returned. None of the patients in the Coloured Overlay group returned their coloured overlay, whereas all patients in the Grey Overlay group did so. At the outset of Session 6, in order to conceal the assigned condition from the experimenter, patients were required to choose between an overlay of their selected colour or a grey overlay to use while being tested. All patients chose to be tested using an overlay of their selected colour, not grey. After Session 6, participants in the Grey Overlay group had their grey overlays exchanged for overlays of their selected colour and were, therefore, now able to use a coloured overlay as and when they wished. No patients selected a grey overlay with which to be tested in either Session 6 or Session 7.

Each normal control was tested on the Rate of Reading Test and on the Circles Search Test during one session.

RESULTS

Control results

None of the controls reported any of the five symptoms on the questionnaire. All were asked to choose the overlay that made the text clearest and most comfortable: Rose (N=5), Yellow (N=2), Lime-green (N=7) and Mint-green (N=5); Pink, Aqua and Blue overlays (N=1). Four of the controls preferred double overlays: Rose/orange, Yellow/yellow, Mint-green/lime-green and Purple/purple.

The mean reading rate with the overlay was 159 words per minute (SD = 27) and without the overlay 158 words per minute (SD = 27), ($t(25) = 0.6$, $p = 0.288$). Any increase in reading rate with overlays was less than 5%.

On the Circles Search Test an average of 36 seconds (SD = 8) was taken to complete each sheet without an overlay, compared with 40 seconds (SD = 9) with the selected overlay(s) an increase of 4 seconds when using the overlays ($t(25) = 5.2$, $p < 0.001$). An average of 0.8 targets (SD = 0.5) was missed without an overlay compared with 0.9 targets (SD = 0.6) with an overlay.

Reliability of choice of overlay colour

At the outset of Sessions 2 and 3 patients were individually required to select the overlay colour under which they perceived the text to be clearest. Pink (N=6), Yellow (N=4), Mint green (N=4) and Lime-green (N=6) were the most frequently chosen and the remainder were Aqua (N=2), Aqua/Aqua (N=1), Blue (N=2), Orange (N=1), and Rose (N=1). Purple was not chosen by any patient. 24/26 patients selected the same colour on both occasions. This consistency is greater than would be expected by chance ($p<10^{-6}$). All the patients who were given a grey overlay (N=13), returned it as being of little use prior to Session 6. All patients requested the use of an overlay of their previously selected colour when tested.

Effects of a coloured overlay on reading speed

Patients were first given the Rate of Reading test during Session 2. The overall mean reading rate with the overlay was 146 words per minute (SD = 28) and without the overlay 126 words per minute (SD = 32), an increase in reading speed with the coloured overlay of 16% ($t(25) = 5.6$, $p < 0.001$). 20 of 26 (77%) patients read at least 5% more quickly when using their selected overlay. 13 of 26 (50%) patients read at least 20% more quickly. Only a small number of errors was made (i.e. omissions, transpositions, substitutions), averaging 0.8 words per version when using the overlay and 2.5 words per version when not using the overlay. Although small, the difference was significant ($t(25) = 5.4$, $p < 0.001$).

Patient 5 was recovering from an episode of optic neuritis at the time of testing, whereas Patient 14 had been diagnosed with developmental dyslexia. When both patients were excluded from the analysis, the difference in reading speed remained significant ($t(23) = 6.7$, $p < 0.001$). Those patients who had never experienced symptoms indicative of optic neuritis (N = 15) read an average of 127 words per minute (SD = 33) when not using their overlays, and an average of 145 words per minute (SD = 28) with their overlays. Those patients who had received a diagnosis of optic neuritis (N = 8) read an average of 123 words per minute (SD = 33) without their overlays and 145 words per minute (SD = 35) with. Patient 5 (who was currently experiencing optic neuritis) showed a large difference in reading speed: 79 words per minute without her overlay and 161 words per minute with.

Effects of a coloured overlay on the speed and accuracy of visual search

Patients were first administered the Circles Search test during Session 3. There were no significant differences in the speed with which the test was completed with or without an overlay ($t(25) = 0.1$, $p = 0.45$). An average of 3 targets was missed without an overlay (SD = 1.7) compared with 1.5 targets with an overlay (SD = 1.2) ($t(25) = 6.7$, $p < 0.001$). 22 of 26 (85%) patients omitted at least 30% fewer targets on the Circles Search test when using an overlay of their selected colour. 14 of 26 (54%) patients omitted at least 60% fewer targets.

