The effects of letter spacing and coloured overlays on reading speed and accuracy in adult dyslexia

Article *in* British Journal of Educational Psychology · September 2016

DOI: 10.1111/bjep.12127

CITATIONS
9

READS
453

3 authors:

Amanda Sjöblom
Aalto University
11 PUBLICATIONS **33** CITATIONS
SEE PROFILE

Elizabeth Eaton
University of Essex
2 PUBLICATIONS **19** CITATIONS
SEE PROFILE

Steven D Stagg
Anglia Ruskin University
25 PUBLICATIONS **327** CITATIONS
SEE PROFILE

British Journal of Educational Psychology (2016)

The British Psychological Society

www.wileyonlinelibrary.com

The effects of letter spacing and coloured overlays on reading speed and accuracy in adult dyslexia

Amanda M. Sjoblom[1,2]*, Elizabeth Eaton[1] and Steven D. Stagg[1]

[1]Anglia Ruskin University, Cambridge, UK

[2]Royal Holloway, University of London, Egham, UK

Background. Zorzi *et al.* (2012, Proc. Natl. Acad. Sci. U.S.A., 109, 11455) found evidence that extra-large letter spacing aids children with dyslexia, but the evidence for the coloured overlays is contradictory (e.g., Henderson *et al.*, 2013, J. Res. Special Educ. Needs, 13, 57; Wilkins, 2002, Ophthalmic Physiol. Opt., 22, 448), and possible combined advantages have not been identified.

Aims. To investigate whether extra-large letter spacing or coloured overlays can alleviate reading problems in dyslexic adults.

Sample. The participants were 24 dyslexic and 24 non-dyslexic university students, matched for age and fluid intelligence.

Methods. The reading speed and the errors made by a dyslexic and a control group were measured in four conditions: with and without coloured overlays and with normally and largely spaced texts.

Results. Large letter spacing improves the reading speed in general, as well as improves the reading accuracy in dyslexic readers.

Conclusions. The results support the positive effect of letter spacing on reading performance.

In the DSM-V (American Psychiatric Association, 2013), dyslexia has now been grouped under specific learning disorders. The specifier dyslexia indicates that the person gave a consistently poor performance particularly in the tests measuring linguistic abilities, but not in the tests of other academic abilities (American Psychiatric Association, 2013). Potential remediation programmes for developmental dyslexia have received an increasing amount of attention in recent research (Tallal, 2004). Some researchers (e.g., Zorzi *et al.*, 2012) have argued that most of these training programmes have focused on too small aspects of the problems people with dyslexia face, such as phonological skills, as well as taking too much time and effort to have any alleviating effects. Two options, coloured overlays and extra-large letter spacing, have been proposed that could immediately ease some of the reading problems of people with dyslexia, but the evidence for their effectiveness is limited and at points contradictory.

Some specific aspects of reading materials have been suggested to be more difficult for people with dyslexia, and these aspects should present a major focal point when designing the remediation programmes for dyslexia. These aspects include word length

*Correspondence should be addressed to Amanda M. Sjoblom, Department of Psychology, Royal Holloway University of London, Egham, Surrey TW20 0EX, UK (email: Amanda.Sjoblom.2015@live.rhul.ac.uk).

DOI:10.1111/bjep.12127

(Zoccolotti *et al.*, 2005) and frequency (Hyönä & Olson, 1995), font size (O'Brien, Mansfield, & Legge, 2005), letter distortions (Stein & Walsh, 1997), crowding (Martelli, Di Filippo, Spinelli, & Zoccolotti, 2009), and contrast of the reading material (Wilkins, 2002).

O'Brien *et al.* (2005) found evidence that people with dyslexia have a larger critical font size, the font size at which they have their fastest reading speed, than people without dyslexia. The larger print size could be helpful because it might make the letters clearer to perceive and provoke less visual stress, which readers with dyslexia have been proposed to suffer from (Wilkins, 2002). However, O'Brien *et al.*'s study did not account for the fact that as the print size is increased, the distance between the letters also increases, which could have accounted for at least some of the effect as demonstrated in the study by Martelli *et al.* (2009).

