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Accepted Version

Joseph, H. S. S. L. ORCID: https://orcid.org/0000-0003-4325-4628, Liversedge, S. P., Blythe, H. I., White, S. J. and Rayner, K. (2009) Word length and landing position effects during reading in children and adults. Vision Research, 49 (16). pp. 2078-2086. ISSN 0042-6989 doi: 10.1016/j.visres.2009.05.015 Available at https://centaur.reading.ac.uk/43403/

To link to this article DOI: http://dx.doi.org/10.1016/j.visres.2009.05.015

Publisher: Elsevier

Word length and landing position effects during reading in children and adults

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Keywords: reading children eye movements landing positions word length

Abstract

The present study examined the effects of word length on children's eye movement behaviour when other variables were carefully controlled. Importantly, the results showed that word length influenced children's reading times and fixation positions on words. Furthermore, children exhibited stronger word length effects than adults in gaze durations and refixations. Adults and children generally did not differ in initial landing positions, but did differ in refixation behaviour. Overall, the results indicated that while adults and children show similar effects of word length for early measures of eye movement behaviour, differences emerge in later measures.

1. Introduction

It is well-known that word length influences adult skilled readers' eye movements (Just & Carpenter, 1980; Rayner, Sereno, & Raney, 1996). There are also systematic differences in where readers fixate a word as a function of word length (McConkie, Kerr, Reddix, & Zola, 1988; Rayner, 1979). While there has been much research examining word length and landing position effects in adult skilled readers, there has been surprisingly little research into these effects in children. We therefore set out to systematically examine both word length and landing position effects in children during normal text reading, and to directly compare their oculomotor behaviour in response to these manipulations with that of adults.

While monitoring eye movements is a well-established methodology in the investigation of adult reading behaviour, this method of investigation has been used much less frequently with children. Early research by Buswell (1922) and Taylor (1965) demonstrated that as reading skill increases, fixation duration decreases, saccade length increases, the number of fixations decreases, and the frequency of regressions decreases (see Rayner, 1998 for a summary). More recently, Rayner (1986) found that beginning readers have smaller perceptual spans than proficient readers (see also Häikiö, Bertram, Hyönä, & Niemi, 2009), and McConkie, Zola, Grimes, Kerr, Bryant and Wolff (1991) reported that beginning readers were more likely to refixate words as compared to older readers (see also Blythe et al., 2006).

While the Rayner (1986) and McConkie et al. (1991) studies both provide important data regarding eye movement behaviour during reading in children, neither study investigated whether children and adults exhibit qualitatively different patterns of eye movements when they process sentences containing a specific target word manipulation, such as word length. Indeed, very few carefully controlled experiments have been conducted to examine such questions in children, especially using eye tracking methodology (though notable exceptions are Blythe et al., 2006; Hyönä & Olson, 1995; Joseph et al., 2008).

1.1 Word length effects. Word length effects are among the most robust in the adult eye movement literature. The probability of fixating a word increases with word length (McConkie & Rayner, 1976) and first pass fixation times also increase as word length increases (Just & Carpenter, 1980). Much of this latter effect is due to increased refixation probability on longer words (Vitu, O'Regan, & Mittau, 1990), although word length influences reading times even when only a single fixation is made on a word (Rayner et al., 1996). When word length is denied, either by removing spaces entirely or replacing them with a mask, reading is impeded (Rayner, Fischer, & Pollatsek, 1998).

Word frequency is highly correlated with word length (Rayner & Duffy, 1986), but even when word frequency is controlled, long words have longer reading times, are less likely to be skipped, and are more likely to be refixated than short words (Liversedge et al., 2004; Rayner et al., 1998). Note that both reading times and refixation probability are known to be modulated by linguistic processing factors such as word frequency (McConkie, Kerr, Reddix, Zola, & Jacobs, 1989; Rayner et al., 1996) and predictability (Balota, Pollatsek, & Rayner, 1985); and refixation probability (and initial landing position) has also been shown to be modulated by orthographic familiarity (e.g. White & Liversedge, 2006). Consequently in the present study word frequency, predictability and word-initial orthographic familiarity were carefully controlled for short (four letter) and long (eight letter) target words.

To our knowledge, there has been only one study which has investigated word length effects during text reading in children (although see Aghababian & Nazir, 2000; Bijeljac-Babic, Millogo, Farioli, & Grainger, 2004 for single word reading studies examining word length effects in children). Hyönä and Olson (1995) recorded the eye movements of dyslexic children (mean age = 14.4 years) and reading-age-matched controls (mean age = 10.5 years) as they read aloud texts which contained words of different lengths. They found a strong effect of word length in both participant groups which was apparent in gaze durations (the sum of first pass fixations before moving to another word) and total word reading times (the sum of all fixations on a word including regressive fixations). However, oral reading might yield a more robust length effect than silent reading, especially if the participant fixates a word until its pronunciation is completed, as beginning readers tend to do (Rayner & Pollatsek, 1989). In any case, it is known that eye movements differ somewhat for reading silently versus reading aloud (Rayner, 1998).

In addition, Hyönä and Olson did not include an adult control group as they were primarily interested in reading performance in the dyslexic group. In contrast, the study reported here directly compared adults' and children's online processing of long versus short words during silent reading and focused on fine grain oculomotor behaviour. Furthermore, unlike previous studies, we used tightly controlled experimental materials in order to ensure that any effects observed were due to word length, rather than linguistic variables known to be correlated with word length.

Following previous research, we predicted that adults and children would both show inflated reading times on long, compared to short, words. Importantly, we also predicted that the magnitude of the word length effects (for measures such as reading times and refixation probability) would be greater in children than in adults for two reasons: First, due to child readers' inexperience, they may require a longer and / or more detailed visual sample of a word in order to initiate and complete lexical processing, especially for longer words for which more of the word is further from fixation and therefore visually degraded (Aghababian & Nazir, 2000). Second, children have a less developed oculomotor system than adults (Klein & Foerster, 2001) and they may not have as fully developed oculomotor mechanisms for efficient reading as have been proposed for skilled readers (e.g. Reichle, Rayner, & Pollatsek, 2003). For example, adults may require only partial information about a word's identity prior to programming a saccade to leave a word, whereas, children may require a greater degree of visual information about the word (and therefore may require longer and more visual samples of the word) before making a similar commitment. This may be especially critical for efficient processing of long words for which more of the word falls outside foveal vision. Hence a developmental oculomotor approach might also predict larger word length effects for children compared to adults.

