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Spacing improves reading in dyslexic children

Indira Madhavan, Sharanjeet-Kaur, Mohd Izzuddin Hairol, Zainora Mohammed

Optometry and Vision Science Programme, Faculty of Health Sciences, Universiti Kebangsaan Malaysia

Abstract

This study investigated the effects of varying spacing between letters, words and lines on reading rate in children with dyslexia. Twenty children with dyslexia, aged 7 to 9 years old, participated in the study. Optimum spacing between letters, words and lines, which improved reading rate, were determined. The stimuli were black lowercase Arial characters presented on a white background, generated and controlled using MatLab (Mathworks, Inc) with Psychophysics Toolbox extension and presented using an Acer Aspire laptop. The optimal inter-letter spacing, inter-word spacing and inter-line spacing were determined in three separate experiments. The results showed that reading rate improved when spacing were made bigger, reaching maximum with spacing of 0.46 deg ($p < 0.001$), 1.14 deg ($p < 0.001$) and 1.21 deg ($p < 0.001$) between letters, words and lines, respectively. Reading rate decreased for spacing larger than these values. We combined all spacing parameters that lead to the fastest reading rate to create an optimised expanded spacing text. We then compared the reading rate measured with the optimised expanded spacing text to that of the default textbook spacing text in the final experiment. There was a significant increment in reading rate with the optimised expanded spacing text compared to default textbook spacing text ($t(19) = -6.49$, $p < 0.001$). The results suggest that increment of spacing between letters, words and lines improve reading rate in children with dyslexia.

Keywords: Dyslexia, Crowding effect, Text spacing, Reading rate

* *Correspondence to:*
Mohd Izzuddin Hairol, Optometry and Vision Sciences Programme, Faculty of Health Sciences, Universiti Kebangsaan Malaysia, Jalan Raja Muda Abdul Aziz, 50300 Kuala Lumpur, Malaysia Email: izzuddin.hairol@ukm.edu.my

Introduction

Developmental dyslexia is the most common learning disability among children (Ziegler, Perry, Ma-Wyatt, Ladner, & Schulte-Körne, 2003) that is neurological in origin (Ambrose & Cheong, 2011). Despite normal intelligence and adequate instruction, dyslexia affects literacy acquisition in 3-5% of school going children worldwide (Gomez & Reason, 2002), where they fail to gain the language skills of reading, writing and spelling. Dyslexia has a strong genetic basis (DeFries & Alarcón, 1996; Shaywitz, 1998; Vellutino, Fletcher, Snowling, & Scanlon, 2004). The prevalence is usually higher in males than females (Pérez, Castro, Álvarez, Álvarez, & Fernández-Cueli, 2012).

Dyslexia is a primary reading disorder characterised by difficulties with accurate and/or fluent word recognition and by poor spelling and decoding abilities (IDA, 2002). It results from a written word processing abnormality in the brain (Shaywitz, 1998). Almost all children with dyslexia show a core phonological deficit (Stanovich, 1988a). One of the key problems in children with dyslexia is reading (Stanovich, 1988b; Wimmer, 1993).

Reading is a complex task involving many visual and linguistic processes, which are fundamental for learning (O'Brien, Mansfield, & Legge, 2005; Wajuihian & Naidoo, 2011). Reading process begins with word learning or code learning (Gough & Hillinger, 1980; Gough, Juel, & Rope-Schneider, 1983). At this stage, readers recognize the pronunciations of the word automatically (LaBerge & Samuels, 1974). The next stage would be to understand the grapheme-phoneme relationship that leads to identification of words (Ehri, 1980, 1984). Finally, reading comprehension, which involves understanding the meaning of words and sentences for efficient reading.