People with dyslexia have also been proposed to suffer from various distortions of the letters they read, such as crowding, blurring, letter reversal, and superimposition, which make reading more difficult (Stein & Walsh, 1997). Martelli *et al.* (2009) tested the crowding effects, the effects of the flanking letters, the letters on either side of the target, on the recognition of the target letter with dyslexic and non-dyslexic children. They reported that children with dyslexia were impaired on word recognition, but not on single-letter recognition tasks compared to the controls. The study found evidence that the dyslexic readers had a larger critical spacing; they needed a larger distance between letters in order to identify the target letters that had flanker letters (Martelli *et al.*, 2009). The flanker letters interfered with the recognition of the target when they are closer to the target than the critical spacing distance. These findings demonstrated that crowding is likely to be at least one of the problems that impair reading in dyslexia, which suggests that reducing the effect of crowding could alleviate some of the reading problems of people with dyslexia.

Eye movement studies in dyslexia (e.g., De Luca, Borrelli, Judica, Spinelli, & Zoccolotti, 2002; Hyönä & Olson, 1995) have reported abnormal eye movements during reading in dyslexic samples, such as differences in the saccadic eye movements. These abnormalities could be related to the effects of the text distortions. Eye tracking methods investigating the eye movement patterns during reading have also supported the argument that crowding impairs the performance of people with dyslexia and that people with dyslexia are affected on a wider visual span, the negative effects extending to para-foveal vision in dyslexic people, but not in normal readers (Moll & Jones, 2013). These results support that at least some of the dyslexic readers' problems could be caused by the crowding effect, suggesting that alleviating them could help people with dyslexia read better.

Most of the above-mentioned studies suggest that the difficulties in dyslexia are due to some aspect of the reading material, such as spacing or print size, having a negative effect on readers with dyslexia. Some have also suggested that the reading difficulties in dyslexia could be at least partially due to a stronger effect of the contrast between the text and its background on people with dyslexia (e.g., Wilkins, 2002), but the evidence is mixed. O'Brien, Mansfield, and Legge (2000) found contradicting evidence when comparing the reading speed of children with dyslexia and adults with age-matched control, and found no differences in the effects of contrast on continuous text at several font sizes. The hypothesis that readers with dyslexia could be differently affected by the contrast of the reading material could be linked with the visual stress theories (O'Brien *et al.*, 2000). Both people with dyslexia and some people without dyslexia have been proposed to suffer from visual stress, a condition in which, according to some theories, the person experiences discomfort, tiring, or visual distortions during reading, which affects reading

negatively. There is contradictory evidence of people with dyslexia suffering from visual stress (e.g., Singleton & Trotter, 2005) and whether it is more common in people with dyslexia than in people without (e.g., Wilkins, 2002).

Two possible reading aids have aimed to target these proposed problems arising from the reading material, which could be useful for adults with dyslexia in alleviating some of the associated reading difficulties. Coloured overlays (e.g., Wilkins, 2002) and extra-large letter spacing (Zorzi *et al.*, 2012) focus on the actual reading performance of people with dyslexia and are intended to make the reading material easier for readers with dyslexia. Unlike lengthy and complex remediation programmes, these reading aids do not require any training time, but could have an instant relieving effect on the reading difficulties of people with dyslexia.

Coloured overlays were created to alleviate the visual stress (Wilkins, 2002). They are coloured sheets of plastic placed on top of the reading material (Wilkins & Lewis, 1999). Coloured overlays have been widely distributed to children and adults with dyslexia, but they have remained controversial form of treatment, as the evidence for their effectiveness is unclear (Henderson, Tsogka, & Snowling, 2013). Some studies have suggested that coloured overlays lessen the visual stress by reducing the contrast of the material (e.g., Singleton & Trotter, 2005; Wilkins, 2002), but the evidence from research in this area is contradictory. Singleton and Trotter (2005) reported that dyslexic people with high visual stress scores benefited from using a coloured overlay. Henderson *et al.* (2013) found no significant gains for the reading speed or reading comprehension of when using coloured overlays. Coloured overlays have also been found to be effective for other groups experiencing atypical development. For example, evidence supports that the reading speed of children with autism is significantly improved with the use of coloured overlays (Ludlow, Wilkins, & Heaton, 2006).