Effects of regular use of the coloured overlay: Rate of Reading Test

Patients were also given the Rate of Reading test during Sessions 6 and 7. Patient 9 was unavailable for testing during Session 6 and Patient 22 discontinued after Session 6. The results for both were excluded from the following analyses. Patients' reading rates under each experimental condition are presented in Table 2.
For the group that had access to a coloured overlay between Sessions 5 and 6, performance when tested *without* the overlay improved relative to previous performance. All of the group reportedly used the overlay for general reading. The mean improvement between Sessions 2 and 6 was 8.1 words per minute (7%), ($t(11) = 2.1$, $p = 0.029$). This improvement did not occur for the Grey Overlay group, which had access only to the grey overlay between Sessions 5 and 6 ($t(11) = 0.1$, $p = 0.478$).

Performance when tested *with* the overlay also improved for the Coloured Overlay group between Sessions 2 and 6. The mean improvement was 9.0 words per minute (6%), ($t(11) = 4.9$, $p = 0.001$). The performance of patients in the Grey Overlay group did not improve ($t(11) = 1.1$, $p = 0.150$).

The patients in the Coloured Overlay group read 17% more quickly when using their coloured overlays during Session 2 and 17% more quickly when using their overlays during Session 6. For patients in the Grey Overlay group the corresponding figures were 18% and 15%.

Performance when tested without the overlay improved for both groups between Sessions 6 and 7, by which time both groups had had experience using the coloured overlay, although for the Coloured Overlay group the experience was of greater duration. The mean improvement for this group was 20.3 words per minute (16%), ($t(11) = 3.9$, $p = 0.002$). The mean improvement for the Grey Overlay group (now using their coloured overlays) was 25.2 words per minute (20%), ($t(11) = 5.5$, $p < 0.001$). Performance when tested with the overlay also improved for both groups between Sessions 6 and 7. The mean improvement for the two groups was, respectively, 9.3 words per minute (6%), ($t(11) = 3.2$, $p = 0.004$) and 18.7 words-per minute (13%), ($t(11) = 5.2$, $p < 0.001$).

The patients in the Coloured Overlay group read 7% more quickly when using their coloured overlays during Session 7. For those in the Grey Overlay group the figure was 8%.

At the outset of the study, the mean reading rate without the overlay was 126 words per minute (SD = 32), and increased to 148 words per minute (SD = 27) with the overlay, $t(23) = 6.1$, $p < 0.001$ (excluding the two patients who did not complete all testing sessions). On study completion, the overall mean reading rate without the overlay was 152 words per minute (SD = 32) and, with the overlay, 164 words per minute (SD = 28), $t(23) = 6.1$, $p < 0.001$, an overall increase of 21% without the overlay and of 11% with the overlay. The increase in reading performance from the first session to the last was significant when patients were reading with their overlays ($t(23) = 8.1$, $p < 0.001$) and when they were reading without them ($t(23) = 6.9$, $p < 0.001$).

Removing Patients 5 and 14 from the analyses for Sessions 6 and 7 did not change the results substantially.

Effects of regular use of the coloured overlay: Circles Search Test

Patients also received the Circles Search test during Sessions 6 and 7. Means (and standard deviations) for omitted target circles across experimental conditions are presented in Table 2.

Performance when tested *without* the overlay improved to a greater extent for the Coloured Overlay group between Sessions 3 and 6. The mean reduction in omitted targets for the Coloured Overlay group was 1.5 targets, ($t(11) = 5.8$, $p < 0.001$). The mean reduction in omitted targets for the Grey Overlay group was 0.4 targets, ($t(11) = 1.0$, $p = 0.174$). Similarly, performance *with* overlay use improved to a greater extent for the Coloured Overlay group. The mean reduction in omitted circles for the Coloured Overlay group was 0.6 targets, ($t(11) = 2.5$, $p = 0.016$). The mean reduction in omitted circles for the Grey Overlay group was 0.17 targets, ($t(11) = 1.1$, $p = 0.153$).

Performance when tested *without* the overlay improved for both groups to a similar extent between Sessions 6 and 7, suggesting that improvement was related to regular use of an overlay of the selected colour. The mean reduction in omitted circles for the Coloured Overlay group was 0.8 targets, ($t(11) = 3.3$, $p = 0.004$). The mean reduction in omitted circles for the Grey Overlay group was 1.2 targets, ($t(11) = 8.4$, $p < 0.001$). Performance when tested *with* the overlay improved to a greater extent for the Grey Overlay group. The mean reduction in omitted target circles for the Coloured Overlay group was 0.3 targets, ($t(11) = 3.0$, $p = 0.007$). The mean reduction in omitted targets for the Grey Overlay group was 0.8 targets, ($t(11) = 4.2$, $p < 0.001$).