The main challenge in dyslexia is remediation. The most common and successful approach is to devise an educational program that train sub skills of reading, especially phonological skills (Agnew, Dorn, & Eden, 2004; Habib, 2000). Another approach would be to focus on the physical properties of the reading material print itself, where some studies have been done to investigate the effects of manipulation of print size (Cornelissen et al., 1998), font type (O'Brien et al., 2005) and spacing (Martelli, Di Filippo, Spinelli, & Zoccolotti, 2009). The present study pursues this approach, motivated by studies that show that dyslexia is highly affected by crowding phenomena (Atkinson, 1991; Bouma & Legein, 1977; Martelli et al., 2009; Spinelli, De Luca, Judica, & Zoccolotti, 2002).

Crowding is interruptions in target recognition due to closely placed flankers. Jeon, Hamid, Maurer, & Lewis, (2010) reported that crowding phenomena affects children more than adults. It sets a limit on reading by impairing the ability to identify a target in clutter. Placing targets and flankers closely together causes information from both of them to pool together, leading to difficulties in target identification (Yu, Cheung, Legge, & Chung, 2007). This in turn reduces reading speed (Pelli et al., 2007) and reading rate (Falkenberg, Rubin, & Bex, 2007). These difficulties can be abated by enlarging the spacing of the text (Strasburger, Harvey, & Rentschler, 1991).

Previous studies have shown that increment in spacing improves identification (Perea, Comesaña, Soares, & Moret-Tatay, 2012; Perea & Lupker, 2004). Indeed, children with dyslexia need larger letter spacing for better letter identification and reading (Zorzi et al., 2012). Larger letter spacing also reduces the time taken to identify or recognize a word and subsequently improves reading speed (Levi, Song, & Pelli, 2007).

Critical spacing is the minimum spacing between targets (i.e. letters, words, etc.) that leads to maximum reading speed (Chung, 2002). If the spacing is smaller than the critical spacing, two or more targets fall within the critical spacing and crowding ensues. Thus, pooling of targets occurs, rendering them unrecognisable (Whitney & Levi, 2011).

However, other researchers have reported conflicting results on the effects increasing spacing on reading and letter recognition. Van den Boer & Hakvoort (2015) reported that increasing the spacing between letters did not influence word naming fluency in a group of Dutch schoolchildren, including in those who were poor readers. Perea et al. (2012) reported similar findings in adult participants, where increasing spacing did not increase the accuracy of Spanish word naming.

In Malaysian schools, standard textbooks are the compulsory reading material for all schoolchildren, including for children with dyslexia. Currently, the spacing which are being used in Malaysian school textbooks are 1.06 mm for inter-letter spacing, 3.18 mm for inter-word spacing and 4.23 mm for inter-line spacing. However, the suitability of this spacing setting for children with dyslexia is unknown, especially when these are also the reading materials for dyslexic children. Therefore, the present study evaluated the effect of spacing in reading performance, and more specifically, on the reading rate. The study was conducted to determine the optimal inter-letter spacing, inter-word spacing and inter-line spacing as well as to compare reading rate between default Bahasa Malaysia textbook spacing and optimised expanded spacing Bahasa Malaysia text.

Methods

Participants

Twenty children diagnosed with dyslexia and aged between seven to nine (mean: 8.10 ± 0.78 years old) from the Centres of Dyslexia Association Malaysia in the Klang Valley participated in this study. The inclusion criteria were having best corrected visual acuity of 6/6 (logMAR of 0.0), and free from sensory, neurological, systemic or ocular problems. At the time of the study, all participants were in the Dyslexia Centre for a three-month short phonological awareness course which ran for four hours per day five days per week.

The recruited children had just enrolled and had not started the course yet. All children spoke Bahasa Malaysia as either their native or second language. Written consent was obtained from the parents or guardians after thorough explanation of the study nature. The Ethics Committee of University Kebangsaan Malaysia approved this study and the study protocol obeyed the requirement of the Declaration of Helsinki for research involving human participants.

Apparatus

Matlab (version R2012a) with Psychophysics Toolbox extension was used to generate the stimuli. An Acer ASPIRE 4715Z laptop (refresh rate: 60 Hz; resolution: 1280 × 800) was used to display the stimuli. The room illumination ranged between 180-200 lux measured using a photometer (ColorCal, Cambridge Research System, Rochester, UK).

