COPY OF:

White, S.J., & Liversedge, S.P. (2004). Orthographic familiarity influences initial eye fixation positions in reading. *European Journal of Cognitive Psychology*, 16, 52-78.

NOT THE FINAL PUBLISHED VERSION

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Orthographic Familiarity Influences Initial Eye Fixation Positions in Reading

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Abstract

An important issue in the understanding of eye movements in reading is what kind of non-foveal information can influence where we move our eyes. In Experiment 1, first fixation landing positions were nearer the beginning of misspelled words. Experiment 2 showed that the informativeness of word beginnings does not influence where words are first fixated. In both experiments, refixations were more likely to be to the left of the initial fixation position if the words were misspelled. Also, there was no influence of spelling on prior fixation durations or refixation probabilities, that is, there was no evidence for parafoveal-on-foveal effects. The results show that the orthographic familiarity, but not informativeness, of word initial letter sequences influences where words are first fixated.

There is considerable evidence to suggest that the visual characteristics of text largely determine where the eyes land during reading. The position of the first fixation on words is mainly dependent on word length, which is visually represented by the spaces between words (McConkie & Rayner, 1975; Morris, Rayner, & Pollatsek, 1990; O'Regan, 1979; O'Regan, 1980; Pollatsek & Rayner, 1982; Rayner, Fischer, & Pollatsek, 1998). First fixations are most likely to land on the preferred viewing position (Rayner, 1979), which is between the beginning and the middle of words (Deutsch & Rayner, 1999; Dunn-Rankin, 1978; McConkie, Kerr, Reddix, & Zola, 1988). Nevertheless, there is substantial variability in the distribution of landing positions on words. McConkie et al. (1988) suggested that variability in landing positions is induced by random error as well as systematic range error related to launch site. In line with this, models of eye movements in reading state that the position of first fixations on words is largely determined by word length and systematic range error (O'Regan, 1990; Reilly & O'Regan, 1998; Reichle, Pollatsek, Fisher, & Rayner, 1998; Reichle, Rayner, & Pollatsek, 1999).

Although it is clear that a substantial amount of the variability in first fixation landing positions on words can be explained by the visual characteristics of text (Vitu, O'Regan, Inhoff, & Topolski, 1995), there is also evidence indicating that linguistic processing of fixated and non-fixated text influences saccade computation. For fixated text, (1) lexical processing can influence the probability of making a refixation (Balota, Pollatsek, & Rayner, 1985; Inhoff & Rayner, 1986; Rayner, Sereno, & Raney, 1996), (2) syntactic processing (Frazier & Rayner, 1982) and clause wrap up can influence the length of subsequent saccades (Hill & Murray, 2000; Rayner, 1975; Rayner, Kambe, & Duffy, 2000), (3) syntactic and discourse processing can influence the probability of regressions (e.g. Garrod, Freudenthal, & Boyle, 1994; Liversedge,

Paterson, & Claves, 2002; Paterson, Liversedge, & Underwood, 1999; Rayner, Carlson, & Frazier, 1983).

Pre-processing of non-fixated text can also influence landing positions in reading. Studies have shown that landing positions are nearer the beginning of words or saccade lengths are shorter (1) when space but not letter (orthographic) information is presented (Inhoff, 1989; Morris et al., 1990; Rayner, Well, Pollatsek, & Bertera, 1982), (2) for words presented in uppercase letters (Inhoff, Starr, & Shindler, 2000), (3) for words in which partially correct previews were presented before they were fixated (Inhoff, 1990), (4) for nonsense letter strings presented in sentences (McConkie, Underwood, Zola, & Wolverton 1985). The results of these studies indicate that non-foveal processing beyond the level of visual word length information can influence where the eyes move. A number of studies have shown that lexical processing can influence where the eyes move in terms of the probability of fixating words (for a review of this area see: Brysbaert & Vitu, 1998). However the issue to be investigated in this article is what kinds of non-foveal processing can influence where words are initially fixated. Some studies have suggested that non-foveal processing of predictability within the context of the sentence (Lavigne, Vitu, & d'Ydewalle, 2000; but see Rayner, Binder, Ashby, & Pollatsek, 2001; Vonk, Radach, & van Rijn, 2000) and morphology (Inhoff, Brihl, & Schwartz, 1996; Hyönä & Pollatsek, 1998; but see Andrews, Miller, & Rayner, 2003) can influence where words are first fixated. Although these studies suggest that non-foveal lexical processing can influence fixation positions, word frequency has not been found to influence where words are first fixated (Rayner et al., 1996). Furthermore, the issue of whether non-foveal sub-lexical processing can influence where words are first fixated