Another form of manipulation proposed to alleviate the reading problems is extra-large letter spacing. Zorzi *et al.* (2012) experimented with the effects of crowding by using reading material that was normally spaced and material with extra-large letter spacing. The extra-large letter spacing was created by increasing the spacing between the letters in the text by 2.5pt (roughly 0.88 mm), which also increases the spacing between the words (Zorzi *et al.*, 2012). Italian and French dyslexic children read short unrelated sentences that were either normally spaced or had extra-large letter spacing (Zorzi *et al.*, 2012). The children made significantly fewer errors on the largely spaced text than on the normally spaced text, and read faster (Zorzi *et al.*, 2012). Control participants who were matched to the children with dyslexia on reading level were not significantly affected by the spacing (Zorzi *et al.*, 2012), which suggests that the crowding effect could be an underlying deficit that affects reading in dyslexia. Perea, Panadero, Moret-Tatay, and Gómez (2012) found similar results when testing skilled readers, young readers, and children with dyslexia. Widened letter spacing produced faster word recognition times in all groups, but the dyslexic group had the largest benefit from the extra-large spacing (Perea *et al.*, 2012). In continuous reading, the children with dyslexia also had significantly faster reading times and increased comprehension scores, while the other groups did not (Perea *et al.*, 2012). These results support that widened spacing between letters could be an effective remediation form for children with dyslexia, and suggest that their effectiveness for adults with dyslexia should be investigated.

Unlike most remediation programmes, the coloured overlays and the extra-large letter spacing seem more plausible methods for helping adults with dyslexia, as they have the potential to be relatively easy to implement and use. The experiment reported in this

study was conducted to investigate and compare how effectively the two manipulations to the reading material, the coloured overlays and the extra-large letter spacing, could alleviate the reading difficulties in adults with dyslexia. The effects of the manipulations on reading speed and the amount of reading errors were measured in a task in which the participants read out loud short continuous texts. The aim of the study was to investigate whether the increased letter spacing has a similar alleviating effect for adult English speakers with dyslexia as it had for the French and Italian children in the study by Zorzi *et al.* (2012), and whether coloured overlays could also have a positive effect for this group, as some research suggests that they have affected the reading difficulties in children (Wilkins, 2002). Adult English speakers with dyslexia have not yet been tested with extra-large letter spacing, and the evidence of the effectiveness of coloured overlays for them has been contradictory (e.g., Singleton & Trotter, 2005). This study also aimed to find evidence whether the combination of the two aids could be more effective than a single method, which has not been tested before.

Given the findings of previous studies, we hypothesized that coloured overlays would improve the reading speed and lessen the amount of errors made by adult readers with dyslexia, as it has done with children with dyslexia (Wilkins, 2002). The second hypothesis was that the extra-large letter spacing would have a similar improving effect on the adult participants with dyslexia, as it was shown to do with children with dyslexia (Zorzi *et al.*, 2012). The combination of the two manipulations was hypothesized to have a similar or potentially stronger effect on participants with dyslexia than either manipulation alone, as they could be affecting different aspects of the reading problems, spacing lessening the effects of crowding (Zorzi *et al.*, 2012), and coloured overlays lessening the effects of visual stress and contrast (Wilkins, 2002).

