Adults with dyslexia show parafoveal preview benefits during silent reading

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ABSTRACT

Readers with dyslexia struggle to read accurately, fluently and efficiently. Their difficulty processing written words in order to read them is often reflected in their eye movement behaviour. The current study was designed to explore parafoveal pre-processing in dyslexic readers, to determine whether dyslexic readers were able to obtain a processing benefit from information presented parafoveally prior to directly fixating it; a robust effect characteristic of skilled adult reading. Twelve skilled adult readers and twelve adults with dyslexia read sixty-four single line sentences, all of which contained a specific target word. The parafoveally presented preview of the target word was from one of four preview manipulations; identical (beach), orthographic (bench), homophone (beech) or random (jfzrp). Once a saccade was made that crossed an invisible boundary directly after the pre-target word this preview changed to the correct target word (beach). The pattern of results suggested dyslexic readers were able to pre-process information parafoveally in a similar manner to skilled readers. Skilled and dyslexic adult readers both received a significant preview benefit from the identical preview compared to all three of the alternative preview conditions. A preview benefit for dyslexic readers was not evident in first fixation duration, but was evident for skilled readers. It was concluded that the lack of preview benefit at first fixation and across the three manipulated preview conditions for dyslexic readers was a result of a global visual attention span deficit. Despite this, dyslexic readers make some use of parafoveal information to increase their reading efficiency, similar to skilled readers.

KEY WORDS:	DYSLEXIA	PARAFOVEAL PROCESSING	READING	EYE MOVEMENTS	VISUAL ATTENTION SPAN

Introduction

Developmental dyslexia affects 5-10% of the population (Stein, 2001), described as a life-time persistent disorder affecting an individual's ability to read (Snowling, 2014). Furthermore, the deficit in reading ability is significantly worse than expected when considering the individuals intelligence quotient (IQ), (Stein, 2001). There has long been a debate concerning the cause of dyslexia, with a number of theories being proposed (Ramus et al., 2003).

One theory is the Phonological Deficit Hypothesis (Ramus et al., 2003; Snowling, 1998), which proposes that weak phonological coding causes the reading impairment seen in dyslexic individuals (Vellutino, Fletcher, Snowling, & Scanlon, 2004). This weak phonological coding is due to difficulty acquiring phonological awareness skills, as a result of poor phonological representations (Vellutino et al., 2004). Poor phonological representations are a deficiency in the ability to use speech and sound codes to represent information in the form of words (Vellutino et al., 2004). There is much evidence supporting this hypothesis, demonstrating dyslexic readers struggle with phonological representations (Dandache, Wouters & Ghesquière, 2014; Farquharson et al., 2014; Ramus et al., 2003).

In contrast, Shaywitz and Shaywitz (2008) argue dyslexia in adulthood is only apparent through a lack of fluent reading rather than difficulty in single word decoding which requires phonological representations, suggesting the Phonological Deficit Hypothesis cannot explain dyslexia in adult readers. Instead Shaywitz and Shaywitz (2008) argue for the role of attentional mechanisms as an explanation for dyslexia in adults.

An attentional mechanisms deficit is supported by the Visual Attention Span Deficit Hypothesis (Bosse, Tainturier, & Valdois, 2007). Visual attention span is defined as the amount of distinct visual information that can be processed in parallel when in a multi-element array (Bosse et al., 2007). It is argued dyslexic readers suffer from a visual attention span deficit and perform significantly worse on visual attention span tasks compared to skilled readers (Lobier, Peyrin, Pichat, Le Bas, & Valdois, 2014). Due to a visual attention span deficit, adults with dyslexia are unable to process as much information in parallel as skilled readers, causing reading difficulties. This deficit is thought to be independent of a phonological deficit (Bosse et al., 2007) and considered the underlying cause for the reading impairment seen in individuals whose impairment cannot be explained by a phonological deficit. For example, Bosse et al. (2007) found visual attention span deficits were apparent in children with dyslexia when controlling for phonological awareness, suggesting the theory provides an alternative explanation for the cause of dyslexia.

A well-established technique used to study the processes involved in reading is to measure a reader's eye movement behaviour. Eye movement data provides information regarding the cognitive processes involved in reading (Liversedge & Findlay, 2000) making it a successful method (Radach & Kennedy, 2013). A reader's eye movement behaviour consists of fixations and saccades; fixations represent when the eye is relatively still and visual information is extracted, while saccades are the movement of the eyes to a different text location (Hyona, 2011). A skilled adult reader's fixations typically average around 250 ms, with their saccades lasting 20-50ms (Schotter, Angele & Rayner, 2012) and averaging 7-9 characters in size (Liversedge & Findlay, 2000). Evidence suggests, dyslexic readers make more and longer fixations as well as shorter saccades, typically 4-7 characters in size (Hawelka, Gagl, & Wimmer, 2010; Rayner, Juhasz, & Pollatsek, 2005). Prado, Dubois, and Valdois (2007) found evidence to suggest the poor visual attention span abilities of dyslexic readers may contribute to their atypical eye movements. Rayner (1998) also argues these differences in eye movement behaviour reflect the processing difficulties dyslexic readers face when reading, making it an effective tool to study the cognitive processes involved in reading across skilled and dyslexic readers.

The visual field available to the eyes can be divided into three areas; foveal, parafoveal and peripheral region (Rayner, 1998). The foveal region corresponds to the central 2° of the visual field around the fixation and has high acuity, while the parafoveal region extends up to 5° of visual angle on either side of the fovea providing less acuity (Rayner, 1998; Schotter et al., 2012). The peripheral region extends further but the acuity declines rapidly (Liversedge & Findlay, 2000). It is well known that during silent reading parafoveal information is used to guide the next saccade (Schotter et al., 2012). While individuals are fixating information within the foveal area they are understood to be already pre-processing information in the parafoveal area, enabling the visual system to guide the next saccade (Rayner, 1998). The extent to which pre-fixated words are processed parafoveally affects the processing of the word when it is later within foveal vision (Schotter et al., 2012).

The amount of processing of the parafoveal word before it is fixated foveally is known as parafoveal preview benefit, because it results in increased processing efficiency when the word is later fixated foveally (Henderson, Dixon, Peterson, Twilley, & Ferreira, 1995). Inhoff, Eiter, and Radach (2005) found extraction of linguistic information from the parafoveal word occurred between 70-140 ms after the onset of the foveal word. Schotter et al. (2012) argue receiving preview benefit may greatly increase the efficiency of reading.

The preview benefit effect is studied using the gaze-contingent boundary paradigm (Rayner, 1975), where an invisible boundary is placed before a target word. The target word represents a chosen preview word, and once the readers' eye crosses the invisible boundary the preview word changes to its correct form. The amount of preview benefit received from any of the preview conditions can be measured by fixation times on the target word, with shorter fixation times representing a preview benefit effect (Schotter et al., 2012). Henderson et al. (1995) argue it is unclear which type of information is integrated across eye movements to produce this benefit.