remains controversial. The current article focuses on how sub-lexical and lexical processing of non-fixated text can influence first fixation positions on words.

The first studies to investigate such landing position effects suggested that the distribution of informativeness (the importance of letter sequences for word recognition) within words could influence where words are initially fixated (Everatt & Underwood, 1992; Hyönä, Niemi, & Underwood, 1989; Underwood, Clews, & Everatt, 1990; Underwood, Hyönä, & Niemi, 1987). However Hyönä (1993, 1995) argued that these studies confounded the variable of informativeness with orthographic, morphological and semantic variables. Furthermore, Rayner and Morris (1992) failed to replicate Underwood, Clews et al.'s findings. However, an increasing number of studies have shown that orthographic non-fixated information can influence where words are first fixated. Hyönä (1995) presented words in Finnish sentences with either orthographically familiar or very unfamiliar word beginnings. The unfamiliar words included letters that rarely occur in Finnish. Hyönä found that fixations landed nearer to the beginning of the orthographically unfamiliar words, especially on the space before the word. Vonk et al. (2000) and Radach, Inhoff, and Heller (2003) also found that orthographic familiarity influences where words are first fixated in Dutch and German respectively. In support of these findings, artificial task experiments¹ have shown that orthographically unfamiliar initial letter sequences produce first fixation landing positions nearer the beginning of French words and nonwords than letter strings with familiar initial letter sequences (Beauvillain, Doré, & Baudouin, 1996; Doré and Beauvillain, 1997; Beauvillain & Doré, 1998). However a number of studies have failed to demonstrate orthographic landing position effects in artificial tasks (Radach, Krummenacher, Heller, & Hofmeister, 1995; Kennedy, 1998, 2000), short passage reading tasks (Inhoff et al., 2000; Liversedge &

Underwood, 1998) and corpus reading studies (Radach & Kempe, 1993; Radach & McConkie, 1998).

A number of possible explanations have been proposed to explain the modulation of landing positions on words by orthography. Hyönä (1993) suggested a pull assumption in which salient features (such as irregular orthography) “pop out” of non-fixated text and pull the eye towards them. Beauvillain et al. (1996) extended this idea by suggesting that irregular letter sequences “pop out” of non-fixated text and influence landing positions by adjusting the word length based saccade computation. More recently, Findlay and Walker (1999) suggested that medium and long-term learning modifies the intrinsic salience of visual stimuli such as orthographic letter sequences. Intrinsic salience then contributes to a salience map in which the distribution of salience across the visual field determines the saccade target. Alternatively, the modulation of first fixation positions on words might be explained by an influence of processing difficulty. McConkie (1979) suggested that saccades are directed to regions of processing difficulty. Hyönä and Pollatsek (1998, 2000) suggested that processing difficulty reduces the perceptual span or the extent of pre-processing, and this shortens saccades (see also Hyönä, 1995).

Overall, there is mixed evidence for whether sub-lexical and lexical processing can influence where words are first fixated. A similar controversy exists over the issue of whether non-fixated information can influence fixation durations, sometimes referred to as “parafoveal-on-foveal” effects. A number of studies using both artificial and sentence reading tasks have reported that fixation durations are influenced by the characteristics of the following word (Inhoff, Radach, Starr, & Greenberg, 2000; Inhoff, Starr, et al., 2000; Kennedy, 1998, 2000; Kennedy, Pynte, & Ducrot, 2002; Murray, 1998; Murray & Rowan, 1998; Pynte, Kennedy, & Ducrot,

2003; Underwood, Binns, & Walker, 2000). However the direction of the effects in these studies is inconsistent and there are concerns about the generalizability of some of the findings (Rayner, White, Kambe, Miller, & Livversedge, 2003).