Method

Participants

Forty-eight native English speakers with normal or corrected to normal vision took part in the study. The dyslexic group was made up of 24 participants (13 males), all with a diagnosis of dyslexia from a trained professional. The comparison group consisted of 24 (6 males) non-dyslexic participants. The groups were matched for chronological age and IQ. The participants' ages and their scores on the Cattell's Culture Fair Intelligence Test are presented in Table 1. There were no significant differences in age, $t(46) = 0.082$, $p = .935$, or scores on the Cattell's Culture Fair Intelligence Test, $t(46) = -0.82$, $p = .416$, between the groups. While the effect size is difficult to calculate for this study, previous research has reported the large effect sizes for reading improvement in dyslexic samples when using coloured overlays (e.g., Perea *et al.*, 2012; *d* between 1.06 and 1.60). Given

Table 1. Participants' ages and Cattell's scores by groups

	Age (year)			Cattell's score	
Group	Range	Mean	*SD*	Mean	*SD*
Dyslexia	19–39	22.58	4.13	35.88	4.44
Control	18–47	22.71	6.24	34.83	4.36

the more conservative estimate of $d = 1$, our study achieved a notional power of 93% ($\alpha = .05$, two-tailed).

Design

Reading times (syllables per minute) and the number of reading errors (mispronunciation, omission, substitution, and additions, errors per 100 syllables) were measured for four conditions (normally spaced text without an overlay, normally spaced text with an overlay, largely spaced text without an overlay, and largely spaced text with an overlay) presented in a controlled randomized order, using a mixed design with all the participants in the two groups (dyslexic and normal readers) completing all conditions.

Apparatus/Materials

The reading materials were adapted from continuous reading sections of the York Adult Assessment (Hatcher & Snowling, 2002) and the York Adult Assessment Battery-Revised (Warmington, Stothard, & Snowling, 2012). The York Adult Assessment and the York Adult Assessment Battery-Revised are standardized assessment tools for dyslexia in adults, with experimental evidence supporting their reliability and validity (Warmington, Stothard, & Snowling, 2013). The two original texts from the tests were broken up roughly in half in order to make four texts that were used in the different conditions. The size and the typeface of the original texts were retained, Calibri and Arial, respectively, both in size of 11.5pt, which remained unchanged in all conditions.

The spacing of the text was manipulated according to the conditions. Participants were presented with two normally spaced texts (~1 mm) with the original line spacing (~4 mm), and two texts in which the letter spacing was increased by 2.5pt (~2 mm). In accordance with the Zorzi *et al.*'s (2012) protocol, in the 2.5-pt spaced condition, the line spacing was increased to 2 (double the regular spacing, ~8 mm) in order to maintain the overall look of the text. Each text was presented on a separate piece of white A4 paper, using black text. A4-sized coloured overlays from Crossbow Education were used in two of the four conditions. The participants chose one of the ten provided colours – yellow, orange, magenta, pink, purple, sky blue, aqua blue, grass green, jade green, and celery green – and either the matte or gloss side. The participants chose the colour of the overlay they wished to use by trying them on unrelated piece of text on a white paper, as instructed by the producer of the overlays in order for users to find the most suitable colour (Coloured overlays, dyslexia, and visual stress, n.d.), and as evidence suggests this to be a reliable way of assigning the colour for the participant that would produce the largest benefit (Waldie & Wilkins, 2004; Wilkins, 2002).

An Olympus digital voice recorder was used to record the participants' reading. The reading speed and the errors were taken from the recording, and the speed timed from when the participant began reading out loud to when they finished the section.

Cattell's Culture Fair Intelligence Test (Cattell & Cattell, 1957) was used to measure the fluid intelligence, to ensure that the groups were matched for IQ. The test is a non-verbal test of fluid intelligence (Cattell & Cattell, 1961). The test has high concept validity, criterion validity, and reliability, with high consistency over the items and parts and over time (Cattell & Cattell, 1961). A demographic questionnaire was created to attain the participants' age, gender, dyslexia status, native language, and whether they have used coloured overlays before.