Stimuli

All stimuli were rendered in lowercase Arial font and displayed as black characters (luminance of 0.5 cd/m^2) on a white background (luminance of 115 cd/m^2), resulting in 99.5% Weber's contrast. Except in one condition, font size was fixed at 2.93 mm, subtending 0.42 deg from 40 cm working distance, following the standard Bahasa Malaysia textbook for Malaysian lower primary (age 7 to 9 years).

A pilot study was conducted to select suitable bisyllabic Bahasa Malaysia words as stimuli. Each word contained four to six letters and nine different sets of words were developed. Normal readers between the ages of seven to nine years were asked to read the nine sets of words and the reading rate was measured. The comparability and consistency of reading rate between the word sets for these normal readers were similar ($p>0.05$), that is, the nine sets of words had equal legibility.

The inter-letter, inter-word and inter-line spacing are described in Figure 1 and further elaborated below.

Study Procedures

Three experiments were conducted to obtain the optimal spacing. In Experiment 1, participants read aloud a set of 20 single words displayed on the laptop screen. In this experiment, the four inter-letter spacings were used (default, +1, +2, +3). The viewing distance for default, +2 and +3 spacings was 40 cm. At these distances, the spacing subtended at the angles of 0.15, 0.46, 0.68 deg, respectively. For +1 spacing, the viewing distance was 90 cm, subtending an angle of 0.37 deg. For this particular inter-letter spacing condition, the size of the letters was enlarged sufficiently to maintain the same angular size of the letter (0.42 deg). Figure 1A shows examples of words and inter-letter spacing presented to the participants.

In Experiment 2, participants were asked to read aloud four words displayed in a single line. The inter-letter spacing used for each word was the one that led to the fastest reading time, determined in Experiment 1. Four inter-word spacing were used (+1, +2, +3, +4; see Figure 1B). At 40 cm viewing distance, these were equivalent to 0.68, 0.91, 1.14 and 1.36 deg, respectively.

In Experiment 3, participants were asked to read aloud five lines of words, where there were four words per line. The inter-letter and inter-word spacing used were those that lead to the fastest reading time as determined in Experiments 1 and 2. Four inter-line spacing were used (default, +1, +2, +3; see Figure 1C). At 40 cm viewing distance, these were equivalent to 0.61, 0.91, 1.21 and 1.52 deg, respectively.

a)

0	abad
+1	a b a d
+2	a b a d
+3	a b a d

b)

+1	b a r a a y a m
+2	b a r a a y a m
+3	b a r a a y a m
+4	b a r a a y a m

c)

0	a b a d p o k o k p a k a i a m a n
+1	a b a d p o k o k p a k a i a m a n
+2	a b a d p o k o k p a k a i a m a n
+3	a b a d p o k o k p a k a i a m a n

Figure 1: Examples of bisyllabic Bahasa Malaysia words used in this study.

A. In Experiment 1, four inter-letter spacings were tested, shown for the word abad (century).

B. In Experiment 2, four inter-word spacings were tested while the inter-letter spacing was fixed, shown for the words bara (flame) and ayam (chicken).

C. In Experiment 3, four inter-line spacings were teted while the inter-letter and inter-word spacings were fixed, shown here for the words abad, pokok (tree), pakai (wear) and aman (peace).

Table 1 summarises the inter-spacing conditions tested in this study.

Once the optimal spacing were determined, another experiment was conducted. In Experiment 4, a text of random words was created based on the results of Experiments 1 to 3. The text consisted of five lines with four words in each line. The inter-letter, inter-word and inter-line spacing were fixed at the largest parameter that resulted in the fastest reading time. Another text of random words was also created with the same number of lines and words per lines. For this text, the inter-letter, inter-word and inter-line spacing were the same as those in a standard Bahasa Malaysia textbook for Malaysian lower primary.

Table 1. Summary of inter-word, inter-letter and inter-line spacings used in the study.