The aim of this study was to investigate whether sub-lexical and lexical processing can influence where words are first fixated in the reading of English sentences. Experiment 1 was designed to test whether orthographic familiarity influences where the eyes move. Experiment 2 was designed to test whether processing of word beginnings to generate possible lexical candidates can influence where words are first fixated. Both experiments also provide an opportunity to test whether orthographic and lexical characteristics of non-fixated words influence fixation durations on the previous word. Throughout this paper we will use the term “orthographically unfamiliar” to indicate that a letter sequence does not exist in the language or is infrequent. We will use the term “orthographically familiar” to indicate that a letter sequence frequently occurs in the language. Orthographic familiarity is measured using token frequency (the sum of the word frequencies of words including a particular letter sequence). We will use the term “informative” to indicate that a letter sequence is found at the beginning of a small number of words and “uninformative” to indicate that a letter sequence is found at the beginning of many words. Orthographic informativeness is measured using type frequency (the number of words including a particular letter sequence). In the present experiment, unless otherwise specified, type and token frequency counts were position specific and case insensitive.

Experiment 1

A correctly spelled condition with frequent word initial trigrams (e.g. agricultural) was compared to four misspelled conditions. Three of the misspelled

conditions had different degrees of orthographic familiarity in order that we might identify those characteristics of an orthographically unfamiliar string that influence saccade computation. The most unfamiliar misspelling condition formed an illegal unpronounceable word initial trigram (e.g. ngricultural). The word “illegal” indicates that no word in the English language begins with such an initial trigram. A second condition formed an illegal but pronounceable word initial trigram (e.g. akricultural). The third misspelled condition had word initial trigrams that occurred in the lexicon but which were unfamiliar (e.g. aoricultural). Following the evidence described above, it was predicted that these three misspelling conditions with unfamiliar initial letter sequences would produce first fixation landing positions nearer the word beginning compared to the correctly spelled condition.

The three unfamiliar misspelling conditions necessarily confounded the orthographic familiarity of the initial trigram with the presence of a misspelling. As a result, a fourth misspelling condition was included in which the word initial trigrams were frequent (e.g. acricultural). There were no differences in the initial bigram and trigram frequencies between the correctly spelled and high frequency misspelled conditions and so it was predicted that landing positions in these two conditions would be the same.

Method

Participants. Forty-five members of the University of Durham community participated in the experiment. All of the participants were native English speakers with normal or corrected to normal vision. The participants were paid to participate and all were naïve in relation to the purpose of the experiment.

Materials. Word frequencies and n-gram frequencies were based on the CELEX English word form corpus (Baayen, Piepenbrock, & Gulikers, 1995). There

were 35 critical strings with a mean word length of 9.7 characters (range 8 to 13) and a mean word frequency of 41 counts per million ($\underline{SD} = 53$). Stimuli were chosen on the basis of position specific token frequency, but type frequencies followed similar patterns. N-gram frequencies were based on counts per 17.9 million because this is a more sensitive measure.

There were five spelling conditions that were manipulated within participants and items. In the baseline condition the critical string was spelled correctly with a high frequency initial trigram. In the high frequency, low frequency and the illegal pronounceable misspelled conditions the second letter of the word was misspelled. In the illegal unpronounceable misspelled condition the first letter was misspelled if the original first letter was a vowel (21 items) and the second letter was misspelled if the original first letter was a consonant (14 items). There were 35 items in all of the conditions except for the illegal pronounceable misspelled condition in which there were 30 items².