Procedure

Participants were seated at a comfortable reading distance from a desk in a well-lit room. Before beginning the study, a short demographic questionnaire was completed by the participants. The participants with dyslexia also presented a copy of their dyslexia diagnosis report. The participants completed the Cattell's Culture Fair Form A, which was conducted according to the instruction manual. The participants were then instructed to test the ten coloured overlays on an unrelated text and to choose the colour and the side they found preferable. On completion, the participants commenced the experimental task. The four reading conditions were presented in a controlled randomized order, and the order in which each of the four conditions was presented to every participant was assigned by chance in a manner which avoided all participants seeing the same combinations in the same order. The four texts were also randomized across which condition they were used for in a way that avoided a single condition being paired up with the same text more times than with other possible texts, in order to avoid measuring the effects of the texts rather than the conditions. For each condition, the text and the coloured overlay (when appropriate) were placed in front of the participant and covered with a white sheet of paper. The participants were instructed to uncover the text and to immediately start reading it out loud at a comfortable speed while they were being recorded. The recording was used to attain the participants' reading time and the amount of errors (mispronunciation, omission, substitution, and additions) they made. After the participants had completed all of the four conditions, they were debriefed; it was made sure that all the questions they might have of the experiment were answered, and it was ensured that they were still happy for their data to be used.

Results

As the reading materials were of unequal lengths, for the purpose of the analyses the reading speed is reported in syllables per minute and the amount of errors is reported in errors per 100 syllables. The primary reading assessment was conducted blind, and to ensure the reliability of performance rating, a second rater, unaware of the manipulations or the purpose of the study, rated all the performances. The average error ratings of the two raters were significantly correlated ($r = .77, p < .001$). The gender balance between the groups was significantly different from the balanced expected by random chance (χ^2 $(1, N = 48) = 4.27, p < .039$); however, independent *t*-tests revealed no significant differences between genders on any measures.

Reading speed

A $2 \times 2 \times 2$ mixed factorial ANOVA was used to analyse the reading speed data (syllables per minute), with groups having two levels (dyslexic and control), spacing of text having two levels (normal spacing and large spacing), and coloured overlays having two levels (text with an overlay and text without an overlay). The reading speeds and standard deviations are reported in Table 2. There were no significant interactions, for groups and spacing $F(1,46) = 1.46$, $p = .233$, $\eta^2 = .031$; for groups and coloured overlays $F(1,46) = 0.136$, $p = .714$, $\eta^2 = .003$; for spacing and coloured overlays F $(1,46) = 0.229$, $p = .634$, $\eta^2 = .005$; and for groups, spacing, and coloured overlays $F(1,46) = 1.246, p = .27$, $\eta^2 = .026$. As there were no significant interactions, the main effects were investigated. The spacing of the text had a significant effect on reading speed,

Table 2. Reading speeds (syllables/minute) by Groups

	Small spacing, no overlay		Large spacing, no overlay		Small spacing, with overlay		Large spacing, with overlay	
	Mean	*SD*	Mean	*SD*	Mean	*SD*	Mean	*SD*
Control	260.2	31.1	264.7	31.8	266.4	35.6	267.5	36.1
Dyslexia	214.0	41.1	219.6	38.1	216.7	37.3	230.5	39.9

$F(1,46) = 4.745$, $p = .035$, $\eta^2 = .094$ (with faster reading with large spacing (245.6, $SE = 4.8$) than with small spacing (239.32, $SE = 4.9$)), but the coloured overlays did not $F(1,46) = 3.354, p = .074, \eta^2 = .068$. The group had a significant effect on reading speed, with non-dyslexic participants reading faster (264.7, $SE = 6.6$) than dyslexic participants, 220.2, $SE = 6.6$; $F(1,46) = 22.785, p < .001, \eta^2 = .331$. The data support the hypothesis that an increased spacing positively affects the reading speed, although possibly not exclusively in dyslexics. The hypothesis that coloured overlays would aid the reading speed was not supported, although it is noted that the results were not far from being significant.