Research into preview benefit has considered a number of potential sources of information which may produce this benefit, including orthographic and phonological. Studies into the use of orthographic information typically focus on the importance of letter order and identity. Johnson and Dunne (2012) used the gaze-contingent boundary paradigm to show an identical preview (eg. calm) provided the greatest preview benefit. They also showed fixation durations on the target word were longer when the preview of the target contained a substituted letter (eg. chum) compared to a transposed letter (eg. clam). Johnson and Dunne (2012) suggested letter identity is extremely important in parafoveal processing as when letter identity was preserved (identical and transposed conditions) this yielded greater benefit compared to when it was not. This is the same for letter order, with greater benefit being received when letter order is preserved (identical condition). This has been taken as evidence for a language processing system which extracts letter identity information independent to absolute letter position. Similarly in a review of studies concerning parafoveal processing, Schotter et al. (2012) stated having the first two or three letters preserved in the preview facilitates processing of the target word, because the reader can use letter information to initiate the lexical access process. Therefore, it is clear orthographic information can provide a preview benefit for skilled readers.

Researchers have also investigated whether skilled adult readers can obtain phonological information from the parafovea, and whether this information provides a preview benefit. Pollatsek, Lesch, Morris, and Rayner (1992) were one of the first to investigate the use of phonological codes across saccades in reading, by using the gaze-contingent boundary paradigm. Readers were presented with sentences either containing an identical preview of the target word (eg. rains), a homophone preview (eg. reins), a visually similar control (eg. ruins) or a visually dissimilar control (eg. mouse). Pollatsek et al. (1992) used a homophone of the target word, as an earlier study by Rayner, McConkie, and Zola (1980) failed to find a preview benefit using only one initial phoneme.

The pattern of results from Pollatsek et al. (1992) showed the identical preview resulted in the shortest fixation times for both first fixation and gaze duration, compared to all other previews. A significant difference in first fixation duration between the homophone and visually similar control was also found, with fixations following the homophone preview shorter. Gaze duration followed the same pattern but was non-significant. Pollatsek et al. (1992) explained the effects found were not huge but were apparent, concluding that phonological and orthographic information cooperate to provide even more preview benefit than orthographic information alone. Therefore, the preview facilitation is a function of grapheme and phonological overlap. Henderson et al. (1995) explained Pollatsek et al's. (1992) findings support the partial phonological coding hypothesis, which proposes that identification of the first few letters of word n+1 allows activation of the phonological code for the word, reducing the number of potential word candidates to be considered once the preview word is fixated.

Similar results were found by Choi and Gordon (2014) who studied skilled adult readers' eye movements using the gaze-contingent boundary paradigm. They found significant differences in gaze duration for the identical condition compared to the homophone and orthographic conditions. They also found that although non-significant, single and first fixation durations as well as gaze duration were shorter for the homophone preview compared to the orthographic preview. Like Pollatsek et al. (1992), the orthographic preview was matched for visual similarity, providing further evidence to suggest orthographic and phonological information combined provides the greatest preview benefit for skilled adult readers.

Radach and Kennedy (2004; 2013) argue more research needs to explore individual differences in reading development through the use of eye movements. One study which has considered reading skill and parafoveal preview benefit was conducted by Chace, Rayner, and Well (2005). Chace et al. (2005) replicated Pollatsek et al's. (1992) study but considered differences across reading skill, by assigning participants to a more or less skilled reading group based on their results on a standardised reading test. In addition to the conditions described in Pollatsek et al. (1992), a random letter string preview condition (eg. jfzrp) was included as the visually dissimilar control. Consistent with previous findings, Chace et al. (2005) found skilled readers obtained more preview benefit from the homophone preview than the orthographic preview, when considering gaze duration on the target word. However, less skilled readers did not show the same effect and instead showed no preview benefit across all conditions. These results suggest less skilled readers do not show preview benefit effects in the same manner as skilled readers. Chace et al. (2005) suggested this was because less skilled readers are devoting so much attention to processing the fixated word they do not obtain information from the parafovea.

Although, Chace et al. (2005) considered reading skill, research since has found contradictory results when exploring parafoveal processing in readers with and without dyslexia during a rapid automatized naming (RAN) task. Jones, Ashby and Branigan (2013) recorded the eye movements of skilled and dyslexic adult readers while completing a RAN task. They showed dyslexic readers were slower to process the foveal letter when orthographically similar letter information was presented in the parafovea, suggesting dyslexic readers must have been able to process the orthographic information in the parafovea in order for it to cause disruption to foveal processing. However, phonological information in the parafovea did not cause confusion for the dyslexic readers. This suggests it was not possible for the dyslexic readers to process phonological information in the parafovea, perhaps due to the suggestion that dyslexic readers have degraded phonological representations and struggle to process phonological information, supporting the Phonological Deficit Hypothesis.

Jones et al. (2013) also found a lag in the interference from the parafoveal information for the dyslexic readers, in terms of overall slower parafoveal processing. Similarly, Yan, Pan, Laubrock, Kliegl, and Shu (2013) found dyslexic children showed positive preview benefits in a RAN task, suggesting they were effectively using information in their parafovea. However, this was with reduced efficiency compared to skilled child readers. Together these findings cast doubt on Chace et al's. (2005) conclusion that less skilled readers do not pre-process parafoveal information. Instead they demonstrate the possibility that dyslexic readers may be able to show a preview benefit effect, similar to skilled readers but at a reduced efficiency, or a benefit restricted to orthographic information. Following the logic of the Visual Attention Span Deficit Hypothesis the lag in parafoveal processing in dyslexic readers may be due to a deficit in the allocation of attention across a number of elements, which can be processed in parallel during reading (Bosse et al., 2007).

These findings suggest dyslexic readers are able to process information from the parafovea, however this may only be applicable to RAN tasks where the task requires only one letter to be processed at a time. At present there appears to be no studies which have investigated whether adults with dyslexia gain parafoveal preview benefit during silent reading. Furthermore, no studies have explored the type of parafoveal information adults with dyslexia might gain if they do benefit from parafoveal information. Therefore, the current study aimed to investigate whether adults with dyslexia receive preview benefit during silent reading by using the gaze-contingent boundary paradigm which included four preview manipulations replicating the study of Chace et al. (2005). As there is much debate concerning the cause of dyslexia, the current study also aimed to gain a better theoretical understanding of dyslexia by exploring what type of information dyslexic readers are able to pre-process to determine whether dyslexia is a result of a phonological or a visual attention deficit.

Following the logic of Jones et al. (2013) and Pollatsek et al. (1992), it was hypothesised that skilled and dyslexic adult readers would receive a preview benefit, with shorter fixation durations for identical previews compared to random letter string previews. Furthermore, it was predicted there would be a main effect, in terms of reading skill, in that dyslexic readers would have longer fixations and reading times than skilled readers regardless of preview condition. It was also predicted fixation times on the target word would differ depending on whether it followed orthographic or homophone previews. In particular, an interaction was predicted in that, the dyslexic readers would gain a greater pre-processing benefit from the orthographic previews compared to the homophone previews, as according to the Phonological Deficit Hypothesis dyslexic readers struggle with phonological information. While the skilled readers would benefit greater from the homophone previews compared to the orthographic previews.