Condition	**Physical distance (mm)**	**Angular size (deg)**	**Normalised distance**
Inter-letter (Experiment 1)	1.06	0.15	0 (default)
	5.82	0.37	+1
	3.18*	0.46	+2
	4.76	0.68	+3
Inter-word (Experiment 2)	4.76	0.68	+1 (twice default)
	6.35	0.91	+2
	7.94	1.14	+3
	9.53	1.36	+4
Inter-line (Experiment 3)	4.23	0.61	0 (default)
	6.35	0.91	+1
	8.47	1.21	+2
	10.58	1.52	+3

**Viewing distance for this condition was 90 cm. Other experimental conditions were conducted at 40 cm working distance. When the viewing distance was increased, the stimulus size was also increased proportionately so that the stimulus subtended at an angle of 0.42 deg.*

Each participant underwent two experimental sessions on two consecutive days for each experiment. All participants read eight sets of words (four sets per day) in Experiments 1 to 3 and four texts (two texts per day) in Experiment 4. The same set of 20 words was used for all tested spacing in each experimental session but the arrangement of the words was randomised to minimise learning effects. The experimenter sat beside the participant and recorded the accuracy of the responses. The display time for each stimulus was not limited but participants were encouraged to read aloud the words as quickly as possible. A button press at the end of each session recorded the time taken to read all 20 words. Participants were given breaks of five minutes minimum between each reading sessions. Typically, each daily session lasted for 30 minutes. Eye movements were not restricted.

Reading rate (in words per minute), R, was calculated as:

$$R = {}^{\varepsilon}/_{t}$$

where ε is total number of correctly identified words in a reading session and t is time taken (in minutes) to read the set of 20 words. Final reading rate for each spacing was obtained by averaging the reading rate of session 1 and session 2. Optimal spacing was determined as the spacing that has the maximum reading rate.

Statistical analysis

Repeated measures analysis of variance (ANOVA) was used to compare the mean reading rate between the four different spacings tested in Experiments 1 to 3. Bonferroni's post hoc test was used to determine the optimal spacing, i.e. the spacing that resulted in the significantly highest reading rate.

Paired t-test was used to analyse the difference in mean reading rate between the default textbook spacing text and the expanded spacing text in Experiment 4.

Results

Experiment 1

Figure 2 shows the mean reading rate (in words per minute) as a function of inter-letter spacing. Repeated measures ANOVA results show that the reading rate was significantly affected by the inter-letter spacing, [F(3, 57) = 40.87, (p<0.001). The reading rate reaches maximum at 0.46 deg inter-letter spacing.

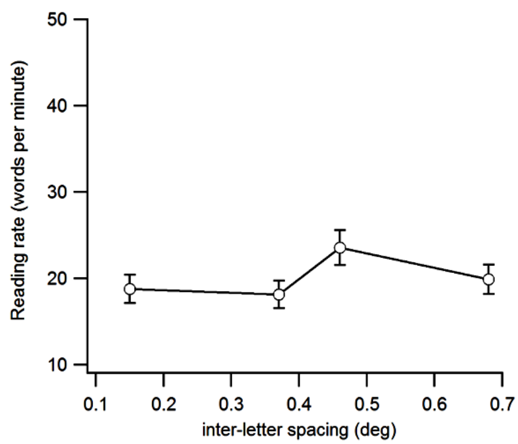

Figure 2: Reading rate, measured in words read correctly per minute, plotted as a function of inter-letter spacing in degrees. Error bars represent ± standard error of the mean (SEM).

Table 2. Mean reading rates and standard errors for different inter-letter, inter-word and inter-line spacings measured in Experiments 1 to 3. Mean reading rate and a standard error for default and expanded texts (Experiment 4) is also compared. Reading rate is in number of words read correctly per minute (wpm).