Reading accuracy

A $2 \times 2 \times 2$ mixed factorial ANOVA was used to analyse the reading accuracy data (errors per 100 syllables), with groups having two levels (dyslexic and control), spacing of text having two levels (normal spacing and large spacing), and coloured overlays having two levels (text with an overlay and text without an overlay). The reading errors and the standard deviations are reported in Table 3. There was a significant interaction between groups and spacing $F(1,46) = 13.643$, $p = .001$, $\eta^2 = .229$. There were no significant interactions between groups and coloured overlays, $F(1,46) = 0.277$, $p = .601$, $\eta^2 = .006$; spacing and coloured overlays, $F(1,46) = 0.484$, $p = .49$, $\eta^2 = .010$; or groups, spacing, and coloured overlays, $F(1,46) = 0.575$, $p = .452$, $\eta^2 = .012$. The interaction between groups and spacing is ordinal, with dyslexic participants making significantly less errors with largely spaced text (1.32, $SE = 0.12$) than with the normally spaced text, 1.97, $SE = 0.17$, $t(23) = -4.76$, $p < .001$, $d = 1.04$, but for control participants there was no significant effect of spacing, $t(23) = -0.314$, $p = .756$, $d = 0.22$. The control participants were more accurate overall than the dyslexic participants, with non-dyslexic participants making significantly less errors (0.804, $SE = 0.103$) than participants with dyslexia, 1.581, $SE = 0.119$; $F(1,46) = 33.138$, $p < .001$, $\eta^2 = .419$. Overall, coloured overlays did not have a significant effect on reading accuracy, $F(1,46) = 0.048, p = .827, \eta^2 = .001$.

Table 3. Reading accuracy (errors/100 syllables) by Groups

	Small spacing, no overlay		Large spacing, no overlay		Small spacing, with overlay		Large spacing, with overlay	
	Mean	*SD*	Mean	*SD*	Mean	*SD*	Mean	*SD*
Control	0.77	0.37	0.84	0.41	0.92	0.49	0.78	0.47
Dyslexia	1.98	0.97	1.32	0.63	1.96	1.01	1.31	0.68

Discussion

We aimed to explore the potential benefits of reading material manipulations, particularly letter spacing and coloured overlays, for the speed and accuracy of reading, focusing on benefits for readers with dyslexia. The study demonstrated that improvements could be made to the reading speed and accuracy with relatively simple adaptations of text. In relation to the reading speed, the results demonstrated that letter spacing improves the reading speed in general but with no specific effect for dyslexic readers. Unlike past research, colour overlays did not increase the reading speed for dyslexic readers, but it is noted that the main effect of overlays for reading speed approached significance, and a failure to detect the effect may be due to a lack of statistical power. The results for reading accuracy demonstrated that letter spacing, and not coloured overlays, improved the accuracy. This effect was specific to the dyslexic group. Overall, the results suggest that for dyslexic reader, larger letter spacing increases the reading speed and that this is not to the determent of reading accuracy, which is also improved.

Our findings suggest that dyslexic students may benefit from a change in letter spacing to reading material. Previous research has demonstrated that crowding can produce reading difficulties in individuals with dyslexia (Martelli *et al.*, 2009), and our results support this finding. Martelli *et al.* suggest that crowding can hamper the recognition of letters and may thus decrease the reading accuracy. Our study suggests that the impact of crowding on readers differs for dyslexic and non-dyslexic readers. Both groups benefited from letter spacing when the speed of reading is being measured, but letter spacing improved the reading accuracy only in the dyslexic group. We remain cautious about these findings due to small sample sizes; however, the difference in effect size between each group was of note. In the dyslexic group, the effect size related to accuracy was $d = 1$, whereas for the non-dyslexic group, it was $d = 0.22$. This is a notably large difference and suggests that particular difficulties in reading are being experienced by the dyslexic group.

The findings of our study add to a growing body of research (e.g., Perea *et al.*, 2012; Zorzi *et al.*, 2012) that has reported the benefits of letter spacing for dyslexic readers. A strength of our study was that it used continuous text rather than unrelated sentences like many previous studies (e.g., Zorzi *et al.*, 2012), as continuous text is more commonly faced in everyday life. This suggests that a reading advantage is still evident in dyslexic readers when spacing between letters is enlarged, even when material provides contextual cues to the reader making comprehension easier. As our results were, however, limited to sans serif typefaces, further investigation is required on whether added spacing would be effective with serif-type fonts as well.