The token frequencies for the initial trigams were high for both the correctly spelled ($\underline{M} = 14514$, $\underline{SD} = 17465$) and the high frequency misspelled ($\underline{M} = 11345$, $\underline{SD} = 12848$) conditions. The stimuli were chosen primarily on the basis of token frequency but type frequencies for the initial trigrams also tended to be high for both the correctly spelled ($\underline{M} = 75$, $\underline{SD} = 88$) and the high frequency misspelled ($\underline{M} = 68$, $\underline{SD} = 115$) conditions. The position in the word at which the high frequency misspelled words became illegal was uncontrolled. The position ranged from four to seven characters and the mean position was 4.6 characters ($\underline{SD} = 0.88$). In the low frequency misspelled condition the initial trigram mean type ($\underline{M} = 3$, $\underline{SD} = 3$) and token frequencies ($\underline{M} = 68$, $\underline{SD} = 63$) were low. To summarise, the position specific token frequencies of the initial trigrams were within the seventh to the ninth deciles

for the correctly spelled condition, the sixth to the ninth deciles for the high frequency misspelling condition and the first to the fifth deciles for the low frequency misspelling condition. For the illegal pronounceable and the illegal unpronounceable misspelled conditions the initial trigram never occurred in the lower case corpus. For the correctly spelled and the high frequency misspelled conditions there were no significant differences between the initial trigram type or token frequencies (t 's < 1). There were significant differences in the initial trigram type and token frequencies between the correctly spelled and the high frequency misspelled conditions compared to the low frequency and illegal initial trigram conditions (t 's > 3.3 , $ps < .01$). The type and token initial bigram frequencies were high for the correctly spelled and high frequency misspelled conditions but low for the low frequency and illegal misspelled conditions. There were no significant differences in the initial or second (second and third letter) bigram type and token frequencies between the correctly spelled and the high frequency misspelled conditions (t 's < 1.5). There were significant differences in initial bigram type and token frequencies between the correctly spelled and the high frequency misspelled conditions compared to the low frequency misspelled conditions and the illegal misspelled conditions (t 's > 3.8 , $ps < .01$). There were no significant differences in non-position specific type or token monogram frequency between the correctly spelled and the high frequency misspelled condition (t 's < 0.6) and the low frequency misspelled condition (t 's < 1.9).

The critical strings in each condition were placed in identical sentence frames. Each of the sentences was no longer than one line of text (78 characters) and the critical strings appeared approximately in the middle of the sentence. The words before (word $n-1$) and after (word $n+1$) the critical string were either five or six letters long and had medium to high frequencies.

Five lists of 171 sentences were constructed and nine participants were randomly allocated to each list. Each list included 34 experimental sentences of which six items were from the illegal pronounceable condition and seven items were from each of the other four conditions. The conditions were rotated following a Latin square design. There were 30 misspelled filler sentences with the misspellings in a variety of word lengths and positions. There were also 107 filler sentences that were spelled correctly. Therefore of the 171 sentences, 57 contained a misspelling. Fifty-eight of the sentences were followed by a comprehension question to ensure that participants concentrated on understanding the sentences. The sentences were presented in a fixed random order with eight filler sentences at the beginning. See Appendix for examples of experimental sentences and critical words.

Procedure. Eye movements were monitored using a Dual Purkinje Generation 5.5 eye tracker. Viewing was binocular but only the movements of the right eye were monitored. The sentences were displayed on a screen at a viewing distance of 70cm. Three and a half characters subtended one degree of the visual angle. The resolution of the eye tracker is 10 min of arc and the sampling rate was every millisecond.

Participants were instructed to ignore the misspellings and to concentrate on understanding the sentence to the best of their ability. A bite bar and head restraint were used to minimize head movements. The initial calibration procedure lasted approximately five minutes and the calibration accuracy was checked after every few trials during the experiment. After reading each sentence the participants pressed a button to continue and used a button box to respond “yes” or “no” to comprehension questions. The entire experiment lasted approximately 45 minutes and participants were given two breaks.

Analyses. Fixations shorter than 80ms that were within one character of the next or previous fixation were incorporated into that fixation. Any remaining fixations shorter than 80ms and longer than 1200ms were discarded. Analyses of word n-1, the critical string and word n+1 included the space before the respective word in each case.