At the outset of the study, the remaining patients had omitted an average of 3 targets without an overlay (SD = 1.6), compared with 1.4 targets with an overlay (SD = 1.2), ($t(23) = 7.3$, $p < 0.001$). On study completion, an average of 1.1 targets was missed without an overlay (SD = 0.7), compared with 0.4 targets with an overlay (SD = 0.4), ($t(23) = 7.0$, $p < 0.001$). The improvement in visual search performance from the first session to the last was significant both with overlays ($t(23) = 4.8$, $p < 0.001$) and without ($t(23) = 6.7$, $p < 0.001$).

Correlation between performance on the two tests

Patients who correctly read more words per minute on the Rate of Reading test during Session 2, omitted fewer targets on the Circle Search test during Session 3, both when an overlay of the selected colour was used (rho = 0.4, p = 0.009) and when an overlay was not used (rho = 0.5, p = 0.002).

Reduction in visual distortion and perceptual symptoms

Once patients had regular access to an overlay of their selected colour the number of symptoms experienced decreased This was the case for all patients except Patient 18, who reported no symptoms to begin with and no benefit from the use of an overlay.

DISCUSSION

In a preliminary investigation for patients with multiple sclerosis, we have shown that, unlike normal controls, 25 of 26 patients reported fewer symptoms of visual stress when using an overlay of their selected colour. The same patients revealed improved performance on both the Rate of Reading Test and the visual search (Circles Search) test, when using an overlay of their selected colour. Use of a coloured overlay appeared to have long-term benefits in improving reading speed, such that reading without the overlay subsequently became more rapid and visual search more accurate. These improvements were experienced by patients in all diagnostic categories, perhaps surprisingly, given the inclusion of patients with a progressive disease course.

The masked design of this study required that some patients receive a grey overlay, while others receive an overlay of their selected colour for use between Sessions 5 and 6. Although the grey overlay was novel, it remains possible that the previous experience with a coloured overlay may have prejudiced patients against its use. The patients were allocated at random to one of the two groups, although two patients did not wish to try grey overlays and were included in the Coloured Overlay group. Importantly, exclusion of these patients from the analyses did not change the substance of the results. None of the patients given a grey overlay reported regular use of that overlay; indeed, 11/13 said that they were unable to read with it. Therefore, even those patients who were happy to accept a grey overlay (which they had not seen previously) did not find it to be of any practical benefit. The photopic reflectance of the grey filters was similar to that of the coloured filters.

In the normal population, symptoms of visual stress have frequently been reported and in 22% of unselected school children reading was >5% faster with an overlay, and in 5% >25% faster [21]. There was an association between the occurrence of symptoms and improvements in reading speed. The prevalence was similar in a sample of adult university students [3]: in 38% reading was >5% faster and in 2% >25% faster. In the present sample of patients with multiple sclerosis, reading was >5% faster in 77% and >25% faster in 31%. These proportions are greater than would be expected in the general population ($p<10^{-5}$).

24/25 patients who reported that the coloured overlay was helpful claimed still to be using it 4 months after the completion of testing. The differential performance, both during and across sessions, between the Coloured Overlay and Grey Overlay groups, together with the consistency of the improved visual performance over time once patients had regular access to their preferred overlays, would indicate that the improvements are unlikely to be due to placebo effects, although the basis for the improvements remains obscure. It is interesting that the improvement brought about by regular use of the coloured overlays carried over to performance without the overlays, once patients were using their preferred overlay. The performance with the overlay invariably remained superior, suggesting that practice is not a sufficient explanation. The results cannot be attributed to a patient who was recovering from optic neuritis or to a patient with long-standing dyslexia.

Visual acuity measurements were not routinely available, but all patients were able to read the 14pt text of the Rate of Reading test.

In future studies, it will be important to consider choice of overlay colour in relation to colour vision deficits.

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We thank the patients who participated in the study. The study initially received the approval of the Norwich (Norfolk 1) Research Ethics Committee (Ref: 99/057) and, subsequently, of the North & Mid Essex Local Research Ethics Committee (Ref: 06/Q0303/1). It was, therefore, performed in accordance with the ethical standards laid down in the 1964 Declaration of Helsinki.

