

Abstract

Background: Coloured overlay and extra-large letter spacing may improve reading speed and accuracy in individuals with dyslexia; however, research has yet to identify which types of reading errors are diminished. **Aim:** To determine the impact of extra-large letter spacing and colour overlay on reading and assess the impact of both interventions on reading errors. **Sample:** Thirty-two dyslexic children were matched on age, verbal and non-verbal IQ with 27 children with no diagnosis of dyslexia. The average age of each group was 13 years. **Method:** Participants read four texts with either standard or extra-large letter spacing with or without a coloured overlay. **Results:** Extra-large letter spacing significantly improved reading speed more substantially for the dyslexia group. In addition, extra-large letters significantly reduced the number of missed word errors made by the dyslexia group. In contrast, coloured overlays did not significantly impact reading speed or the reduction of errors. **Conclusion:** Increasing letter spacing is an effective way for teachers to improve reading skills in students with dyslexia.

Keywords: Dyslexia, reading speed, reading accuracy, large letter spacing, coloured overlays, reading errors

Dyslexia denotes a specific learning difficulty that affects reading accuracy, reading rate, fluency and reading comprehension (APA, 2013). Developmental dyslexia is thought to affect between 3% and 7% of the population (Peterson & Pennington, 2015) and is more commonly diagnosed in boys than girls (Cai et al., 2020; Rutter et al., 2004). Individuals with dyslexia experience difficulties learning both to read and spell, even given sufficient levels of intelligence and adequate educational instruction (APA, 2013). Slower reading speed is a prominent feature of dyslexia and is one element that differentiates individuals with dyslexia from normal readers (Tressoldi, Stella, & Faggella, 2001; Ziegler, Perry, Ma-Wyatt, Ladner, & Schulte-Körne, 2003). Numerous methods have been proposed to increase reading speed and reduce errors in individuals with dyslexia; these include colour overlays (Bouldoukian, Wilkins, & Evans, 2002), larger letters (O'Brien, Mansfield, & Legge, 2005) and larger letter spacing (Sjoblom, Eaton, & Stagg, 2016).

Research suggests that visual crowding is one factor responsible for decreased reading speed and accuracy with dyslexia (Callens, Whitney, Tops, & Brysbaert, 2013; Moores, Cassim, & Talcott, 2011). Visual crowding refers to difficulties in detecting a stimulus when other stimuli surround it. In the context of reading, dyslexic readers may have problems identifying or detecting a letter when it is surrounded by other letters but not when the letter occurs on its own. Research suggests that children with dyslexia require a more significant distance between letters to identify target letters with flanker letters surrounding them (Martelli, Di Filippo, Spinelli, & Zoccolotti, 2009). In Martelli et al.'s study, flanker letters interfered with target letter recognition when they were closer to the target than when placed within the critical spacing distance. The research suggests 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 experienced by people with dyslexia.

One method used to decrease the impact of crowding has been to increase the space between letters rather than increasing the font size. Research suggests that this method increases reading speed in individuals with dyslexia. For example, increasing the space between letters by 2.5 pt (roughly 0.88 mm) results in children with dyslexia making fewer reading errors and increasing reading speed (Zorzi et al., 2012). Similar findings have been reported for adult readers with dyslexia (Sjoblom et al., 2016) and for children with and without dyslexia (Hakvoort, van den Boer, Leenaars, Bos, & Tijms, 2017; Perea, Panadero, Moret-Tatay, & Gómez, 2012).

Visual stress has also been proposed to affect the reading speed and accuracy of readers with and without dyslexia; although the prevalence of visual stress has been reported to be higher in readers with dyslexia (Irlen, 1991; Singleton & Henderson, 2007). Visual stress relates to cortical hyperexcitability to sensory stimulation and can result in perceptual distortion and discomfort when reading (A. J. Wilkins, 1995). Readers with visual stress experience perceptual distortion and general visual discomfort (A. Wilkins, Huang, & Cao, 2004), which can significantly slow down reading (Hollis & Allen, 2006). It has been suggested that the contrast between the text and its background may particularly impact individuals with dyslexia (A. Wilkins, 2002). Coloured overlays (coloured sheets of plastic placed over the reading material) have been created to alleviate visual stress. In other developmental disorders, such as autism, the use of coloured overlays has been used effectively to increase reading speed (Ludlow, Wilkins, & Heaton, 2008). Evidence for increased reading speed and accuracy in individuals with dyslexia, however, has been mixed. Singleton and Trotter (2005) reported significant gains in

reading speed in adults with dyslexia and high visual stress but smaller non-significant gains in adults without visual stress. Although individuals with dyslexia show contrast effects when viewing low-level visual stimuli, similar findings have not been found when using meaningful text (O'Brien, Mansfield, & Legge, 2000), and research suggests that colour overlays may have little impact on improved reading (Henderson, Tsogka, & Snowling, 2013).