In relation to coloured overlays, our findings did not support a specific dyslexic improvement. Reading speed was improved for both groups when using overlays, although these results missed statistical significance at the $\alpha = .05$ value. As such, our results contradict previous research that has found coloured overlays to be beneficial to dyslexic readers (e.g., Singleton & Trotter, 2005). Evidence for the benefit of coloured overlays is mixed with some researchers finding no benefit of using them (Henderson *et al.*, 2013). Overlays may be more useful to individuals with dyslexia who experience particular visual stress such as the kind reported in Meares–Irlen syndrome. This may be why groups in which visual stress is commonly reported, such as autism spectrum disorder, show a benefit from coloured overlays (Ludlow *et al.*, 2006). Although the results did not support the hypothesis for the effectiveness of the coloured overlays for reading accuracy, the effect size from the analysis on reading speed does suggest a

potential, small beneficial effect of coloured overlays. The effect could likely have been significant with a larger sample size, and it could be associated with the relative shortness of the reading materials. The benefits from the coloured overlays may not emerge until longer reading periods which may cause tiring that the coloured overlays could alleviate. Longer reading periods should be investigated in the future research before these results are taken as evidence against the use of the coloured overlays.

Many of the dyslexic participants spontaneously mention during debriefing that they found the extra-large letter spacing, the coloured overlays, or the combination of the two very helpful in comparison with the other conditions. The non-dyslexic participants did not make any such comments. While this was not quantifiable data and was not measured in the experiment, the notion that the people with dyslexia felt that these manipulations were useful is an interesting point and should motivate further research. The manipulations were described, for example, to ease concentration on the material, to make the text easier to follow, to make the words less crowded or mixed up and other descriptions of easier reading.

With the promising results for reading speed and accuracy, an important question for future research is whether reading comprehension is affected by the manipulations, as it is perhaps more important than the speed and accuracy at which people can read out loud. Future research should also investigate whether these manipulations could aid reading from computer screen, as this seems to be coming more and more common. Another intriguing question is whether the extra-large letter spacing could be made into a form of treatment programme, perhaps by aiming to use the large spacing to aid people with dyslexia reach a higher reading level. In their current form, neither of the manipulations can correct the deficits in dyslexia, only act as a potentially external aid. Future research will need to investigate the optimal spacing of letters in text for individuals with dyslexia, and how such spacing may change the attentional focus of the reader.

Acknowledgements

We thank Duru Gün Özkan and Ann-Kathrin Johnen for their assistance with the experiment.

References

American Psychiatric Association. (2013). *Diagnostic and statistical manual of mental disorders* (5th ed.). Washington, DC: Author.

Cattell, R. B., & Cattell, A. K. S. (1957). *Test of g: Culture fair (Scale 2, Form A)*. Champaign, IL: Institute for Personality and Ability Testing.

Cattell, R. B., & Cattell, A. K. S. (1961). *Measuring intelligence with the Culture-Fair tests: Manual for Scales 2 and 3*. Champaign, IL: Institute for Personality and Ability Testing.

Coloured Overlays, Dyslexia and Visual Stress (n.d.) Retrieved from http://www.crossboweducation.com/articles/dyslexia-coloured-overlays-and-visual-stress

De Luca, M., Borrelli, M., Judica, A., Spinelli, D., & Zoccolotti, P. (2002). Reading words and pseudowords: An eye movement study of developmental dyslexia. *Brain and Language*, *80*, 617–626. doi:10.1006/brln.2001.2637

Hatcher, J., & Snowling, M. J. (2002). *The York adult assessment*. York, UK: Centre for Reading and Language, University of York.