Experiment	**Spacing**			
1 (Inter-letter)	0.15°	0.37°	0.46°	0.68°
Reading rate (wpm)	18.79±7.38	18.14±7.20	23.57±8.95	19.89±7.73
2 (Inter-word)	0.68°	0.91°	1.14°	1.36°
Reading rate (wpm)	20.48±10.12	21.19±10.05	26.31±12.38	23.45±10.45
3 (Inter-line)	0.61°	0.91°	1.21°	1.52°
Reading rate (wpm)	27.21±12.90	27.25±12.26	32.39±12.67	28.59±12.97
4 (default and expanded texts)	Default		Expanded	
Reading rate (wpm)	24.84±11.26		32.39±12.67	

wpm: words per minute

A Bonferroni's post hoc pairwise comparison analysis reveals significant differences in reading rate between 0.46 deg (+2 spacing) and 0.15 deg (0, default spacing) inter-letter spacing ($p<0.02$). However, reading rate reduces at the largest inter-letter spacing. The mean reading rate for the four inter-letter spacings is presented in Table 2.

Experiment 2

In this experiment, inter-letter spacing was fixed at 0.46 deg (determined from Experiment 1). The optimal inter-letter spacing was equal to the default textbook's inter-word spacing. Therefore, the smallest (hence, default) inter-word spacing was set at 0.68 deg (+1 spacing) to maintain a proportionate appearance of the stimuli. The other inter-word spacing tested was 0.91, 1.14 and 1.36 deg (normalised spacing values of +2, +3 and +4).

As shown in Figure 3, an inter-word spacing of 1.14 deg yields the maximum reading rate (26.31±12.38 ppm). At the largest inter-word spacing (1.36 deg), reading rate reduces. Table 2 shows the mean reading rate for all inter-word spacings tested.

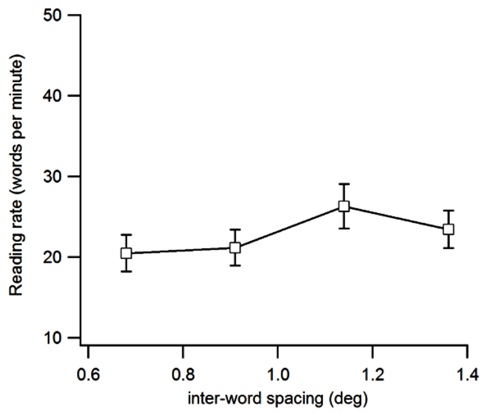

Figure 3: Reading rate (words read correctly per minute) plotted as a function of inter-word spacing (degrees). Error bars represent ± SEM.

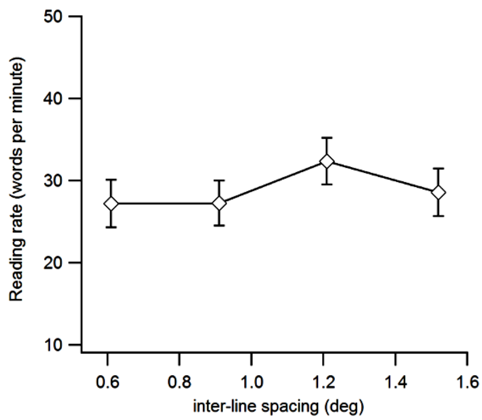

Figure 4: Reading rate (words read correctly per minute) plotted as a function of inter-line spacing (degrees). Error bars represent ± SEM

The effect of various inter-word spacings in reading rate is highly significant [F (1.83, 34.75) = 19.19 (p<0.001)]. A Bonferroni's post hoc pairwise comparison analysis reveals significant differences in reading rate between 1.14 deg (+3) and 0.68 deg (+1) inter-word spacing (p<0.02).

Experiment 3

Reading rate was measured for texts with different inter-line spacing, where the inter-letter and inter-word spacing were fixed at 0.46 and 1.14 deg, respectively, based on the results of Experiment 1 and Experiment 2. Four inter-line spacing were tested: 0.61 deg (default, based on school textbook), 0.91, 1.21 and 1.52 deg, equivalent to inter-line spacing values of 0, +1, +2 and +3.