Programmes to improve reading skills are often narrow in scope and can be challenging to implement (Zorzi et al., 2012); in contrast, colour overlays and text manipulation offer a relatively easy implementation. Coloured overlays (A. 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. Unlike long and complicated remediation programmes, these reading aids do not require any training time but could have an instant relieving effect on reading difficulties. The experiment reported in this paper was conducted to investigate and compare how effectively two manipulations to reading material, coloured overlays and extra-large letter spacing, alleviate reading difficulties in children with dyslexia. We also examined specific reading errors and the effect of both interventions on these. Given the findings of previous studies, we hypothesised that extra-large letter spacing would improve the reading speed and decrease the number of errors made by children with dyslexia. We did not expect to see gains with coloured overlays. To our knowledge, no research has examined specific reading errors concerning coloured overlays and letter spacing, and we report exploratory data in this area.

Method

Participants

Participants were recruited from schools in Cambridgeshire, Hertfordshire and London. A total of 22 schools were initially contacted; of those who replied, six schools agreed to participate in the study. Schools gave consent for participation in the study. Parents were informed of the study and their right to withdraw their child from the study. Each participant was informed of the study and the study protocol. Consent was obtained from participants before the study commenced. All participants were informed of their right to withdraw from the study, and the study gained ethical approval from the factuality ethics Committee at [University]. Students were drawn across year groups seven (11- 12 years; 20%), eight (12-13 years; 27%), nine (13 – 14 years; 32%) and 10 (14 to 15; 21%). The youngest child to take part was 11 years and four months, and the oldest child was 15 years and ten months. The dyslexia group consisted of 32 children (23 males and nine females), all with a statement of dyslexia; the comparison group comprised 27 children (16 males and 11 females) who did not have dyslexia. The participants were not assessed for any other developmental disorders other than dyslexia. Children taking part in the study were selected by the schools dependent on timetabling. The groups were matched on age. The Raven's Progressive Matrices (RPM) were used to provide scores for non-verbal intelligence, and the British Picture Vocabulary Scales (BPVS) provided a measure of receptive language ability. To ensure that any group differences in the dependent variables were not

attributable to age or non-verbal reasoning ability, the groups were matched on these measures (Table 1).

PLACE TABLE 1 HERE

Materials

The Raven's Standard Progressive Matrices Plus (Raven, 2008) was used to match the two groups on non-verbal intelligence. The plus version is an updated and improved version of the standard progressive matrices designed to measure non-verbal reasoning skills. The measure comprises 60 items divided over five sets of 12 items, with the sets ranging from A to E, with each set becoming progressively more difficult. The measure was used to ensure that the two groups did not differ significantly on non-verbal intelligence.

The British Picture Vocabulary Scale-II (BPVS). The BPVS-II (Dunn et al., 1997) assesses receptive vocabulary through verbal comprehension. The participant is asked to point to one of four pictures that best represents a word read by the administrator. Scores on the BPVS are highly correlated with mental age and IQ derived from the Wechsler Intelligence Scale (BPVS-II manual, p. 35-36; Dunn, Dunn, Whetton, & Burley, 1997).

Following the method used by Sjoblom et al. (2016), two original texts taken from the continuous reading sections of the York Adult Assessment (Hatcher & Snowling, 2002) and the York Adult Assessment Battery-Revised (Warmington, Stothard, & Snowling, 2013) were each divided roughly in half to make four texts that were used in the different conditions. The size (11.5 pt) and the typeface of the original texts were retained (Calibri and Arial).

The normal-spaced text retained the original spacing of the stimulus material, and the large-spaced text increased the letter spacing from the original text by 2.5 pt. Similarly to the method used by both Zorzi et al. (2012) and Sjoblom et al. (2016), in the 2.5 pt spaced condition,

the line spacing was increased to 2 (double the regular spacing) 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 were permitted to choose the colour of the overlay they wished to use. Evidence suggests this is a reliable way of assigning the colour that would produce the most significant benefit for the participant (Waldie & Wilkins, 2004; A. Wilkins, 2002). Recordings were made using an Apple iPad.