1.2 Landing position effects. The present study also provides an opportunity to investigate whether adults and children differ in their saccade targeting strategies, specifically in terms of where words are first fixated and refixated. The initial landing position on a word is the location that the eyes initially fixate after making a first pass saccade into that word. Rayner (1979) first labelled the position within a word where readers typically make their initial fixation during text reading as the *Preferred Viewing Location* (PVL). The PVL is a little to the left of the word centre, though it tends to be nearer the centre for short than long words (McConkie et al., 1988; Rayner, 1979).

We noted above that refixation probability can be modulated by both word length and general processing difficulty. The probability of refixation is also influenced by the initial fixation location on a word such that refixations are more likely when initial fixations land at the beginning or end, compared to the middle, of a word . This pattern of effects has been observed during normal text reading (Rayner et al., 1996; Vitu & O'Regan, 1995; Vitu et al., 1990), as well as with isolated words (O'Regan & Lévy-Schoen, 1987). It is possible that refixations are more common when initial fixations are at the beginnings or ends of words because these initial fixations are more likely to have been mislocated (Nuthmann, Engbert, & Kliegl, 2005), although processing difficulty may also play a role. In addition, as many as 20% of refixations may be pre-planned, using word length information available parafoveally to plan two saccades (McDonald & Shillcock, 2004).

Although the location of intra-word refixations has been examined in a number of specialised tasks (see Beauvillain, Dukic, & Vergilino, 1999; O'Regan & Lévy-Schoen, 1987; Vergilino-Perez, Collins, & Dore-Mazars, 2004; Vergilino & Beauvillain, 2000, 2001), very little research has been undertaken on refixation locations in normal reading (McConkie et al., 1989). O'Regan and colleagues (O'Regan, 1990; O'Regan & Lévy-Schoen, 1987) argued that refixation location (as well as refixation probability) is determined by the location of the initial fixation. If the initial fixation is close to the beginning of the word, then the refixation will be targeted towards the end of the word and if the initial fixation is close to the end of the word, the refixation will be located closer to the beginning of the word. Importantly, this pattern of effects has been observed during normal text reading (McDonald & Shillcock, 2004; Rayner et al., 1996), as well as with isolated words (O'Regan & Lévy-Schoen, 1987).

There has been very little research investigating the location of initial or second fixations during natural reading in children. McConkie et al. (1991) reported data from Grimes (Grimes, 1989), which showed that during their first year of reading instruction, children show the same pattern of landing positions as adults, although full analyses were not given. Furthermore, McConkie et al. found that, like adults, children were more likely to refixate a (five-letter) word following an initial fixation on the space before a word or the first letter than if the first fixation was close to the word centre. However, these inferences were made from observing trends in the data rather than from formal statistical analyses.

Vitu et al. (2001) conducted extensive analyses using three existing data sets from text reading studies: two data sets had eye movement data from adult readers, and one data set contained data from child readers (mean age = approximately 12 years). The children did not appear to differ from the adults in the locations of their first or second fixations, although this was not tested directly. Note, however, that like the McConkie et al. (1991) study, the stimuli used in Vitu et al.'s work were not controlled a priori, but rather were split by word length post-hoc. In contrast, in the current experiment the four and eight letter target words were presented in sentences which were otherwise identical, and target words were controlled for a number of linguistic factors in order to eliminate the possibility of factors other than word length influencing eye movement behaviour on those target words.

Based on the findings from Vitu et al. and McConkie et al. suggesting that there are no qualitative differences between adults and children in terms of their landing positions, we predicted similar patterns of landing position effects for the children and adults in the present study. Specifically, we predicted that children and adults would initially fixate words close to the word centre, such that the mean initial landing position would be a greater number of characters into the word for the long than the short words. Second, we predicted that both adults and children would be more likely to make a refixation following an initial fixation at the beginning or end (as compared to the middle) of a word. Finally, we expected that initial fixations on the word beginning would be more likely to be followed by a refixation toward the word end, and vice versa.

In summary, while there has been some, limited, research investigating word length effects on temporal and spatial aspects of children's eye movements during reading, until now there has not been a comprehensive examination of children's eye movements in relation to stimuli in which word length was manipulated a priori. Following previous research, we predicted that children would show much larger word length effects than adults for eye movement measures that reflect processing difficulty (reading times and refixation probabilities), due to less developed linguistic processing or less optimal oculomotor control skills. In contrast, we predicted that children and adults should show more similar eye movement behaviour for measures reflecting basic saccade targeting such as initial fixation positions on words, and refixation probability and location as a function of initial landing position.

2. Method

2.1 Participants. Twenty adults and twenty children took part in the experiment. Children were between seven and eleven years old, with a mean age of 10 years and 4 months. It is worth noting here that additional post-hoc comparisons showed no differences between age groups within the group of children (split both by chronological and reading age), and so although there was a large age range in the child group, the effects observed did not appear to be modulated by age. All participants were native English speakers with uncorrected vision and no known reading difficulties. Adults were paid for their participation at a rate of £5 per hour. The children, who received a small gift in return for taking part, completed the Wechsler Objective Reading Dimensions (WORD; Wechsler, 1993) test which provided assessments of basic word reading, spelling and reading comprehension. They scored highly on all three assessments, with a mean score of 111 (standardized mean = 100, SD = 15), and had a mean reading age of 12.2 years.[1]

2.2 Materials. There were 56 experimental sentences in total, 28 of which contained a word length manipulation; such that the critical word was either four or eight letters long (see sentences 1a and 1b, where *medicine* and *salt* are the target words [2]):

1a. Her brother was really mean and put some medicine in my tea.