DECLARATION OF INTEREST

The *Intuitive Overlays* were designed by AW when he was employed by the Medical Research Council. The MRC receives royalties on sales, a proportion of which are distributed to AW as a discretionary ‘award to inventors’. The data from the present study were collected by BW, who has no financial interest.

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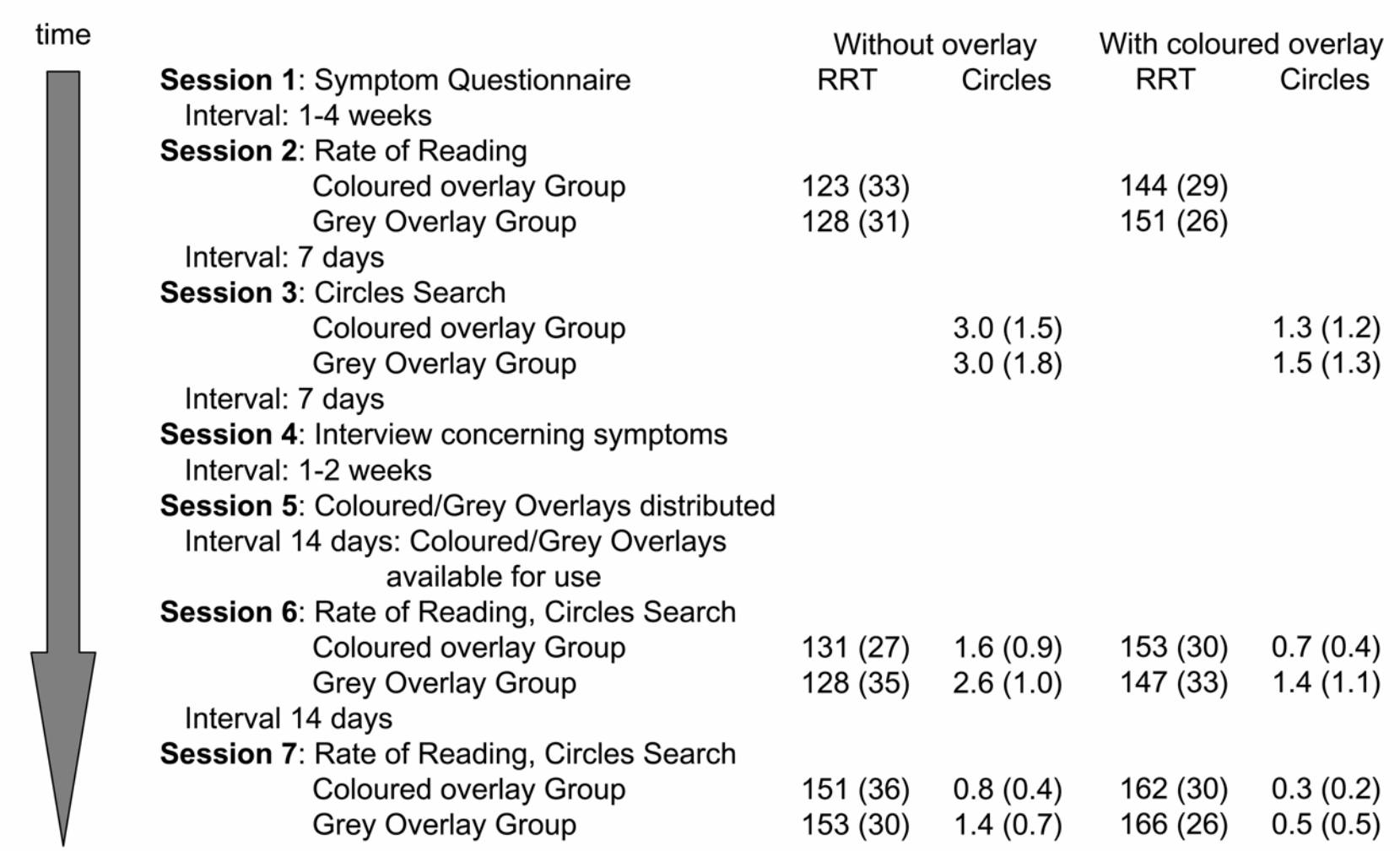
Table 1. Patient details