Figure 4 shows the mean reading rate as a function of inter-line spacing. Inter-line spacing of 1.21 deg results in the highest reading rate, but the largest spacing (1.52 deg) reduces it. The mean reading rate for each inter-line spacing is presented in Table 2.

The effects of increasing inter-line spacing on reading rate is highly significant [F(3, 57) =13.96, p<0.001]. A Bonferroni's post hoc pairwise comparison analysis reveals significant differences in reading rate for 1.21 deg (+2) and 0.61 deg (default, 0) inter-line spacing (p<0.02).

Experiment 4

The inter-letter, inter-word and inter-line spacing were fixed to 0.46, 1.14 and 1.21 deg, respectively, based on the results of Experiments 1 to 3. Reading rate for this optimised expanded spacing text was compared to that obtained with the default textbook spacing text, which had 0.15 deg inter-letter spacing, 0.46 deg inter-word spacing and 0.61deg inter-line spacing.

The mean reading rates for both texts are presented in Table 1 and Figure 5. The reading rate was significantly higher for optimised expanded text [t(19) = -6.49, p<0.001] compared to that obtained with the default textbook spacing text.

Discussion

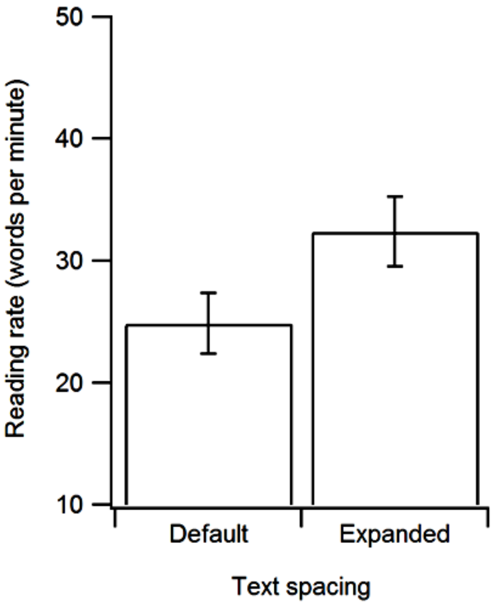

Figure 5: Mean reading rate, in words read correctly per minute, for default text (school textbook spacing settings) and the optimised expanded spacing text. Error bars represent ± SEM.

We found that reading rate improved as the spacing between letters, words and lines were enlarged, to a certain extent, relative to default textbook spacing. This is consistent with our hypothesis that the optimal spacing for children with dyslexia is larger than default textbook spacing. Our findings showed that, for Bahasa Malaysia text, the optimal spacing between letters, words and lines are 0.46, 1.14 and 1.21 degrees, respectively.

Theoretically, there is a crowding zone in the visual field that must be exceeded in order to identify an object when they are placed close together (Pelli, 2008). In our context, this is known as optimal spacing. Identification of letters is difficult for children (Reynolds & Walker, 2004) because letter pooling becomes ambiguous (Kohsom & Gobet, 1997). The time taken to read the words would be longer and mistakes made would be higher as the level of confusion is high. Therefore, reading rate would be lower if the spacing between letters is too small. An increase in inter-letter spacing relative to default textbook spacing shows an improvement in reading rate.

Increased spacing between letters help the process of letter position coding. During letter position coding, letters are coded according to their position in a word before the word is identified (Rumelhart & McClelland, 1982). If letter coding process is disrupted, the word such as casino and caniso is indistinguishable (Perea & Lupker, 2003, 2004). This transposition of letters is a common mistake made by children with dyslexia during reading. As readers have difficulties with letter position coding more than letter identification in a word (Ratcliff, 1981), increasing the spacing between letters ensures smooth and accurate letter position encoding process without the interruption of the neighbouring letters.