1b. Her brother was really mean and put some salt in my tea.

Eight letter words were selected rather than longer words because very long words are less likely to be familiar to young readers. All sentences were between 50 and 60 characters long and were not semantically related to one another. Target words were presented either towards the beginning (50% of sentences) or towards the end of the experimental sentences. All target words were at least 20 characters from the start/end of the sentence. Word frequencies were calculated using the CELEX English word form corpus (Baayen, Piepenbrock, & Gulikers, 1995). There was no difference in word frequency between long and short target words, t (1, 27) = 1.29, p = .21. The mean frequency for long target words was 48 counts per million (SD = 43) and the mean frequency for short target words was 52 counts per million (SD = 49). In addition, there were no significant differences in token or type initial trigram frequency (either position specific or non-position specific) between the eight and four letter (or six letter) words (all ps > .1), and no differences in predictability between long and short target words ($t < 1.3$, $p > .2$), as rated by ten adults who did not take part in the main experiment.

There were a further 28 items containing a six letter word which were used only for the initial and refixation position analyses. The mean word frequency of these six letter words was 79 counts per million (SD = 203). Note that although the frequency of these items was somewhat higher than for the four and eight letter words, evidence suggests that word frequency (Rayner et al., 1996; Vergilino-Perez et al., 2004; White, 2008), and predictability (Rayner, Binder, Ashby, & Pollatsek, 2001), do not affect initial landing position. Although linguistic variables have been shown not to influence initial fixation location, to our knowledge no studies have so far tested the effect of word frequency or predictability on refixation location. Consequently differences between the six letter and other word lengths for refixation location may be interpreted as being due to processing at or beyond the level of visual word length information.

2.3 Apparatus. Participants' eye movements were monitored using a Fourward Technologies Dual Purkinje Image eye tracker as they read sentences from a computer monitor at a viewing distance of 100cm. Each character covered 0.19° of horizontal visual angle so that five characters equalled one degree of visual angle. The eye tracker was interfaced with a Pentium 4 computer, with all sentences presented on a 24" monitor. Sentences were presented in white in Courier New font, on a black background. Although participants read binocularly, only data from the movements of the right eye were analysed.

2.4 Procedure. Participants sat in a customised chair in front of a computer monitor. Head movements were minimized by the use of a bite bar and forehead rests; a restraint was also secured around the back of their head. Participants undertook a calibration procedure during which they looked at each of three horizontal fixation points. Sentences were then presented one at a time. In addition to the 56 experimental items, five practice items were also presented at the beginning of the experiment. To minimise the duration of the experiment (especially for the child participants) no filler sentences were used. Participants were required to read the sentences normally and then press a button when they had finished reading. Participants were asked to respond yes/no to comprehension questions after 20 of the sentences, distributed randomly throughout the experiment, by pressing a button. The comprehension questions were syntactically and semantically simple in order that young children could answer them easily. For example, the question that followed sentence (1a) above was, "Did he put medicine in my tea?" The experimental session lasted approximately 20 minutes.

2.5 Analyses. Custom-designed software was used for the data analyses. Fixations were manually identified such that fixations began after the overshoot that is characteristic of the output for Dual Purkinje Image eye trackers (Deubel & Bridgeman, 1995). Fixations less than 80ms were deleted from the data set. In addition, first fixations more than 1200ms were deleted, as well as outliers (more than 2.5 SDs from the mean for each participant per condition). Trials were excluded if they were not completed, or if there was tracker loss, accounting for 18% of trials. Note that while all our participants were extremely cooperative, it is very difficult to run young children on a DPI eye tracker and it is for this reason that a comparatively large proportion of our data was excluded due to fatigue. We never put pressure on participants to finish the experiment in its entirety and it was therefore not unusual for children to stop before completing all the trials.

The following eye movement measures were computed: first-fixation duration (the duration of the first fixation on a target word), gaze duration (the sum of all first pass fixations on the target word), refixation probability (the probability of making an additional first pass fixation within the word before leaving it), and total reading time (the sum of all fixations on a target word including regressive fixations).

3. Results

All participants scored 75% or higher on the comprehension questions which followed 19 of the experimental sentences. Though the difference in scores between adults and children was significant, $t(19) = 3.39$, $p < .005$, the overall high mean scores for both adults (98%) and children (92%) indicates that neither group of participants had difficulty understanding the sentences.

3.1 Global measures. We first conducted global analyses in order to make general comparisons between the oculomotor behaviour of adults and children during reading, independent of the manipulations employed in the experiment. Table 1 shows that children made shorter saccades, longer fixations, more regressions and had longer total sentence reading times than adults, consistent with previous research (Blythe et al., 2006; McConkie et al., 1991; Rayner, 1986). All of the differences between the children and adults were significant (all $ps \leq .01$), except for saccade length in which the difference was reliable by items ($p < .001$) but not by participants ($p = .2$).

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Insert Table 1 here

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3.2 Word length analyses. The data from 28 sentences, including the four or eight letter long target words (14 per participant per condition) were analysed using 2 (group: adults, children) x 2 (word length: long, short) mixed design Analyses of Variance (ANOVAs) based on participants (F1) and items (F2) variability.

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Insert Table 2 here

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Table 2 shows the mean reading times and fixation probabilities for adults and children on all target words. There was a reliable effect of length on the probability of word skipping, with readers skipping short words (0.29) more than long words (0.08), $F1\ (1, 38) = 111$, $p < .001$; $F2\ (1, 27) = 48.89$, $p < .001$. There was an effect of group, reliable by items ($F2\ (1, 27) = 5.15$, $p < .05$), but not by participants ($F1 < 1.3$, $p > .2$), and there was no reliable interaction ($Fs < 2.7$, $ps > .1$). Overall, both adults and children skipped short words more than long words, and at least numerically, adults' skipping rates were increased relative to the children.