Method

Design

A 2x4 repeated measures ANOVA design was used. There were two independent variables; reading skill, which had two levels – skilled or dyslexic readers, and preview condition, which had four levels - identical, orthographic, homophone and random. The dependent variables were gaze, first fixation and single fixation duration. Gaze duration is the sum of all fixations on the target before the eye leaves the target, while first fixation duration is the duration of the first fixation on the word (Pollatsek et al., 1992). Single fixation duration is the duration of the fixation when there is only one (Rayner, 1998).

Participants

Twelve adults with dyslexia (Mean age= 22.25, SD= 5.97) and twelve skilled adult readers participated (Mean age= 20.33, SD= 1.30). All participants were students at Bournemouth University recruited through Bournemouth University's Psychology Research Participation website, in which Psychology students volunteered in return for course credits. Adults with dyslexia were recruited through Additional Learning Support at the university, in which students volunteered to take part. All adults with dyslexia had a formal diagnosis from the university or their previous place of education. All participants were native English speakers with normal or corrected to normal vision.

Apparatus

Participants' eye movements were recorded using an SR Research Eyelink 1000+ eye tracker, which had a sampling rate of 1000Hz. Viewing was binocular, however, only data from the right eye was recorded. Participants sat at a viewing distance of 66cm from a Lacie Electon 22 Blue IV monitor with a screen resolution of 1280 x 1024 and refresh rate of 160 Hz. Participants read sentences from the monitor presented in black Courier New font, size 14, on a white background, while their head was placed on a chin and forehead rest.

Stimuli

The stimuli consisted of sixty four single-line sentences taken from Chace et al. (2005). Each sentence contained a target word from a possible four preview conditions; 1) identical to the target word, 2) an orthographic control word, 3) a homophone of the target word or 4) a random string of consonants (see Table 1 for an example).

Each of the 64 target words were embedded in a sentence made up of no more than 80 characters. The sentence appeared on a single line and contained both a pre-target and a target word. The pre-target word was a 5-8 character low frequency word (M= 28.34, SD= 25.20). These characteristics were selected to increase the likelihood of the participant fixating the word. Target words were 4-6 characters and were matched for frequency across all conditions containing a real word preview (Kucera & Francis, 1967; Francis & Kucera, 1982): Identical (M= 34.23 SD= 54.52), Homophone (M= 48.94 SD= 148.34), Orthographic (M= 64.28 SD= 156.53). These three conditions were matched for orthographic overlap, in that when the homophone condition shared the same first two letters then the orthographic control condition did also. All but five of the target words were one syllable in length.

Table 1

Example sentence from each preview condition

Condition	Sentence
Identical	Many students look forward to graduate **week** as a favourite tradition.
Orthographic	Many students look forward to graduate **well** as a favourite tradition.
Homophone	Many students look forward to graduate **weak** as a favourite tradition.
Random	Many students look forward to graduate **xwrq** as a favourite tradition.

The target word appeared after the pre-target word, and directly after an invisible boundary. Once the reader's eyes crossed the boundary, the target word was replaced with the correct presentation of the word. Four randomised experimental lists were constructed; each list contained a different version of the target word for each sentence. Participants saw 64 sentences, 16 sentences from each preview condition.

As the sentences were taken from Chace et al. (2005) they were piloted on thirteen skilled adult readers to ensure they were understandable and coherent. Each participant was asked to tick yes or no as to whether the sentences made sense or not (see Appendix A). Any sentences that scored over 50%, in terms of 'does not make sense' were altered or removed. This meant that one pre target word was altered in one sentence (eg. from senior to graduate), while one sentence was completely changed, however the target word remained. (see Table 2).

Table 2

Example of the altered sentence

Condition	Original Sentence	Altered Sentence
Identical	Alison wrinkled her nose at the taste of sour beet in the dinner salad.	Alison tried to listen to the quick beat of the music.
Orthographic	Alison wrinkled her nose at the taste of sour beak in the dinner salad.	Alison tried to listen to the quick beak of the music.
Homophone	Alison wrinkled her nose at the taste of sour beat in the dinner salad.	Alison tried to listen to the quick beet of the music.
Random	Alison wrinkled her nose at the taste of sour qzsj in the dinner salad.	Alison tried to listen to the quick qzsj of the music.

Materials

In addition to the eye tracking task, participants took part in a number of tests which are detailed below.

Visual Attention Span Task

Participants carried out a global and partial letter report task to assess their visual attention span abilities. Stimuli were random 6-consonant letter strings presented in black upper case letters, Courier New font, size 26 on a white background. At the start of each trial, a central fixation point was displayed for 1000ms followed by a blank screen for 50ms. The horizontal 6 letter consonant string was presented for 200ms, in the same position as the central fixation point. In the global task, participants were asked to report all letters they had seen with no time pressure. The task included ten training trials and twenty four experimental trials. The score for the global task was the number of accurately reported letters, regardless of order, making the maximum score 144. In the partial task, participants were asked to report the cued letter from the letter string. The task included ten training trials and seventy two experimental trials. At the onset of the string the cued letter appeared underlined for 50ms. The score for the partial task was whether the cued letter was accurately reported making the maximum score 72. Participants only received feedback for the training trials.

Stimuli for the training trials were consonant strings built up from ten consonants (CGJKQVXYZF), while stimuli for the experimental trials were consonant strings built up from twelve different consonants (BPTFLMDSRHWN). In the global task each letter was used twelve times and appeared twice in each position. In the partial task each letter was cued six times. During the task participants sat in front of the computer screen at a viewing distance of 66cm. In both tasks each letter subtended a visual angle of 0.43°, with the visual angle between each letter 0.43°. The visual angle of the whole consonant string was 4.73°. The above specifications of the visual span task were selected based upon previous research (Lallier et al., 2010; Lobier et al., 2014; Valdois et al., 2014).

IQ test

Participant's IQ was measured using the Wechsler Abbreviated Scale of Intelligence (WASI; Wechsler, 1999). The two subtests version of the WASI was conducted using the vocabulary subtest and matrix reasoning subtest.

Test of Word Reading Efficiency

The Test of Word Reading Efficiency (TOWRE; Rashotte, Torgesen & Wagner, 1999) was used to test participant's word reading accuracy and fluency to determine overall reading ability. The TOWRE consisted of two subtests; the Sight Word Efficiency test where participants were given 45 seconds to identify out loud real printed words and the Phonetic Decoding Efficiency test where participants were given 45 seconds to identify out loud pronounceable printed non-words.