Procedure

Participants completed the Raven's Progressive Matrices either before or after the recording session. All testing was completed at the participant's school. In the recording phase, participants were instructed to test the ten coloured overlays on an unrelated text and choose their preferred colour. The four reading conditions were presented in a controlled randomised order; the order in which each of the four conditions was presented to every participant was assigned by chance to avoid the combinations being presented in the same order for all participants. The four texts were also randomised across the condition for which they were used to avoid a single condition being paired with the same text more times than with other possible texts; this was done 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 immediately start reading it out loud at a comfortable speed while being recorded.

The recording was used to measure the participants' reading time and the number of errors they made. After the participants had completed all four conditions, they were debriefed. Errors were coded into four categories: missed words (a word in the text was not spoken); added words (a word was spoken that was not in the text); wrong words (a word spoken was a recognisable word but not exactly the word in the text; this included assigning the wrong tense or plurality to the word); and pronunciation (an attempt at speaking the word was made but resulted in a mispronunciation or an unrecognisable pronunciation of the word).

Statistical analysis

Time taken to read the text was calculated as the average number of syllables read per minute (spm). The overall reading time was calculated from when the first and last words of the text were spoken. The Shapiro–Wilk test was used to test for normality for each of the variables included in the analyses. Where normality was not met (e.g., the test results were below the .05 cut off) non-parametric tests were used. Reading speed was normally distributed and was analysed using parametric tests (ANOVA). Errors were measured as the number of errors made per 100 words (ephw). To determine the reliability of the error coding, Cohen's κ was run on six coded scripts rated independently by both researchers. There was good agreement between the two sets of ratings, $\kappa = .79$ (95% CI, .72 to .86), $p < .0005$. Error scores were not normally distributed and were, therefore, analysed using non-parametric tests. The effect size for the group comparisons conducted using the non-parametric Wilcoxon signed rank test was calculated using the formula $r = z/\sqrt{N}$ (Rosenthal, 1994). A Bonferroni correction was applied to correct for multiple comparisons.

Results

A 2×2×2 mixed factorial ANOVA was used to analyse the reading speed data (syllables per minute), with group having two levels (dyslexia and control), spacing of text having two levels (normal spacing and large spacing) and coloured overlays having two levels (overlay present and overlay absent). Mean scores for reading speed are presented in Table 2. As predicted, the two groups differed significantly on reading speed $F(1, 57) = 18.88, p < .0001, \eta^2 = .25$ with the dyslexia group slower (142 spm) than the comparison group (191 spm). There was no significant two-way interaction between letter spacing and group $F(1, 57) = 1.92, p = .17, \eta^2 = .03$, between overlay and group $F(1, 57) = .01, p = .96, \eta^2 = .001$, or between letter spacing and overlay $F(1, 57) = .47, p = .50, \eta^2 = .008$; there was no significant three-way interaction between letter spacing, overlay and group $F(1, 57) = 2.98, p = .09, \eta^2 = .05$. The main effect of overlay was not significant $F(1, 57) = 1.28, p = .26, \eta^2 = .02$. As predicted, the main effect of letter spacing was statistically significant $F(1, 57) = 23.89, p < .001, \eta^2 = .30$. The results illustrate that both groups improved reading speed when reading the larger spaced texts. On average, the dyslexia group showed a 13% increase in reading speed whereas the comparison group showed a 5% increase.

INSERT TABLE 2 AROUND HERE

A Mann-Whitney U test was run to determine if there were differences between the dyslexic group and the non-dyslexic group on each of the error measures. For ease of interpretation, the mean scores for errors are presented in Table 3; although it is noted that the

nonparametric Mann-Whitney U test is based on median scores. Due to multiple tests, a Bonferroni correction was applied to all the results and the alpha level set to .01. There was no significant difference between the two groups on missed words $U = 366, z = -1.02, p = .31, r = 0.13$ or added words $U = 488, z = .88, p = .30, r = 0.11$; however, the groups showed a significant difference on wrong words $U = 274, z = -2.40, p = .01, r = 0.31$ and pronunciation $U = 194, z = -3.63, p < .001, r = 0.47$ with the dyslexic group making more errors than the non-dyslexic group (see Table 2).