There was no effect of word length on the duration of the first fixation on the critical word ($Fs < 1.3$, $ps > .2$). Adults' first fixations were significantly shorter (46ms) than those of children overall, $F1\ (1, 38) = 16.72$, $p < .001$; $F2\ (1, 27) = 55.29$, $p < .001$, and there was no interaction between group and word length ($Fs < 1$).

As predicted, there was a highly significant effect of word length on gaze durations, $F1\ (1, 38) = 21.47$, $p < .001$; $F2\ (1, 27) = 18.71$, $p < .001$, and adults exhibited longer gaze durations overall, $F1\ (1, 38) = 18.79$, $p < .001$; $F2\ (1, 27) = 150$, $p < .001$. There was also a significant interaction between group and word length, $F1\ (1, 38) = 12.82$, $p < .005$; $F2\ (1, 27) = 12.05$, $p < .005$. Pairwise analyses showed that although adult participants had numerically longer (16ms) gaze durations on long than on short words, this difference was not significant ($ts < 1.4$, $ps > .2$). Children, however, did gaze significantly longer (88ms) at long than short words, $t1\ (1, 19) = 4.49$, $p < .001$; $t2\ (1, 27) = 4.54$, $p < .001$, showing that children exhibited a more marked difference in their gaze durations on long than short words, and that this was more robust than that for adults.

Consistent with the null effects in first fixation durations and significant differences in gaze durations, there was also a reliable effect of word length on the probability of making one or more intra-word first pass refixations , $F1\ (1, 38) = 34.2$, $p < .001$; $F2\ (1, 27) = 23.94$, $p < .001$, as well as an effect of group, $F1\ (1, 38) = 6.28$, $p < .05$; $F2\ (1, 27) = 16.57$, $p < .001$, with children making more refixations overall (29%) than adults (18%). There was also a reliable interaction, $F1\ (1, 38) = 5.53$, $p < .05$; $F2\ (1, 27) = 5.80$, $p < .05$ between word length and group. Pairwise analyses indicated that both adults, $t1\ (19) = 3.26$, $p < .005$; $t2\ (27) = 2.80$, $p < .01$, and children, $t1\ (19) = 4.86$, $p < .001$; $t2\ (27) = 4.63$, $p < .001$, showed word length effects on their refixation probabilities. However, this effect was stronger for children than adults.

Finally, participants spent longer fixating long as compared to short words overall, as shown by total word reading time, $F1\ (1, 38) = 20.2$, $p < .001$; $F2\ (1, 27) = 10.24$, $p < .005$. Consistent with earlier measures, adults spent less time fixating words in total as compared to children, $F1\ (1, 38) = 29.9$, $p < .001$; $F2\ (1, 27) = 353$, $p < .001$. There was no significant interaction between group and condition ($Fs < 2.6$; $ps > .1$).

To summarise, both adults and children skipped short words more than long words, and made significantly more refixations on long than short words. For both gaze durations and refixation probability, the magnitude of the word length effect was greater for children than adults.

3.2 Initial fixation and refixation positions. For the landing position analyses, data for target words in all 56 experimental items were analysed. Of these items, for each participant, 14 contained four letter words, 28 contained six letter words, and 14 contained eight letter words. Initial landing position, the probability of making a refixation as a function of initial landing position, and location of refixations as a function of initial landing position were calculated.

Insert Table 3 here

Insert Figure 1 here

Table 3 shows the mean landing positions for adult and children on four, six, and eight letter words. In addition, Figure 1 shows landing position distributions for adults and children for each of the three word lengths. A 3 (word length: four, six and eight letter words) x 2 (group: adults, children) mixed design Analysis of Covariance (ANCOVA) was conducted. Launch site was entered as a covariate as it has been shown to influence initial landing position (McConkie et al., 1988). Because the six letter words were not a within-item variable, and because there were higher levels of word skipping and fewer refixations on four letter words resulting in fewer data points per cell, only F1 analyses were carried out for all word lengths. There was a reliable effect of word length on initial landing position: consistent with previous research (Rayner, 1979), landing positions were further into a word as length increased, $F (2, 75) = 20.98.1$, $p < .001$. There was no effect of group ($ps > .5$). There was a marginal interaction between word length and group, $F (2, 75) = 2.84$, $p = .065$, but Table 3 shows that the differences between adults and children were very small for all word lengths: less than half a character in all cases.

Overall, the results replicate previous research which has shown that adults make saccades further into a word the longer it is (e.g. McConkie et al., 1988; Rayner, 1979). They also support findings that children, as well as adults target their saccades towards the word centre during reading (McConkie et al., 1991; Vitu et al., 2001).

Insert Table 4 here

As reported in the previous section, word length and group influenced the probability of refixation, with more refixations being made by children than adults, and more refixations being made on long, compared to shorter, words. There was a reliable effect of word length on the probability of making a refixation, $F (2, 92) = 3.33$, $p < .05$: readers made significantly more refixations on eight- compared to six-letter words, $t (39) = 4.05$, $p < .001$; on six- compared with four-letter words, $t (39) = 2.90$, $p < .01$; and on eight- compared with four-letter words, $t (39) = 5.56$, $p < .001$. There was a main effect of group, $F1 (1, 92) = 11.55$, $p < .005$; $F2 (1, 37) = 9.67$, $p < .005$, with children making more refixations overall as compared to adults.

The probability of making a refixation as a function of initial landing position was also examined. In order to enable us to carry out these analyses (i.e. to have enough data in each condition) we categorised each initial landing position for each word length as falling at the beginning, middle or end of a word. This was quite straightforward for the eight letter words, as when the space before the word was included; there were nine possible landing positions which fell neatly into three categories. Categorising the landing positions for four and six letter words was more problematic, however, and for this reason we conducted two sets of analyses for each word length in which the categorisation of landing positions was different. For six letter words, in the first set of analyses, the beginning was categorised as letter positions 0 and 1, the middle as 2, 3 and 4, and the end as 5 and 6; and in the second set of analyses the beginning category encompassed letters 0, 1 and 2, the middle encompassed letters 3 and 4, and the end encompassed letters 5 and 6. For the four letter words, in the first set of analyses the beginning was categorised as letter position 0, the middle as 1,2, and 3, and the end as letter 4; and in the second set of analyses the beginning category encompassed letters 0 and 1, the middle encompassed letters 2 and 3, and the end encompassed letter 4. There was no difference in the results for these two sets of analyses and so only the first set are reported here. Note that the proportion of data in each category was not equal: participants (there were no differences between adults and children) fixated the 'beginning' on 28% of occasions, the middle category on 56% of occasions, and the end category on 16% of occasions.