Case	M/F	Age	Date of Diagnosis	Disease Course	EDSS	Optic neuritis	Ophthalmic lenses for…	Tints
Colour Overlay Group:								
1	Male	37	1999	RR	4.0			
2	Female	33	2003	RR	3.0	ON	Myopia	
3	Female	37	1986	RR	4.0			
4	Female	53	1986	RR	3.0	ON	Presbyopia	
5	Female	57	1984	RR	4.5	ON+	Presbyopia	Blue*
6	Female	60	2000	RR	4.0	ON	Myopia	
7	Male	50	2004	SP	6.0		Hypermetropia	
8	Male	52	1982	SP	5.0	ONS		
9	Male	63	1980	SP	6.0	ON		
10	Female	48	1980	SP	6.0	ON	Hypermetropia	
11	Female	50	2002	SP	6.5		Myopia	
12	Female	63	1999	PP	5.5			
13	Female	69	1975	PP	6.0		Myopia	
Grey Overlay Group:								
14**	Male	33	2003	RR	3.5	ON	Presbyopia	
15	Female	47	2005	RR	2.5		Myopia	
16	Female	60	1977	RR	3.5	ONS	Myopia, Presbyopia	
17	Male	40	1998	SP	7.0		Myopia	
18	Female	52	2001	SP	6.0		Myopia, Presbyopia	
19	Female	56	1985	SP	6.0	ON	Presbyopia	
20	Female	57	2001	SP	6.0		Myopia	Photochromic***
21	Female	61	1990	SP	6.5		Hypermetropia	
22	Female	64	1996	R-SP	6.0	ON	Myopia, Presbyopia	
23	Female	66	1992	SP	6.0		Hypermetropia	
24	Male	40	2000	PP	5.0			
25	Male	47	2003	PP	6.0			
26	Female	50	1982	PP	6.0			

* Case 5 had been given blue tinted spectacles to wear by her ophthalmologist, but these were not worn during testing sessions
** Case 14 had received a diagnosis of developmental dyslexia
*** The photochromic lenses worn by Case 20 did not noticeably darken during the testing sessions
RR = Relapsing-remitting, SP = Secondary progressive, R-SP = Relapsing-Secondary progressive, PP = Primary progressive
ON+ = Optic neuritis (Presently and previously), ON = Previous episode(s), ONS = Symptoms indicative of previous optic neuritis

Table 2. Time line showing the testing sessions, their content and the intervals between them. Each patient was tested on the same day of the week across sessions. Means (and SDs) for the Coloured Overlay Group (N=13) and for the Grey Overlay Group (N=13) are presented for reading speed (words per minute) on the Rate of Reading Test and targets omitted on the Circles Search Test. Irrespective of the overlay available for use between testing sessions, patients were tested with and without the chosen coloured overlay. The data for Patients 9 and 22 has been omitted from the results reported in the table.



	Without overlay		With coloured overlay	
Session 1: Symptom Questionnaire	RRT	Circles	RRT	Circles
Interval: 1-4 weeks				
Session 2: Rate of Reading				
Coloured overlay Group	123 (33)		144 (29)	
Grey Overlay Group	128 (31)		151 (26)	
Interval: 7 days				
Session 3: Circles Search				
Coloured overlay Group		3.0 (1.5)		1.3 (1.2)
Grey Overlay Group		3.0 (1.8)		1.5 (1.3)
Interval: 7 days				
Session 4: Interview concerning symptoms				
Interval: 1-2 weeks				
Session 5: Coloured/Grey Overlays distributed				
Interval 14 days: Coloured/Grey Overlays available for use				
Session 6: Rate of Reading, Circles Search				
Coloured overlay Group	131 (27)	1.6 (0.9)	153 (30)	0.7 (0.4)
Grey Overlay Group	128 (35)	2.6 (1.0)	147 (33)	1.4 (1.1)
Interval 14 days				
Session 7: Rate of Reading, Circles Search				
Coloured overlay Group	151 (36)	0.8 (0.4)	162 (30)	0.3 (0.2)
Grey Overlay Group	153 (30)	1.4 (0.7)	166 (26)	0.5 (0.5)

1

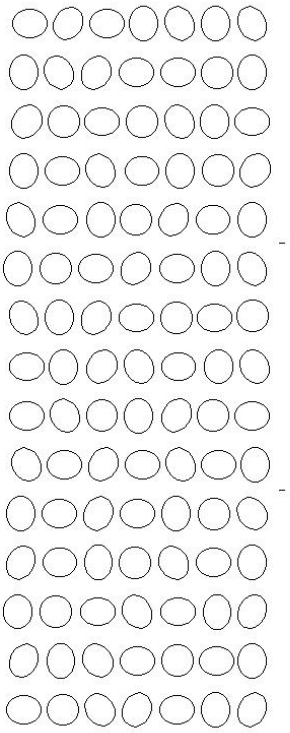


Figure 1. Circles Search Test (Sheet 1)