Wilcoxon signed rank tests were used to determine whether errors scores were related to the presentation method of the texts for both groups; the alpha level was set to 0.01. For the dyslexia group large letter spacing resulted in a significant decrease in the number of errors made in the missed word category $z = -2.95, p = .003, r = 0.50$ there was no significant reduction in errors for wrong words $z = -.17, p = .86, r = 0.03$, added words $z = -.49, p = .62, r = .09$ or pronunciation $z = .01, p = 1$. None of the comparisons reached significance for the non-dyslexia group: missed words, $z = -2.06, p = .04, r = 0.39$, wrong words, $z = -1.75, p = .08, r = .34$ added words, $z = -1.46, p = .15, r = 0.28$, pronunciation, $z = -.08, p = .94, r = .01$

In relation to coloured overlay, for the dyslexic group none of the error categories reached significance at the alpha level of 0.01: missed words, $z = -1.46, p = .15, r = 0.25$, wrong words, $z = -1.38, p = .17, r = .24$, added words, $z = -.50, p = .62, r = .09$ and pronunciation $z = -2.23, p = .03, r = .39$. The non-significant results were repeated across each error category for the typically developing group: missed words, $z = -2.34, p = .02, r = .45$, wrong words, $z = -.09, p = .93, r = .02$, added words, $z = -.17, p = .87, r = .03$, pronunciation $z = -1.66, p = .10, r = 0.32$.

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Discussion

The study reported in this paper examined whether extra-large letter spacing and coloured overlays improve reading speed and reading accuracy in a small sample of adolescent children with dyslexia. Our findings suggest that extra-large letter spacing increases reading speed in children with and without dyslexia. The percentage increase suggests a more substantial gain in speed for children with dyslexia. In contrast, coloured overlays had no impact on reading speed. Extra-large letter spacing significantly decreased the number of words the dyslexic participants skipped when reading, and this proved a robust finding.

Teaching professionals are often frustrated by absent or conflicting information on how supporting learners with dyslexia (Worthy et al., 2016). When viewed in the context of previous research, our findings strongly suggest that teaching professionals can be confident that both readers with and without dyslexia will benefit from changes in letter spacing in reading materials. The growing body of research reporting the benefits of extra-large letter spacing (Hakvoort et al., 2017; Perea et al., 2012; Sjoblom et al., 2016; Zorzi et al., 2012) should provide confidence in the technique across all ages. Research has now been conducted with readers spanning early childhood through adolescence to adulthood, demonstrating that the positive effect of extra-large letter spacing is developmentally stable. Increasing the spacing between letters in a text is a simple but effective step that educators can take when producing handouts and worksheets. The fact that our research and others (Hakvoort et al., 2017; Sjoblom et al., 2016; Zorzi et al., 2012) show that all readers, regardless of diagnostic status, benefit from this

textual manipulation means that readers with dyslexia need not feel singled out by the introduction of specially adapted reading materials.

A strength of our study was its use of continuous text, which is more commonly faced in everyday life, rather than unrelated sentences as in many previous studies (Zorzi et al., 2012). The results of our study suggest that a reading advantage is still evident in readers with dyslexia when the spacing between letters is enlarged, even when reading material provides the reader with contextual cues and, therefore, makes comprehension easier. Given this finding, printed coursebooks could be made more suitable for readers with dyslexia. At present, dyslexia friendly textbooks tend to focus on colour contrasts and font type to facilitate reading.

We suggest that extra-large letter spacing works by reducing the crowding effect (Martelli et al., 2009), which may hamper the recognition of letters and reduce reading speed. Our results, taken together with previous findings, suggest that crowding has a more significant impact on readers with dyslexia. While both dyslexic and non-dyslexic readers benefited in our study from extra-large letter spacing, the effect of that benefit was considerably higher in the dyslexia group, who showed a 13% increase in reading speed. Similarly, the effect size for the dyslexia group ($d = .30$) was also considerably higher than for the comparison group ($d = .06$).

Colour overlays have been shown to improve reading speed in some developmental disorders (Ludlow et al., 2008). However, with dyslexia, the findings of existing research have not been consistent: some studies have reported no effect or a detrimental effect on reading with the use of colour overlays (Denton & Meindl, 2016; Ritchie, Della Sala, & McIntosh, 2011) while others have reported improvements (Iovino, Fletcher, Breitmeyer, & Foorman, 1998; Williams, Kitchener, Press, Scheiman, & Steele, 2004). Our results suggest that colour overlays do not improve reading speed in children with dyslexia. The poor performance of colour

overlays could be attributed to the fact that we did not distinguish between children with and without visual stress; however, this explanation seems unlikely. Ritchie et al. (2011) reported no improvement in reading speeds in children who were diagnosed with Irlen Syndrome. The use of colour overlays or coloured lenses thus remains controversial.