Table 4 shows the refixation probabilities for adults and children for each word length as a function of initial landing position. A 3 (landing position: beginning, middle or end) x 3 (word length: eight, six and four letters) x 2 (group: adults and children) mixed design ANOVA (with Greenhouse-Geisser correction) showed a reliable effect of landing position, $F(1.8, 18) = 8.54$, $p < .001$: readers made more refixations following initial fixations at the beginning as compared to the middle of a word, $t(39) = 4.60$, $p < .001$, and at the end as compared to the middle of the word, $t(39) = 2.34$, $p < .05$, but only marginally more refixations at the beginning compared to the end of a word, $t(39) = 1.91$, $p = .06$. There were no reliable interactions between landing position, word length or group ($ps > .1$), showing that adults and children did not differ in the probability of making a refixation as a function of initial landing position. These results were in line with predictions, as well as with previous research (Rayner et al., 1996) and are illustrated for each word length in Figure 2.

Insert Figure 2 here

Finally, we examined the direction of refixation saccades, and the location of those refixations. Specifically, for cases in which there were multiple first pass fixations, we calculated whether participants made a progressive (i.e. rightward) or regressive (i.e. leftward) saccade to refixate a word following an initial fixation. Analyses were undertaken on the probability of making a regressive refixation using a 3 (word length: four, six and eight letters) x 2 (group: adults and children) mixed design ANOVA. Table 5 shows the proportion of progressive versus regressive intra-word saccades for adults and children on all word lengths.

Insert Table 5 here

There was no significant difference in the proportion of regressive versus progressive refixation saccades between adults and children across word lengths ($p > .6$), although Table 5 shows that children made numerically more regressive saccades than adults. However, there was an effect of length on the proportion of regressive versus progressive refixations, $F(2, 72) = 3.04$, $p = .05$. Both adults and children made relatively fewer regressive refixation saccades as word length increased. Finally, there was no interaction between word length and group ($p > .6$).

Insert Figure 3 here

Figure 3 provides a graphical description of where adults and children located their refixations relative to their first fixations (note that we were unable to conduct statistical analyses on these data due to insufficient data points). Figure 3 illustrates that adults exhibited quite a clear pattern of refixations in all word lengths, and particularly in the six and eight letter words. Adults tended to fixate the beginning of the word and then refixate the end of the word. Children, however, appear to have made a larger proportion of shorter saccades from the beginning to the middle, from the middle to the beginning, or from the end to the middle of a word. Analyses of saccade length further confirm this observation (see Table 5). In line with previous research (Rayner, 1986), children's within-word saccades were shorter (2.87 characters) than adults (3.71 characters) overall, $F(1, 22) = 12.57$, $p < .005$, and saccade length decreased as word length decreased, $F(1.5, 44) = 12.13$, $p < .001$ (with Greenhouse-Geisser correction). There was no interaction between word length and group ($ps > .3$).

4. Discussion

Oculomotor behaviour can provide valuable insights into the online visual and linguistic processing that takes place during reading. It is well-documented that adults exhibit reliable differences in their eye movements when reading long as compared to short words (Rayner & McConkie, 1976; Rayner et al., 1996). In the experiment reported here, we directly compared children's and adults' eye movements as they silently read sentences containing long and short target words. We found, in concordance with previous research, that adults' eye movements were significantly influenced by word length, even when linguistic factors (specifically word frequency and predictability) were controlled for. Adults showed both first pass and later effects of word length and were more likely to skip, and less likely to refixate, a short as compared to a long word. We know from previous research using a disappearing text paradigm (Blythe, Liversedge, Joseph, White, & Rayner, 2009; Liversedge et al., 2004) that refixations aren't always necessary for efficient reading in adults. Nevertheless, the present study shows that when the visual information is present, longer words do encourage more refixations, providing a strong argument that word length is a visual factor which in itself modulates refixation probability. Hence, refixation behaviour is not only determined by linguistic processing difficulty related to factors such as word frequency.

The main focus of the present study was to establish whether children showed similar effects of word length on oculomotor behaviour compared to adults. While word length effects have been found in oral reading in older children (Hyönä & Olson, (1995), these effects have not yet been shown for critical words presented in carefully controlled, silently read, sentences, or for younger children. In line with our predictions, we found that children exhibited strong effects of word length in gaze durations and refixation probabilities. Furthermore, the effects of word length were larger for children compared to adults, such that children were relatively slower to process longer words than adults. As suggested in the Introduction, there are at least two possible explanations for this. First, longer words will necessarily have more letters available in more visually degraded vision. Given child readers' inexperience, they may require a longer and / or more detailed visual sample of a word in order to initiate and complete lexical processing. Hence the longer words may be particularly difficult for children to process, resulting in an increased length and number of fixations on long words.

An alternative possibility is that the longer fixation durations and higher refixation probabilities may be caused by children requiring very detailed visual information about a word prior to initiating a saccade to leave that word (and fixate a new word). More skilled readers, in contrast, may begin programming a saccade when word identification is not yet complete, committing to make such saccades based only on partial information (Reichle, Rayner, & Pollatsek, 2003). This in turn may lead to shortened fixations and reduce the likelihood of unnecessarily refixating words. In contrast, children may not have developed this skill, and may be more likely to refixate words if the decision to leave a word is based on a more conservative measure of completion of word processing, such as full lexical identification. Reaching such a stage may be especially time consuming for long words as they need to be processed in visually degraded vision, hence word length effects are larger for children than adults.