Comprehensive Test of Phonological Processing

The Comprehensive Test of Phonological Processing – Second Edition (CTOPP-2; Wagner, Torgesen, Rashotte, & Pearson, 2013) was used to assess participants phonological processing abilities. The phonological awareness composite score comprising of the elision, blending words and phoneme isolation subtests, and the RAN composite score comprising of the rapid digit naming and rapid letter naming subtests, were taken.

These specific measurements were taken as Kuperman and Van Dyke (2011) noted individual scores in RAN and word identification tests are the most reliable predictors of reading ability and eye movement patterns. Kuperman and Van Dyke (2011) also showed components of the phonological composite score are predictive of early eye movement measures. This is in addition to phonological processing deficits (Vellutino et al., 2004) and a visual attention span deficit (Lobier et al, 2014) considered to be responsible for the poor reading outcomes seen in dyslexic individuals.

Procedure

Participants were briefed about the study via an information sheet (see Appendix B) as well as a verbal briefing to ensure participants were aware of the procedure. If participants agreed to take part they were asked to complete a consent form (see Appendix C). Participants first took part in the visual attention span task. This took approximately fifteen minutes, after which participants were offered a break before continuing. Participants then took part in the IQ, TOWRE and tests of phonological processing, which took approximately thirty minutes and again participants were offered a break. The final part involved the eye tracking task. Before participants began, the eye tracker was set up to ensure the camera was able to track the participants' eye and participants were sitting comfortably with their head on the chin and forehead rest. Participants were given verbal instructions of what the task would involve and were made aware that if they wished to have a break at any point they should inform the researcher when the black fixation dot was on the screen. The eye tracker was calibrated in which participants viewed dots in three screen locations, representative of where the sentence would appear. The validity of these eye positions was checked and validation was accepted if the error was 0.2° or lower. Validation of the readers eye position was also accepted prior to the initiation of each sentence, by asking the participant to fixate on a fixation dot before each sentence appeared. If the calibration was not valid the eye tracker was recalibrated. When validation was accepted the researcher allowed the sentence to appear. Participants were instructed to silently read the sentences at their own pace and press a button on a control pad once they had finished. A comprehension question appeared after sixteen of the sentences. Participants either answered yes or no through a button on the control pad. Participants read a total of ten practice sentences and sixty four experimental sentences, lasting around twenty five minutes. Once the participants had finished the eye tracking task they were asked if they noticed anything unusual while reading the sentences, with any responses being noted on a record sheet (see Appendix D). Before leaving, participants were given a written debrief form (see Appendix E) and the opportunity to ask questions.

Results

Reading Measures

Mean scores were obtained for participants' results in the IQ, RAN, TOWRE, phonological awareness (PA) and visual attention span measures. Independent t-tests were used to examine any significant differences in the scores between the two groups (see Table 3 below).

Table 3

Mean scores and standard deviations (presented in parenthesis) from the reading tests for skilled and dyslexic readers, as well as the t-test results

	Dyslexic Readers	Skilled Readers	T-Test Result
IQ	105.08 (9.91)	107.00 (10.70)	*t*(22)= -.46, *p*= .65
TOWRE	84.50 (13.60)	97.42 (12.27)	*t*(22)= -2.44, *p*= .02
RAN	79.08 (18.76)	102.92 (10.15)	*t*(22)= -3.87, *p*=.001
PA	89.42 (9.34)	93.25 (15.03)	*t*(22)= -.75, *p*= .46
Global VA	68.17 (20.66)	88.67 (20.77)	*t*(22)= -2.42, *p*= .02
Partial VA	60.50 (8.42)	64.08 (3.15)	*t*(22)= -1.38, *p*= .18

There was no significant difference in IQ scores for the two reading groups, with both groups falling within the normal range (IQ>90). However, dyslexic readers performed significantly worse than skilled readers on the TOWRE, RAN and the global report of visual attention span. There were no significant differences in performance on the phonological awareness task or report of partial visual attention span, between the two groups.

Eye Movement Measures

The eye movement data was cleaned to exclude fixations less than 80ms or more than 1200ms, this represented 5.74% of the data. Trials were excluded based on the following criteria; 1) the boundary was triggered prior to a saccade being made across the boundary, 2) the display change completed more than 10ms after fixation landed on the target word, 3) the end of a saccade briefly crosses the boundary, but ended up landing before the boundary, 4) participants blinked on the pre-target and/or target word. In total 646 trials were removed representing 23.78% of the data (this is typical for studies of this kind, see Chace et al., 2005).

Global Analysis

Global measures were taken including; total reading time, average fixation duration and fixation count for both dyslexic and skilled readers, which are presented below in Table 4.

Table 4

Mean scores and standard deviations (presented in parenthesis) for total reading time, average fixation duration and number of fixations for dyslexic and skilled readers

	Dyslexic Readers	Skilled Readers	T-Test Result
Total Time	4875 (2224)	3404 (840)	$t(14)= 2.14$, $p= .05$
Fixation Duration	250 (47)	239 (26)	$t(22)= .75$, $p= .46$
Fixation Count	18.04 (7.14)	13.50 (2.55)	$t(22)= 2.08$, $p=.05$

The global analysis indicates dyslexic readers require a significantly longer total reading time and make significantly more fixations than skilled readers across the whole sentence. However, although the dyslexic readers had a slightly longer average fixation duration (M=250, SD=47) than skilled readers (M=239, SD=26), it was not significantly longer.

Target Word Analysis

Further analysis concentrated on the target word; specifically gaze duration, first fixation duration and single fixation duration across all preview conditions. Table 5 represents the descriptive data for the target word across the four conditions for both reading groups.

Table 5

Mean gaze, first and single fixation duration for the target word in milliseconds and standard deviation (presented in parenthesis), as a function of preview condition and reading group

Gaze Duration

A Shapiro-Wilk test showed the identical condition was normally distributed for dyslexic readers (p =.451) and skilled readers (p= .313). The orthographic condition was not normally distributed for dyslexic readers (p= .021), but was normally

	Preview Type			
	Identical	Orthographic	Homophone	Random
Gaze Duration				
Dyslexic	317 (107)	348 (129)	341 (101)	339 (116)
Skilled	279 (60)	318 (71)	313 (72)	333 (85)
First Fixation				
Dyslexic	266 (72)	313 (121)	294 (94)	288 (90)
Skilled	245 (38)	271 (62)	269 (51)	299 65)
Single Fixation				
Dyslexic	276 (77)	329 (138)	310 (95)	306 (99)
Skilled	253 (45)	285 (74)	289 (63)	322 (93)

distributed for skilled readers (p= .314). The homophone condition was normally distributed for dyslexic readers (p= .930) and skilled readers (p= .503). The random condition was not normally distributed for dyslexic readers (p= .012) but was normally distributed for skilled readers (p= .736). As not all of the data conforms to the parametric statistical assumption of normal distribution the findings must be treated with caution.