During reading, words are segmented into letter components and the signal from each letter component is processed. During this process, spatial attention functions to increase the intensity of the signal of each letter component. However, for children with dyslexia, the spatial attention process is slow and inaccurate (Facoetti et al., 2010; Rayner, Sereno, Morris, Schmauder, & Clifton, 1989; Vidyasagar & Pammer, 2010). Although spatial attention modulates noise removal and optimize the perceptual filter during reading, the process is still slow and sluggish due to crowding. Previous studies have shown that pulling spatial attention to the target by placing a cue next to it improves spatial attention process and reading performance (Huckauf & Heller, 2002). In current study, increasing inter-letter spacing could be the cue for spatial attention in children with dyslexia. Therefore, the increase in stimulus intensity signal occurs more smoothly without the interference of noise from adjacent letter after the removal of crowding effect (Carrasco, Williams, & Yeshurun, 2002). That could be one of the reasons for higher reading rate in optimal spacing, 0.46 deg, compared to standard inter-letter spacing of 0.15 deg.

However, for very wide inter-letter spacing reading rate reduces. Indeed, earlier studies have reported similar findings (Cohen et al., 2003; Cohen, Dehaene, Vinckier, Jobert, & Montavont, 2008; Eriksen & St James, 1986; Lavidor, Ellis, Shillcock, & Bland, 2001; Legge, Mansfield, & Chung, 2001; O'Regan, Lévy-Schoen, & Jacobs, 1983; Reynolds & Walker, 2004; Vinckier, Qiao, Pallier, Dehaene, & Cohen, 2011; Yu et al., 2007). When the inter-letter spacing is too wide, the word cannot be seen as a single unit anymore and is beyond one's visual span (Perea et al., 2012). Although the increase in inter-letter spacing reduces crowding, spacing larger than the optimal spacing causes the word to be physically longer, causing some letters to fall in the peripheral visual field which has low acuity and positional accuracy problem (Yu et al., 2007).

It is postulated that children with dyslexia group letters from the boundaries of neighbouring words incorrectly and automatically reads words from incorrectly grouped letters. Thus, the words read are not correct semantically and synthetically (Epelboim, Booth, Ashkenazy, Taleghani, & Steinman, 1997). Dyslexic children might be able to detect the mistake but still force themselves to spend time figuring out how to correct the errors by trying new grouping of letters. This could be one of the reasons as to why children with dyslexia showed lower reading rate at inter-word spacings 0.68 and 0.91 deg. Reading rate increases and reaches maximum at the optimal inter-word spacing, 1.21 deg. With this inter-word spacing, wrong grouping of letter can be avoided by the larger blank space between the words as the interaction between the beginning and end letters of adjacent words is reduced.

Based on reading model proposed by Morrison (1984), when a word is fixated on the fovea, attention and eyes will be in the same spatial location. At this point, words are processed in detail. When the processing reach at one certain level, attention moves forward to the next word even though the eye fixates at the same location. This is known as parafovea preview. Parafovea processing begins when eye fixates at the first word, say n, while attention moves to the adjacent word, say n+1. Some information about the word n+1 is received at parafovea position before it is fixated using the fovea. Parafovea preview is assumed to speed up the reading since information of the n+1 word is gained from the process (Boden & Giaschi, 2007). Information that is gained from parafovea preview is about the beginning and end letters of adjacent words, word length and word form (Rayner, Inhoff, Morrison, Slowiaczek, & Bertera, 1981). This process could be disrupted by crowding where the indistinguishable boundaries between words might cause a delay in children with dyslexia when processing word information at periphery while reading a sentence with small inter-word spacing. Thus, an increment in inter-word spacing to optimal would optimise the parafovea preview. This is could be another reason why reading rate is maximum at the optimal spacing.

Inter-word spacing larger than the optimal spacing, on the other hand, reduces reading rate. We found that reading rate reduced when the inter-word spacing increased from 1.14 deg (optimal spacing) to 1.36 deg. Similar results have been reported by other researchers (Martelli et al., 2009; Rayner & Duffy, 1986; Rayner et al., 1989; Spinelli, De Luca, Judica, & Zoccolotti, 2002). Inter-word spacing that is too large could result in an increase in time taken to shift one's gaze to identify words located far from the fovea, increasing the possibility of making mistakes in identifying the words. Children with dyslexia might have difficulties in receiving information of adjacent word that is placed too far from fovea where resolution acuity is comparatively low, thus interrupting with word recognition.