Importantly, we know from recent research (Blythe et al., 2009) that children, as well as adults, can efficiently read six letter words which disappear after as little as

40ms without refixating them. However, the results from the current experiment suggest that for longer words, certainly for those words which are visually available as in normal text reading, children do make many more refixations than adults.

Note that the effect of word length on adults' gaze durations was small (16ms) and not significant. Hence the difference in reading times between adults and children may have been exacerbated by differences in text difficulty between the two groups, indicating that processing difficulty may also have a role in modulating word length effects during reading. Although it was important to use the same stimuli with both groups of participants, in order that direct comparisons between their eye movement behaviour could be made, this necessarily meant that our adult group would find the sentences easier to process than our child group. This, together with the fact that the 'long' words were only eight letters may have accounted for the lack of reliable effects in gaze durations in the adult group.

We also found that both children and adults were more likely to skip short words as compared to long words. There are several possible explanations for how word length might be used to influence the probability of a word being fixated (Brysbaert, Drieghe, & Vitu, 2005; Brysbaert & Vitu, 1998): (1) As noted by Brysbaert, et al., (2005) even a "blind saccade selection strategy" for which saccade lengths were randomly selected would predict that short words would be skipped more often than long words. (2) Parafoveal processing of word length could be used with a basic mechanism, such as one that simply targeted the longest word (Reilly & O'Regan, 1998). (3) Word length effects on skipping might also be explained by parafoveal linguistic processing of words (cf. Brysbaert & Vitu, 1998; Reichle, Pollatsek, Fisher, & Rayner, 1998). Importantly, although the present study demonstrates that word length influences word skipping for both adults and children, it could be that each group may use quite different mechanisms to produce this outcome.

We also examined initial landing position distributions on four, six and eight letter words. We found that adults and children did not differ in their fixation locations on all word lengths, in line with predictions, and consistent with previous adult studies (McConkie et al., 1988; Rayner, 1979). While previous research has indicated that children target their saccades towards the word centre during reading (McConkie et al., 1991), the present study provides the first robust evidence, using well controlled materials, that children and adults are alike in their saccadic targeting across different word lengths, and that landing position distributions change relative to word length in children as well as adults. Critically, (in contrast to the effects of word length on word skipping), the effects of word length on initial landing position provide strong evidence that both adults and children do process word length information in parafoveal vision, and that this influences their saccade programmes. Furthermore, these data provide empirical support for Reichle and Laurent's (Reichle & Laurent, 2006) reinforcement learning model in which "intelligent" eye movements, including fixating close to the word centre, emerge quite quickly during learning.

Refixation probability as a function of initial landing position was also examined. While both adults and children were more likely to refixate a word if their initial fixation was away from the word centre (i.e., at the beginning or end of the word), and while children made more refixations overall as compared to adults, there was no reliable interaction between group and the probability of making a refixation as a function of landing position. This result shows that both adults and children make early decisions regarding intra-word refixations, either on the basis of initial fixation location, or perhaps even earlier while programming their initial saccade to a word (McDonald & Vergilino-Perez, 2006). Note that there may also be differences in language processing between adults and children that account for refixation and skipping behaviours, for example, in their capacity to use predictability information to lexically identify a word thereby eliminating the need to refixate it, or enabling a reader to skip it entirely.

We also investigated the size and direction of refixation saccades. Previous research (Blythe et al., 2006; McConkie et al., 1991; Rayner, 1986), has shown that adults make longer saccades than children overall. The current study specifically examined within-word refixation saccades and found that they too are shorter in children than adults. This may be explained by the fact that the amount of letter information that is available during a fixation increases with age (Häikiö et al., 2009). Both adults and children made relatively fewer regressive refixation saccades as word length increased, perhaps because, in relation to the word centre, the initial fixation on a word tended to be further into the word for short than long words.

Overall, this study provides the first investigation of the effects of word length on children's eye movement behaviour when other variables were carefully controlled. The experiment reported here also shows that even when linguistic factors are held constant, the length of a word reliably influences both the location and duration of first pass fixations in children as well as in adults during normal text reading. Children, like adults, are able to use parafoveal visual information to guide their saccades during reading. Word length information also influences both initial fixation positions and refixation positions in children.

References

Aghababian, V., & Nazir, T. (2000). Developing normal reading skills: Aspects of visual processes underlying word recognition. *Journal of Experimental Child Psychology, 76*, 123-150.

Baayen, H., Piepenbrock, R., & Gulikers, L. (1995). The CELEX lexical database (CD-ROM): University of Pennsylvania, Philadelphia: Linguistic Data Consortium.

Balota, D. A., Pollatsek, A., & Rayner, K. (1985). The interaction of contextual constraints and parafoveal visual information in reading. *Cognitive Psychology*, *17*, 364-390.

Beauvillain, C., Dukic, T., & Vergilino, D. (1999). The planning of successive saccades in letter strings. In W. Becker & H. Deubel & T. Mergner (Eds.), *Current oculomotor research: physiological and psychological aspects* (pp. 333-340). New York: Kluwer Academic Plenum Publishers.

Bijeljac-Babic, R., Millogo, V., Farioli, F., & Grainger, J. (2004). A Developmental investigation of word length effects in reading using a new on-line word identification paradigm. *Reading and Writing, 17*(4), 411-431.

Blythe, H. I., Liversedge, S. P., Joseph, H. S. S. L., White, S. J., Findlay, J. M., & Rayner, K. (2006). The binocular co-ordination of eye movements during reading in children and adults. *Vision Research, 46*(22), 3898-3908.

Blythe, H. I., Liversedge, S. P., Joseph, H. S. S. L., White, S. J., & Rayner, K. (2009). Visual information capture during fixations in reading for children and adults. *Vision Research* (in press).

Brysbaert, M., Drieghe, D., & Vitu, F. (2005). Word skipping: Implications for theories of eye movement control in reading. In G. Underwood (Ed.), *Cognitive processes in eye guidance* (pp. 53-78). Oxford: Oxford University Press.