Between groups homogeneity of variance was not met for the identical condition (p= .030) but was met for the orthographic condition (p= .308), homophone condition (p= .353), and random condition (p= .677). Although homogeneity of variance was not met for all conditions, there were equal group sizes across conditions. Sphericity of within-groups variance was not assumed (p= .030), therefore Greenhouse-Geisser was referred to in the ANOVA output.

A 2x4 repeated measures ANOVA indicated there was no significant effect of reading skill on gaze duration, $F(1,22)$= .501, p= .486, η^2_p= .022. However, there was a significant effect of preview condition on gaze duration, $F(2.31,50.89)$= 4.81, p= .009, η^2_p= .180. Bonferroni post-hoc tests revealed significantly shorter fixations for the identical compared to the orthographic preview (p= .024) and homophone (p= .002) preview, as well as marginally significant shorter fixations for the identical compared to the random preview (p= .063), see Figure 1. There was no significant difference in gaze duration for the orthographic preview compared to the homophone (p= 1.00) and random preview (p= 1.00) or for the homophone compared to the random preview (p= 1.00). There was no significant interaction between preview condition and reading skill, $F(2.31,50.89)$= .724, p= .509, η^2_p= .032.

A post-hoc power analysis produced an effect size of 0.15 and a power of 0.12 for between groups and an effect size of 0.47 and power of 1.00 for within groups. A sample size of 26 participants would be needed for the between group effect to achieve a power of 0.80.

First Fixation Duration

A Shapiro-Wilk test showed the identical condition was not normally distributed across dyslexic readers (p= .045), but was normally distributed across skilled readers (p= .868). The orthographic condition was normally distributed across dyslexic (p= .055) and skilled readers (p= .383). The homophone condition was not normally distributed across the dyslexic group (p= .020) but was normally distributed across skilled readers (p= .856). The random condition was not normally distributed across dyslexic readers (p= .032), but was normally distributed across skilled readers (p= .180). As not all of the data conforms to the parametric statistical assumption of normal distribution the findings must be treated with caution.

Between groups homogeneity of variance was met for all preview conditions; identical (p= .152), orthographic (p= .086), homophone (p= .256) and random (p=.379). Sphericity of within-groups variance was also assumed (p= .334).

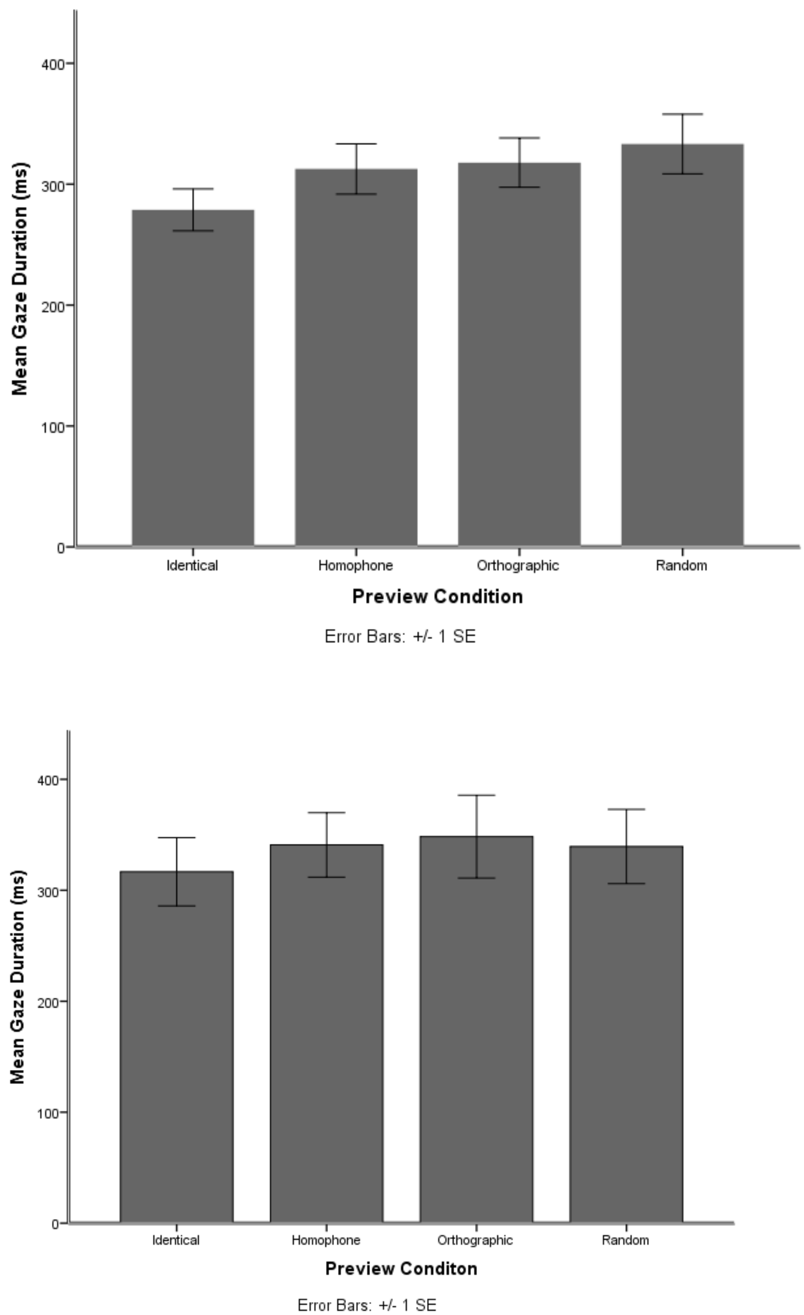

Figure 1: Mean gaze duration (ms) on the target word across preview conditions for skilled (top) and dyslexic readers (bottom), with standard error bars

A 2x4 repeated measures ANOVA indicated there was no significant effect of reading skill on first fixation duration, $F(1,22)= .418$, $p= .525$, $\eta^2_p= .019$. However, there was a significant main effect of preview condition on first fixation duration, $F(3,66)= 6.89$, $p <.001$, $\eta^2_p= .238$. Bonferroni post hoc tests revealed significantly shorter fixations for the identical preview compared to the orthographic ($p= .020$), homophone ($p= .010$) and random preview ($p <.001$), see Figure 2. There was no significant difference in first fixation duration for the orthographic preview compared to the homophone ($p=$

1.00), and the random preview (*p*= 1.00) or for the homophone compared to the random preview (*p*= 1.00).