Crowding between adjacent words does exist vertically (Bentley, 1921). Reading performance has been shown to improve with additional spaces between vertically adjacent words (Paterson & Tinker, 1932). Our study demonstrated an increase in reading rate as inter-line spacing increased. Yu, Akau, & Chung (2012) reported that increasing inter-line spacing reduces crowding effect, which occurs between vertically adjacent words. When two adjacent lines in a text fall within the same crowding area, the crowding effect would become more prominent. Although we did not test this specifically, small inter-line spacing might cause children with dyslexia to drift their eyes from one line to the next thus breaking their concentration level and disrupting the word identification process. When inter-line spacing is increased, reading rate increases as vertical crowding decreases (Bernard, Anne-Catherine, & Eric, 2007) due to the improvement of the ability of the children to stay on the correct line. An increase in the vertical space between lines of words are known to increase the number of accurate return sweep (Vanderschantz, 2008) and this consequently improves the reading rate.

However, extra-wide inter-line spacing resulted in deterioration in reading rate. It has been reported that the awareness of the extra-wide spacing between lines of words would slow down the word identification process (Götz, 1998). When the next line is further away, readers may become conscious of both line and space between the lines thus disrupting the reading process.

Our results showed that the reading rate was significantly higher among children with dyslexia when reading the optimised expanded spacing text compared with default textbook spacing text (an increase of 30%, $p<0.001$). Previous studies found that the reading performance while reading crowded and tight text is lower (Lefton & Fisher, 1976; Rayner, Fischer, & Pollatsek, 1998). In our case, it is clear that default textbook spacing text was difficult for the children with dyslexia to read fluently because the letters, words and lines were closely spaced. Optimised expanded spacing text, on the other hand, reduced crowding and made reading easier. With this text setting, we can assume that positional accuracy is higher as crowding is eliminated. Parafovea preview process could also have occurred more smoothly, allowing children with dyslexia to navigate eyes from one line to the next line more accurately, thus increasing their overall reading rate.

Comparison with other studies

Our findings clearly show that expanding the spacing between letters, words and lines to certain optimum values help children with learning disabilities, particularly dyslexia, to read faster and to reduce mistakes when recognising words. Other studies have also reported that wider spacing helped sentence reading and word naming in dyslexic children (Martelli et al., 2009; Perea et al., 2012; Zorzi et al., 2012). In normal adults, however, with wider spacing, word naming/sentence reading is either unaffected (Risko, Lanthier, & Besner, 2011; Slattery & Rayner, 2013) or becoming more difficult (Vinckier et al., 2011). Van den Boer & Hakvoort (2015) reported that, for a group of Dutch children identified as poor readers, increasing inter-letter spacing did not benefit their word naming fluency, which is contradictory to the results reported in our study. The difference could be due to the difference in language used for the text. Their poor readers were identified from the One Minute Test (Brus & Voeten, 1995), which may include children with and without dyslexia. In our study, all children had been diagnosed with dyslexia. It is likely that wider spacing helps reading particularly for dyslexic children, but may not help for children who are poor readers without dyslexia.

Conclusions

Our findings show that that spacing in a reading text has an effect on the reading rate in children with dyslexia. Generally, increments in the spacing between letters, words and lines improve reading rate in these children. However, further increases in spacing beyond the optimal spacing reduces reading rate. Overall, our results showed that modification in spacing is an effective way to improve reading in children with dyslexia. These can be implemented in school textbooks that would be beneficial to students with reading disabilities, particularly to children with dyslexia to learn and read like other students. However, further research is needed to confirm the relationship between spacing and eye movement in reading among children with dyslexia.

Declaration of Conflicting Interests

The authors declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

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