Brysbaert, M., & Vitu, F. (1998). Word skipping: Implications for theories of eye movement control in reading. In G. Underwood (Ed.), *Eye Guidance in Reading and Scene Perception* (pp. 125-148). Oxford, UK: Elsevier.

Buswell, G. T. (1922). *Fundamental reading habits: A study of their development*. Chicago: University of Chicago Press.

Deubel, H., & Bridgeman, B. (1995). Fourth Purkinje image signals reveal eye-lens deviations and retinal image distortions during saccades. *Vision Research, 35*(4), 529-538.

Grimes, J. (1989). Where first grade children look in words during reading (Unpublished masters thesis), University of Illinois.

Häikiö, T., Bertram, R., Hyönä, J., & Niemi, P. (2009). Development of letter identity span in reading: Evidence from the eye movement moving window paradigm. *Journal of Experimental Child Psychology, 102*(2), 167-181.

Hyönä, J., & Olson, R. K. (1995). Eye fixation patterns among dyslexic and normal readers: effects of word-length and word-frequency. *Journal of Experimental Psychology: Learning Memory and Cognition, 21*(6), 1430-1440.

Joseph, H. S. S. L., Liversedge, S. P., Blythe, H. I., White, S. J., Gathercole, S. E., & Rayner, K. (2008). Children's and adults' processing of anomaly and implausibility during reading: Evidence from eye movements. *Quarterly Journal of Experimental Psychology, 61*(5), 708-723.

Just, M., & Carpenter, P. (1980). A theory of reading: from eye fixations to comprehension. *Psychological Review, 87*(4), 329-354.

Klein, C., & Foerster, F. (2001). Development of prosaccade and antisaccade task performance in participants aged 6 to 26 years. *Psychophysiology, 38*(2), 179-189.

Liversedge, S. P., Rayner, K., White, S. J., Vergilino-Perez, D., Findlay, J. M., & Kentridge, R. W. (2004). Eye movements when reading disappearing text: is there a gap effect in reading? *Vision Research*, *44*(10), 1013-1024.

McConkie, G. W., Kerr, P. W., Reddix, M. D., & Zola, D. (1988). Eye-movement control during reading: 1. The location of initial eye fixations on words. *Vision Research, 28*(10), 1107-1118.

McConkie, G. W., Kerr, P. W., Reddix, M. D., Zola, D., & Jacobs, A. M. (1989). Eye movement control during reading: II. Frequency of refixating a word. *Perception & Psychophysics, 46*(3), 245-253.

McConkie, G. W., & Rayner, K. (1976). Asymmetry of the perceptual span in reading. *Bulletin of the Psychonomic Society, 8*, 365-368.

McConkie, G. W., Zola, D., Grimes, J., Kerr, P. W., Bryant, N. R., & Wolff, P. M. (1991). Children's eye movements during reading. . In J. F. Stein (Ed.), *Vision and visual dyslexia* (pp. 251-262). Boston: CRC Press.

McDonald, S. A., & Shillcock, R. C. (2004). The Potential Contribution of Preplanned Refixations to the Preferred Viewing Location. *Perception and Psychophysics, 66*(6), 1033-1044.

McDonald, S. A., & Vergilino-Perez, D. (2006). Estimating the proportion of preplanned refixations in natural reading using Monte-Carlo simulations. *Visual Cognition, 13*(1), 109-118.

Nuthmann, A., Engbert, R., & Kliegl, R. (2005). Mislocated fixations during reading and the effect of inverted optimal viewing position. *Vision Research, 45*(17), 2201-2217.

O'Regan, J. K. (1990). Eye movements and reading. In E. Kowler (Ed.), *Eye movements and their role in visual and cognitive processes* (pp. 395-447). New York: Elsvier.

O'Regan, J. K., & Lévy-Schoen, A. (1987). Eye movement strategy and tactics in word recognition and reading. In M. Coltheart (Ed.), *Attention and performance XII: The psychology of reading* (pp. 363-383). Hillsdale, NJ: Erlbaum.

Rayner, K. (1979). Eye guidance in reading: Fixation locations within words. *Perception, 8*, 21-30.

Rayner, K. (1986). Eye movements and the perceptual span in beginning and skilled readers. *Journal of Experimental Child Psychology*, *41*, 211-236.

Rayner, K. (1998). Eye Movements in Reading and Information Processing: 20 Years of Research. *Psychological Bulletin, 124*(3), 372-422.

Rayner, K., Binder, K. S., Ashby, J., & Pollatsek, A. (2001). Eye movement control in reading: word predictability has little influence on initial landing positions in words. *Vision Research, 41*(7), 943-954.

Rayner, K., & Duffy, S. A. (1986). Lexical complexity and fixation times in reading: effects of word frequency, verb complexity, and lexical ambiguity. *Memory & Cognition, 14*(3), 191-201.

Rayner, K., Fischer, M. H., & Pollatsek, A. (1998). Unspaced text interferes with both word identification and eye movement control. *Vision Research, 38*, 1129-1144.

Rayner, K., & McConkie, G. W. (1976). What guides a reader's eye movements? *Vision Research, 16*(8), 829-837.

Rayner, K., & Pollatsek, A. (1989). *The psychology of reading*. Hillsdale: Erlbaum.

Rayner, K., Sereno, S. C., & Raney, G. E. (1996). Eye movement control in reading: A comparison of two types of models. *Journal of Experimental Psychology-Human Perception and Performance, 22*(5), 1188-1200.

Reichle, E. D., & Laurent, P. A. (2006). Using Reinforcement Learning to Understand the Emergence of "Intelligent" Eye-Movement Behavior During Reading. *Psychological Review, 113*(2), 390-408.

Reichle, E. D., Pollatsek, A., Fisher, D. L., & Rayner, K. (1998). Toward a model of eye movement control in reading. *Psychological Review, 105*(1), 125-157.