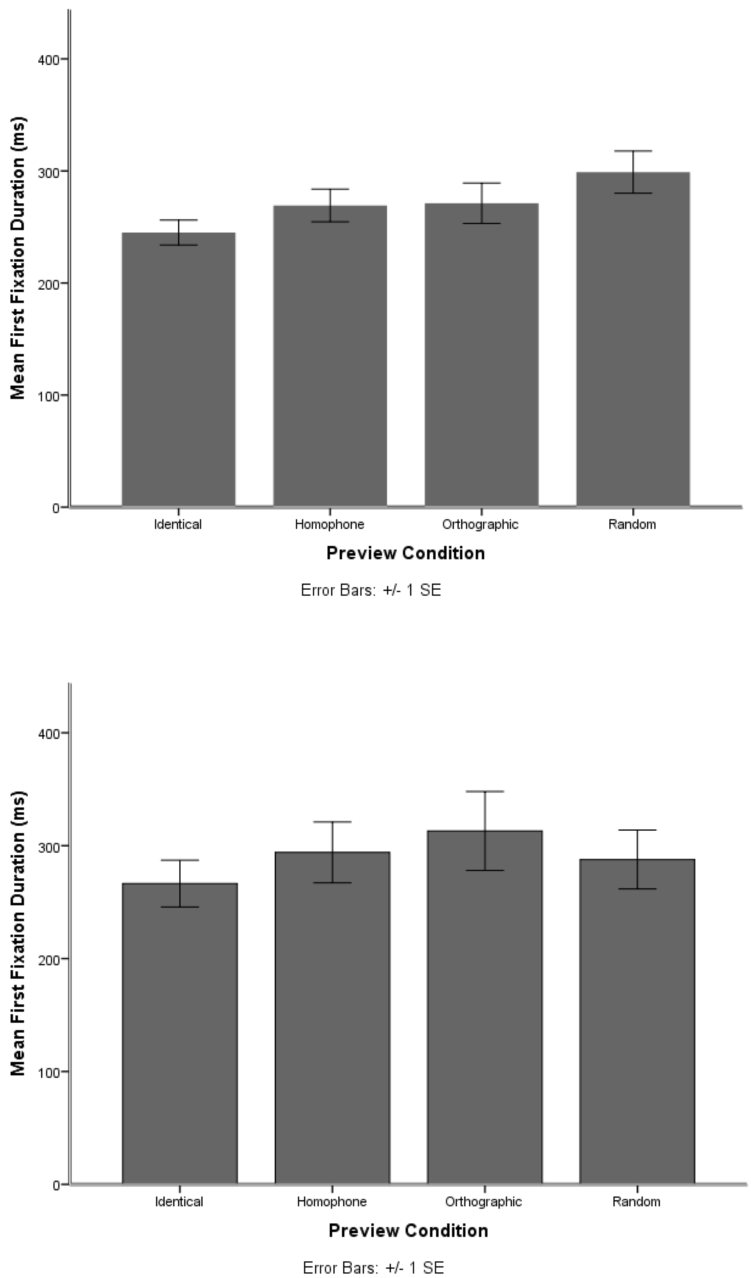

Figure 2: Mean first fixation duration (ms) on the target word across preview conditions for skilled (top) and dyslexic (bottom) readers, with standard error bars

The ANOVA indicated there was a significant interaction between reading skill and preview condition, $F(3,66) = .277$, $p = .048$, $\eta^2_p = .112$. Further examination indicated dyslexic readers did not show a significant benefit in first fixation durations for the identical preview compared to the orthographic ($t(11) = -.254$, $p = .028$), homophone (*t*(11)= -2.09, *p*= .061) or the random preview (*t*(11)= -2.06, *p*= .064). However, skilled readers did show a significant benefit in first fixation durations for the identical compared to the homophone (*t*(11)= -4.10, *p*= .002) and random preview (*t*(11)= -4.28, *p*= .001). There was no significant difference in benefit received from the identical compared to the orthographic preview (*t*(11)= -2.15, *p*= .055) for skilled readers.

A post-hoc power analysis produced an effect size of 0.14 and a power of 0.11 for between groups and an effect size of 0.56 and a power of 1.00 for within groups as well as an effect size of 0.36 and a power of 1.00 for the between-within group interaction. A sample size of 26 participants would be needed for the between group effect to achieve a power of 0.80.

Single Fixation Duration

A Shapiro-Wilk test revealed the identical condition was normally distributed across dyslexic (*p*= .125), and skilled readers (*p*= .630). The orthographic preview condition was not normally distributed across the dyslexic group (*p*= .022) but was normally distributed across skilled readers (*p*= .352). The homophone preview condition was normally distributed across dyslexic (*p*= .105) and skilled readers (*p*= 1.00). The random condition was also normally distributed across dyslexic (*p*= .062) and skilled readers (*p*= .335). As not all of the data conforms to the parametric statistical assumption of normal distribution the findings must be treated with caution.

Between groups homogeneity of variance was met for all preview conditions; identical (*p*= .153), orthographic (*p*= .132), homophone (*p*= .263) and random (*p*=.644). Sphericity of within-groups variance could not be assumed (*p*= .025), therefore Greenhouse-Geisser was referred to in the ANOVA output.

A 2x4 repeated measures ANOVA indicated there was no significant effect of reading skill on single fixation duration, *F*(1,22)= .292, *p*= .594, η^2_p= .013. There was a significant main effect of preview condition on single fixation duration, *F*(2,53)= 6.03, *p*= .003, η^2_p= .215. Bonferroni post-hoc tests revealed significantly shorter fixations for the identical preview compared to the orthographic (*p*= .026), homophone (*p* <.001) and the random preview (*p* =.005), see Figure 3. There was no significant difference in first fixation durations for the orthographic preview compared to the homophone (p= 1.00), or the random preview (*p*= 1.00) or for the homophone compared to the random preview (*p*= 1.00). The ANOVA also indicated no significant interaction between reading skill and preview condition, *F*(2,53)= 1.91, *p*= .152, η^2_p= .080.

A post-hoc power analysis produced an effect size of 0.11 and a power of 0.16 for between groups and an effect size of 0.52 and a power of 1.00 for within groups. A sample of 62 participants would be needed for the between group effect to achieve a power of 0.80.