Henderson, L. M., Tsogka, N., & Snowling, M. J. (2013). Questioning the benefits that coloured overlays can have for reading in students with and without dyslexia. *Journal of Research in Special Educational Needs*, *13*(1), 57–65. doi:10.1111/j.1471-3802.2012.01237.x

Hyönä, J., & Olson, R. K. (1995). Eye fixation patterns among dyslexic and normal readers: Effects of word length and word frequency. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *21*, 1430–1440. doi:10.1037/0278-7393.21.6.1430

Ludlow, A. K., Wilkins, A. J., & Heaton, P. (2006). The effect of coloured overlays on reading ability in children with autism. *Journal of Autism and Developmental Disorders*, *36*, 507–516. doi:10.1007/s10803-006-0090-5

Martelli, M., Di Filippo, G., Spinelli, D., & Zoccolotti, P. (2009). Crowding, reading, and developmental dyslexia. *Journal of Vision*, *9*(4), 14. doi:10.1167/9.4.14

Moll, K., & Jones, M. (2013). Naming fluency in dyslexic and nondyslexic readers: Differential effects of visual crowding in foveal, parafoveal, and peripheral vision. *The Quarterly Journal of Experimental Psychology*, *66*, 2085–2091. doi:10.1080/17470218.2013.840852

O'Brien, B. A., Mansfield, J. S., & Legge, G. E. (2000). The effect of contrast on reading speed in dyslexia. *Vision Research*, *40*, 1921–1935. doi:10.1016/S0042-6989(00)00041-9

O'Brien, B. A., Mansfield, J. S., & Legge, G. E. (2005). The effect of print size on reading speed in dyslexia. *Journal of Research in Reading*, *28*, 332–349. doi:10.1111/j.1467-9817.2005.00273.x

Perea, M., Panadero, V., Moret-Tatay, C., & Gómez, P. (2012). The effects of inter-letter spacing in visual-word recognition: Evidence with young normal readers and developmental dyslexics. *Learning and Instruction*, *22*, 420–430. doi:10.1016/j.learninstruc.2012.04.001

Singleton, C., & Trotter, S. (2005). Visual stress in adults with and without dyslexia. *Journal of Research in Reading*, *28*, 365–378. doi:10.1111/j.1467-9817.2005.00275.x

Stein, J., & Walsh, V. (1997). To see but not to read; The magnocellular theory of dyslexia. *Trends in Neurosciences*, *20*, 147–152. doi:10.1016/S0166-2236(96)01005-3

Tallal, P. (2004). Improving language and literacy is a matter of time. *Nature Reviews Neuroscience*, *5*, 721–728. doi:10.1038/nrn1499

Waldie, M., & Wilkins, A. (2004). How big does a coloured overlay have to be? *Ophthalmic and Physiological Optics*, *24*(1), 57–60. doi:10.1046/j.1475-1313.2003.00169.x

Warmington, M., Stothard, S. E., & Snowling, M. J. (2012). *The York adult assessment battery-revised*. York, UK: Centre for Reading and Language, University of York.

Warmington, M., Stothard, S. E., & Snowling, M. J. (2013). Assessing dyslexia in higher education: The York adult assessment battery-revised. *Journal of Research in Special Educational Needs*, *13*(1), 48–56. doi:10.1111/j.1471-3802.2012.01264.x

Wilkins, A. (2002). Coloured overlays and their effects on reading speed: A review. *Ophthalmic and Physiological Optics*, *22*, 448–454. doi:10.1046/j.1475-1313.2002.00079.x

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

Zoccolotti, P., De Luca, M., Di Pace, E., Gasperini, F., Judica, A., & Spinelli, D. (2005). Word length effect in early reading and in developmental dyslexia. *Brain and Language*, *93*, 369–373. doi:10.1016/j.bandl.2004.10.010

Zorzi, M., Barbiero, C., Facoetti, A., Lonciari, I., Carrozzi, M., Montico, M., ... Ziegler, J. C. (2012). Extra-large letter spacing improves reading in dyslexia. *Proceedings of the National Academy of Sciences of the United States of America*, *109*, 11455–11459. doi:10.1073/pnas.1205566109

Received 30 July 2015; revised version received 5 September 2016