Reichle, E. D., Rayner, K., & Pollatsek, A. (2003). The E-Z Reader model of eye-movement control in reading: Comparisons to other models. *Behavioral and Brain Sciences, 26*(4), 445-476.

Reilly, R. G., & O'Regan, J. K. (1998). Eye movement control during reading: A simulation of some word-targeting strategies. *Vision Research, 38*(2), 303-317.

Taylor, S. E. (1965). Eye movements while reading: Facts and fallacies. *American Educational Research Journal, 2*, 187-202.

Vergilino-Perez, D., Collins, T., & Dore-Mazars, K. (2004). Decision and metrics of refixations in reading isolated words. *Vision Research, 44*(17), 2009-2017.

Vergilino, D., & Beauvillain, C. (2000). The planning of refixation saccades in reading. *Vision Research, 40*(25), 3527-3538.

Vergilino, D., & Beauvillain, C. (2001). Reference frames in reading: evidence from visually and memory-guided saccades. *Vision Research, 41*(25-26), 3547-3557.

Vitu, F., McConkie, G. W., Kerr, P., & O'Regan, J. K. (2001). Fixation location effects on fixation durations during reading: an inverted optimal viewing position effect. *Vision Research, 41*(25-26), 3513-3533.

Vitu, F., & O'Regan, J. K. (1995). A challenge to current theories of eye movements in reading. In J. M. Findlay & R. Walker & R. W. Kentridge (Eds.), *Eye movement research: Mechanisms, processes, and applications* (pp. 381-393). Amsterdam: North Holland.

Vitu, F., O'Regan, J. K., & Mittau, M. (1990). Optimal Landing Position in Reading Isolated Words and Continuous Text. *Perception & Psychophysics, 47*(6), 583-600.

White, S. J. (2008). Eye movement control during reading: Effects of word frequency and orthographic familiarity. *Journal of Experimental Psychology: Human Perception and Performance, 34*, 205-223.

Footnotes

1 Although a longitudinal design (with the same participants tested across different ages) would have been optimal, a cross-sectional design (comparing between groups of different ages) was adopted for practical reasons.

2 A full list of experimental sentences can be obtained by contacting the first author.

Acknowledgments

Portions of these data were presented at the 2007 Experimental Psychology Society meetings in London and Edinburgh. This research was supported by an ESRC studentship to the first author, Leverhulme Trust grants F/00 128/AB and F/00 128/ABG to the second author, and a National Institute of Health Grant HD26765 to the last author. We would like to thank the parents and children who took part in this experiment as unpaid volunteers. We also thank two anonymous reviewers for their helpful comments on a prior version.

Figure captions

Figure 1: Mean initial landing positions of adults and children on eight- (top panel), six- (middle panel) and four- (bottom panel) letter words.

Figure 2: Probability of making a refixation as a function of initial landing position for adults and children on eight- (left panel), six- (middle panel) and four- (right panel) letter words.

Figure 3: Destination of refixations as a function of landing position of initial fixations on 8-letter (top row), 6-letter (middle row) and 4-letter (bottom row) words for adults (left) and children (right).

Table 1: Global reading time measures, mean saccade length and proportion of regressions for adults and children. Standard deviations is parentheses.

	Adults	Children
Saccade length (characters)	8.2 (*5*.6)	7.6 (*6.7*)
Fixation duration (ms)	235 (*104*)	283 (*141*)
Total sentence reading time (ms)	2932 (*1038*)	5381 (*2232*)
Proportion of regressions	0.22 (*0.09*)	0.29 (*0.04*)

Table 2: Means and standard deviations (in parentheses) of eye movement measures for adults and children on long and short words.

		First fixation duration (ms)	Gaze duration (ms)	Probability of skipping	Probability of refixating	Total reading time (ms)
Adults	Long	234 (*77*)	280 (*114*)	0.08 (*0.14*)	0.23 (*0.16*)	335 (*151*)
	Short	240 (*78*)	264 (*99*)	0.32 (*0.13*)	0.12 (*0.12*)	288 (*130*)
Children	Long	288 (*107*)	438 (*238*)	0.08 (*0.11*)	0.41 (*0.24*)	663 (*402*)
	Short	298 (*117*)	350 (*175*)	0.25 (*0.12*)	0.17 (*0.16*)	588 (*404*)

Table 3. Mean landing positions (characters) on four letter, six letter and eight letter words for adults and children. Standard deviations in parentheses.

	Four letters	Six letters	Eight letters
Adults	2.21 (*1.30*)	2.94 (*1.80*)	2.97 (*2.08*)
Children	2.00 (*1.38*)	2.73 (*1.73*)	3.39 (*2.15*)

Table 4: Refixation probabilities as a function of initial landing position (beginning, middle or end of a word*) for four letter, six letter and eight letter words for adults and children.

	4 letter words			6 letter words			8 letter words		
	Beginning	Middle	End	Beginning	Middle	End	Beginning	Middle	End
Adults	0.19	0.09	0.19	0.31	0.06	0.13	0.42	0.06	0.1
Children	0.27	0.12	0.19	0.39	0.25	0.33	0.56	0.28	0.49

*For 8 letter words, beginning = characters 0, 1, 2; middle = characters 3, 4, 5; end = characters 6, 7, 8
For 6 letter words, beginning = characters 0, 1; middle = characters 2, 3, 4; end = characters 5, 6
For 4 letter words, beginning = character 0; middle = characters 1, 2, 3; end = character 4

Table 5: Probability of making a progressive or regressive refixation, and mean intra-word saccade length on eight-letter, six-letter and four-letter words for adults and children. Standard deviations are in parentheses.

	4 letters		6 letters		8 letters	
	adults	children	adults	children	adults	children
progressive	0.45	0.485	0.72	0.55	0.88	0.65
regressive	0.55	0.52	0.28	0.45	0.12	0.35
saccade length	2.68 (*1.17*)	2.48 (*1.24*)	3.87 (*1.57*)	3.06 (*1.48*)	4.82 (*1.62*)	3.54 (*1.47*)