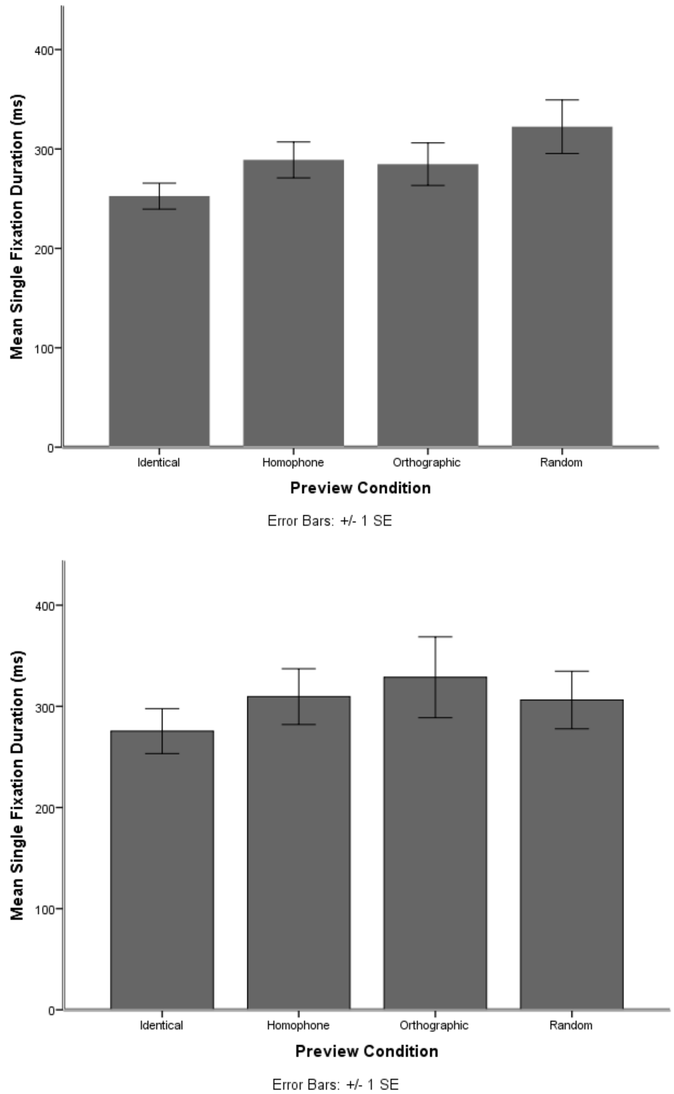

Figure 3: Mean single fixation duration (ms) on the target word across preview conditions for skilled (top) and dyslexic (bottom) readers, with standard error bars

Discussion

The present study explored the differences in the eye movement patterns of skilled adult readers and adults with dyslexia. Specifically, the study examined whether dyslexic readers receive a preview benefit from parafoveal information in a similar manner to skilled readers. The study aimed to replicate the finding that skilled readers receive a greater preview benefit from a homophone preview than an orthographic preview (Chace et al., 2005; Pollatsek et al., 1992) as well as determine whether dyslexic readers show a difference in the amount of preview benefit received between an orthographic and homophone preview. Less benefit was predicted from a homophone preview as dyslexic readers are thought to suffer from a phonological deficit (Ramus et al., 2003).

The results showed dyslexic readers exhibited different patterns of eye movements to skilled readers; such as longer total reading times and more fixations. The results also showed both dyslexic and skilled readers were able to pre-process information parafoveally and receive a significant preview benefit from the identical preview. However, when exploring parafoveal processing in more detail, the study did not find a difference in the amount of preview benefit received between a homophone, orthographic or random preview across both reading groups.

To explore the differences in the eye movement patterns of skilled and dyslexic readers, the study examined global eye movement measures. Similar to previous research from Hawelka et al. (2010), dyslexic readers had significantly longer total reading times and a significantly larger number of fixations across the sentence compared to skilled readers. There were also group differences in the reading measures taken, namely; the TOWRE, RAN, and global report of visual attention span. However, the two groups did not significantly differ on measures of phonological awareness or partial report of visual attention span. The differences in the global eye movement measures across the two groups suggest a difference in the eye movements of dyslexic and skilled readers during reading, with dyslexic readers showing longer and more effortful processing. The differences in the eye movements of the dyslexic readers may be explained by the poor performance on the global report of visual attention span. This supports Prado et al's. (2007) assumption that poor visual attention span abilities of dyslexic readers contributes to their atypical eye movements, as during reading dyslexic readers find it difficult to increase their visual attention span.

Together, the global eye movement measures and measures of reading ability suggest there are differences between the two reading groups, as suggested by previous research (Hawelka et al., 2010; Lobier et al., 2014; Shaywitz & Shaywitz, 2008). In contrast, the data did not provide evidence for group differences in gaze and single fixation duration on the target word, suggesting dyslexic readers are able to process parafoveal information in a similar manner to skilled readers. However, a power analysis indicated there was extremely low power for the between group effect, and therefore it cannot be completely disregarded that there is no difference in viewing durations on the target word between skilled and dyslexic readers. Rather, a larger sample size; 26 for gaze and 62 for single fixation duration is needed to allow for a more reliable conclusion regarding whether skilled and dyslexic readers differ in their viewing durations on the target word.

A main effect of preview condition was apparent for gaze and single fixation duration. For both measures, the identical preview provided a significantly greater preview benefit, with shorter durations, compared to all other preview conditions. This effect occurred for both skilled and dyslexic readers, suggesting both groups are able to efficiently make use of information in the parafovea, supporting the study hypothesis. The finding that skilled adult readers receive preview benefit is in line with previous research (Chace et al., 2005; Johnson & Dunne, 2012; Pollatsek et al., 1992). However, the finding that adults with dyslexia exhibit a parafoveal preview benefit goes against previous research from Chace et al. (2005), which found less skilled readers did not receive parafoveal preview benefit.

On further examination, the results showed there were no significant differences in the preview benefit received across the remaining preview conditions; orthographic, homophone and random, for either group. The finding that skilled readers did not receive a significant preview benefit from the homophone condition over the orthographic condition is an unexpected result and is not in line with the study hypothesis or previous research (Chace et al., 2005; Pollatsek et al., 1992).

Previously, Pollatsek et al. (1992) showed first fixation durations following the homophone preview were significantly shorter than those following the visually similar preview, for skilled readers. Similarly, Chace et al. (2005) found the same significant result when considering gaze duration on the target word for skilled readers. When concluding on their results, Pollatsek et al. (1992) explained the effects were not large but were apparent, even suggesting they were not expecting to find an effect even if there was one, because an orthographic preview alone provides a large preview benefit (Johnson & Dunne, 2012), therefore does not leave much room to observe a homophony effect also.

It is therefore clear that finding a significant homophony effect in skilled readers is difficult. For example, Pollatsek et al. (1992) did not find a significant effect when considering gaze duration, Chace et al. (2005) when considering first fixation duration and Choi and Gordon (2014) when considering gaze, first and single fixation duration. Although, the studies did find a trend in fixation durations across the preview conditions in support of the homophony effect. This suggests the homophony effect is so small it is difficult to find a significant result even if there is a trend to suggest one, which may be the case in the current study. The present findings for skilled readers; mean fixation durations for gaze, first and single fixation duration, follow the same trend found by Pollatsek et al. (1992), however are non-significant. Consequently, it cannot be concluded skilled readers do receive a greater preview benefit from a homophone preview which is matched for visual similarity compared to an orthographic preview. Rather, there is no difference in the amount of preview benefit received between an orthographic and a homophone preview for skilled readers.

Thus far the discussion of results has focused on the findings from single and gaze duration as both measures displayed similar patterns of results. However, the results for first fixation differ to those found for single and gaze duration. An interaction was found between reading skill and preview condition for first fixation duration. Analysis of the interaction indicated at first fixation dyslexic readers showed no significant evidence of receiving a preview benefit, across any preview condition. However, skilled readers did show significant evidence of receiving preview benefit, with the identical preview providing a significant preview benefit over the homophone and random preview. There was no significant difference in the preview benefit received between the identical and orthographic preview for the skilled readers, however when considering previous research surrounding parafoveal processing and preview benefit

(Johnson & Dunne, 2012; Schotter et al., 2012) this finding seems particularly unusual and may therefore not be a meaningful result.