An examination of errors made by the readers suggests that extra-large letter spacing decreases the number of words missed during reading. Missing words necessarily decreases comprehension and slows the reader down, as they must rescan the text for missing information. In our study, some readers missed a few words in each text while others missed entire lines of text. Research suggests that back scanning (re-reading parts of the text) is a common feature among readers with dyslexia (Kirkby, Webster, Blythe, & Liversedge, 2008; Rayner, 1998). We suggest that missed word errors are a major contributing factor to this phenomenon and that these errors can be reduced with extra-large letter spacing.

The dyslexic and non-dyslexic groups differed significantly in the number of wrong word errors and pronunciation errors made. Wrong word insertion can be subtle in instances when the original word changes in tense or plurality (e.g., '*they were viewed with apathy*' is read as '*they were view with apathy*') or can represent a fundamental error when the word is changed completely with no connection to its original meaning (e.g., '*the great court is completed in November*' is read as '*the great county it complained in November*'). Both changes cause problems for the reader and slow down reading. In addition, changes in tense and plurality often result in a build-up of confusion: as readers progress through the text, they may become puzzled by a past event becoming a present event or by numerical disparities. A complete word change can also bring readers to a halt as the text no longer makes sense. While our study did not find improvements in wrong word errors using either large letter spacing or coloured overlays,

improvements were found for pronunciation errors in the dyslexia group when using overlays. However, it is noted that this result does not remain significant when corrected for multiple comparisons. Presently, there is limited research into the effects colour overlays may have on error reduction in individuals with reading difficulties. Our research points to some key areas that need further investigation.

Limitations

The current study has some limitations that must be addressed in future research. A primary concern is that the reading material in the study was relatively short and could be read within a few minutes. The short reading duration may put colour overlays at a disadvantage as research suggests that their benefits may not become apparent if reading time is less than 10 minutes (Tyrrell, Holland, Dennis, & Wilkins, 1995). Colour overlays may not increase reading speeds, but they may extend reading stamina (i.e., the duration for which a child can read before becoming tired), and more work needs to be conducted in this area. In the present study, we did not test participants for visual stress, which is common in dyslexia (Singleton & Trotter, 2005). Including children in the study who did not have visual stress may have decreased the impact of colour overlays. Future research should also test text comprehension. Our study can conclude that larger letter spacing increases reading speed, but this does not necessarily equate with a greater understanding of the text. Finally, the null results reported in the study need to be interpreted with caution give the relatively small sample size. The small sample size is particularly relevant to the analysis of errors which, due to the applied Bonferroni correction, produce very conservative results. Probably, advantages found with larger letter spacing for the dyslexia group would also be found for the comparison group with a larger sample size.

Conclusion

The results reported in this paper, along with those of previous studies, suggest that extra-large letter spacing can have a beneficial impact on reading speed and accuracy in children with dyslexia. Furthermore, this intervention is relatively simple to implement in the case of self-created teaching materials, and it can be used with readers with and without dyslexia. While we found little impact for colour overlays, we suggest that research evidence in this area is limited and that children should be encouraged to use overlay if they find these help their reading.

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Tables

Table 1 Matching criteria

	Dyslexia Group (n = 32)	Comparison Group (n = 27)	<i>t</i>	<i>p</i>
Age	13y 6m (1.10)	13y 3m (1.35)	.79	.43
RPM	30.53 (6.29)	30.93 (6.38)	.24	.81
BPVS	129 (19)	129 (12)	.26	.98

Standard deviations in parentheses. Raw scores for both the RPM and BPVS are given in the table.

Table 2 Means and Standard Deviations for Reading Speed (syllables read per minute)

	Dyslexia Group	Comparison Group
<u>Reading speed</u>		
Normal spacing	130 (45)	187 (42)
Normal spacing overlay	136 (44)	185 (43)
Large spacing	150 (47)	191 (42)
Large spacing overlay	151 (56)	200 (53)

Table 3 mean error scores across groups and conditions

		Missed words	Wrong words	Added words	Pronunciation
Dyslexia	Normal space	1.63	4.17	0.53	3.63
	Large space	1.17	4.36	0.47	3.59
Non-dyslexia	Normal space	1.43	2.43	0.69	1.59
	Large space	1.04	2.72	0.48	1.61
Dyslexia	No overlay	1.47	4.48	0.53	4.48
	Overlay	1.28	4.04	0.56	4.05
Non-dyslexia	No overlay	1.39	2.48	0.57	2.48
	Overlay	1.03	2.67	0.55	2.67

non-parametric tests were performed using median scores and means are provided in the table for ease of interpretation