An interesting finding from the study is that for gaze and single fixation duration the dyslexic readers showed a significant preview benefit effect. However, at first fixation duration they showed no significant preview benefit effect. Gaze duration and first fixation duration are the most commonly used measures in eye movement research as they yield similar results (Radach & Kennedy, 2013; Rayner, 1998). However, the current findings suggest this is not the case when considering dyslexic readers. Although the two measures produce similar results across skilled readers (Rayner, 1998), they tap different stages of lexical processing. First fixation duration is related to early orthographic processing while gaze duration is related to later stages of word processing such as lexical access (Radach & Kennedy, 2013). Therefore, the current findings may suggest a processing delay for dyslexic readers, in terms of parafoveal processing, due to a struggle with early stages of orthographic word processing, resulting in no preview benefit effect at first fixation.

It can be argued single fixation duration, which represents complete processing of the word in a single fixation (Rayner, 1998), signifies a similar stage and time frame of lexical processing as first fixation duration. Therefore, one would not expect a difference between the two measures. The difference in the current study may be explained by the low power of the between group effect for single fixation duration, with 62 participants needed to make a more reliable conclusion. Rayner (1998) also argues the inclusion of single fixation duration as a measure can sometimes lead to the elimination of too much data because many words are fixated more than once or skipped altogether. Therefore, this may explain the differences in results for this measure in comparison to first fixation duration.

Another interesting finding is that dyslexic readers showed no deficit in phonological awareness, performing similarly to skilled readers on phonological awareness tasks. This is in line with Shaywitz and Shaywitz (2008) and suggests by adulthood dyslexic readers have overcome their difficulty with phonological processing, questioning the Phonological Deficit Hypothesis (Ramus et al., 2003; Snowling, 1998). This idea is also apparent due to the descriptive finding that fixation durations for dyslexic readers were always shorter in the homophone condition compared to the orthographic condition, for gaze, first and single fixation duration, suggesting dyslexic readers may not struggle with phonological processing. Although this suggestion is based upon descriptive results as the homophone preview did not provide a significant preview benefit. Instead, the results would suggest dyslexic readers suffer from a visual attention span deficit, apparent through significantly worse performance on the global report of visual attention span, supporting the Visual Attention Span Deficit Hypothesis (Bosse et al., 2007).

The results showed dyslexic readers performed significantly worse on the global report of visual attention span compared to skilled readers, but performed similarly to skilled readers on the partial report task. This suggests dyslexic readers may have a deficient visual attention span which does not allow them to process information in a global mode (Prado et al., 2007). In the current study this may explain why dyslexic readers were unable to receive a significant preview benefit from the homophone preview. The dyslexic readers may only be able to process information in an analytical mode and thus cannot process a multitude of information in parallel at once. The homophone preview condition was matched for homophony across the whole word therefore would have to have been processed in global mode to gain a significant benefit. As the dyslexic readers have a deficient global visual attention span this may explain why they did not receive a significant benefit from the homophone preview.

However, it was predicted dyslexic readers would receive a greater preview benefit from the orthographic preview than the homophone preview. Analysis of the results suggests the orthographic preview seemed to provide the least preview benefit, although this is only a trend not a significant result. This further suggests dyslexic readers may struggle with a visual attentional deficit rather than a phonological deficit, as only the identical preview provided a significant preview benefit.

Strength of the current study is it is the first to demonstrate adult readers with dyslexia are able to gain parafoveal preview benefit during silent reading. This finding supports previous research which has concentrated on RAN tasks (Jones et al., 2013; Yan et al., 2013), and suggests dyslexic readers are able to improve their reading efficiency by gaining information from the parafovea, similar to skilled readers (Johnson & Dunne, 2012; Pollatsek et al., 1992). This goes against previous research by Chace et al. (2005) which suggested receiving parafoveal preview benefit is determined by reading skill. However, the current findings do suggest dyslexic readers are unable to pre-process parafoveal information on first fixation suggesting a reduced reading efficiency at this early measure compared to skilled readers.

The study has also allowed for a better theoretical understanding of dyslexia in adult readers, particularly concerning their eye movements during reading. In the sample of dyslexic readers in the current study, there seemed to be no deficiency concerning phonological awareness. The trend from the eye movement data specific to the target word also suggests dyslexic readers required greater processing of the orthographic preview than the homophone preview. Although this was not significant, it questions the assumption that dyslexic readers suffer from a phonological deficit and that this is the cause of their reading impairment, as the readers did not seem to struggle processing phonological information specifically. Rather, the data would suggest a visual attention span deficit, in which the global visual attention span of dyslexic readers was affected, and so they struggled to process any global information not just phonological information, particularly at first fixation. This may explain why dyslexic readers received no significant preview benefit at first fixation and no significant benefit from the orthographic, homophone or random condition across gaze and single fixation duration. This supports Prado et al's. (2007) suggestion that a visual attention span deficit in dyslexic readers is related to their atypical eye movements.

A limitation of the study is the lack of power for the between group effect across gaze, first and single fixation duration. A larger sample size would improve this and allow for firmer conclusions to be made. It could also be argued that a limitation is that a low frequency pre-target word was used. Pollatsek et al. (1992) argue the pre-target word should be of reasonably high frequency as foveal processing difficulty, due to a low frequency word, may result in parafoveal information not being used. Chace et al. (2005) suggest this was the reason less skilled readers did not receive a preview benefit in their study. However, in the current study a low frequency word was used to ensure the readers fixated on the pre-target word and so to ensure the target word was in parafoveal vision when initially processed. As the evidence suggests both reading groups obtained preview benefit, it may be the case that foveal processing difficulty was not an issue.

It is clear further research is needed to explore parafoveal processing during silent reading in dyslexic readers, as this study is one of the first. The current study suggests dyslexic readers do receive parafoveal preview benefit when considering gaze and single fixation duration but not at first fixation duration. As single and first fixation duration tap similar stages of lexical processing, future research should explore whether dyslexic readers are able to pre-process parafoveal information at this early measure and as a result receive preview benefit during silent reading.

In conclusion, the present study demonstrated skilled and dyslexic adult readers differ in their eye movement behaviour. However, both groups of readers are able to pre-process information in the parafovea during silent reading and receive a preview benefit. It is also clear an identical preview provides the greatest preview benefit for both types of reader, while the other previews provided no significant benefit. When considering first fixation duration the results suggest dyslexic readers are unable to pre-process information in the parafovea at this early measure, and as a result receive no significant preview benefit. The lack of preview benefit seen at this measure and across preview conditions for the remaining measures, is thought to be a result of a visual attention span deficit, rather than a phonological deficit.

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