Five percent of trials were excluded due to either no first pass fixations on the sentence prior to word n-1 or tracker loss or blinks on first pass reading of word n-1 or the critical string. Five participants were replaced due to more than 15 percent of trials being excluded in this manner and one participant was replaced due to an error rate greater than 15 percent on the comprehension questions.

Results

Repeated measures analyses of variance (ANOVAs) were undertaken across the five spelling conditions, with participants (F_1) and items (F_2) as random variables. If there were significant main effects across both participants and items then simple effects were computed comparing the correctly spelled condition with each of the misspelled conditions. Paired samples t-tests were undertaken across both participants (t_1) and items (t_2) for comparisons between pairs of variables. The duration of the first fixation, gaze duration (the sum of fixations on a word before leaving it) and total time (the sum of all fixations within a word) were calculated for word n-1, the critical string and word n+1. For the critical string, landing positions, incoming saccade extent, launch site and frequency of refixations were analysed. The mean error rate on the comprehension questions was five percent.

Parafoveal-on-foveal effects. Table 1 shows the mean reading time measures on word n-1 and mean fixation durations prior to fixating the critical string. For word n-1 there were no significant effects of spelling on first fixation or gaze duration (F 's

< 1.2). There was no effect of the spelling of the critical string on the probability of refixating word n-1 (F 's < 1). There was no significant effect of spelling on the duration of the fixation prior to the first fixation on the critical string for all of the data (F 's < 1), for only those trials when the prior fixation was on word n-1, $F_1(4, 176) = 1.42$, $p = .231$, $MSE = 1470$; $F_2 < 1$, and for only those trials when the prior fixation was three or less characters away³, $F_1(4, 144) = 1.27$, $p = .284$, $MSE = 3556$; $F_2 < 1$. These data provide no evidence of parafoveal-on-foveal effects.

Insert Table 1 here

Reading time measures. Table 1 shows the mean reading time measures on the critical string and word n+1. There was a significant effect of spelling on the reading time measures on the critical string for first fixation, $F_1(4, 176) = 5.28$, $p < .01$, $MSE = 1803$; $F_2(4, 116) = 4.43$, $p < .01$, $MSE = 1727$, gaze duration⁴, $F_1(3.5, 152.2) = 18.06$, $p < .01$, $MSE = 12744$; $F_2(2.7, 79.6) = 13.83$, $p < .01$, $MSE = 17027$, and total time, $F_1(3.2, 140.6) = 33.21$, $p < .01$, $MSE = 23999$; $F_2(2.9, 84.3) = 18.14$, $p < .01$, $MSE = 37272$. For all of these measures the correctly spelled words were fixated for a significantly shorter time than the misspelled conditions, F 's > 4.6, p s < .05. There were also significant differences between the high frequency and the illegal unpronounceable misspelled conditions on the critical string for first fixation duration, $t_1(44) = 2.02$, $p = .05$; $t_2(34) = 2.23$, $p = .03$, and gaze duration, $t_1(44) = 3.23$, $p < .01$; $t_2(34) = 2.55$, $p = .02$, which suggests that the words with more irregular misspellings were more difficult to recognise than the words with less irregular spellings.

There was no effect of spelling on the duration of the fixation after leaving the critical string (F 's < 1). There was no significant effect of spelling on the first fixation

on word $n+1$ (F 's < 1) and although there was a significant effect of spelling on gaze duration on word $n+1$ across participants this was not significant across items, $^5 F_1(4, 168) = 3.44, p = .01, \underline{MSE} = 2309$; $F_2(4, 116) = 1.93, p = .11, \underline{MSE} = 2571$. However spelling did significantly influence total reading times on word $n+1$, $F_1(3.4, 151.1) = 5.31, p < .01, \underline{MSE} = 5855$; $F_2(4, 116) = 4.24, p < .01, \underline{MSE} = 5646$. The correctly spelled condition produced shorter total reading times on word $n+1$ than each of the misspelled conditions (F 's $> 8.7, p$ s $< .01$).

To summarise, there were no effects of the critical string on prior fixations. However fixation durations were increasingly longer on the critical string, and for later measures on word $n+1$, the more irregular the misspelling. The misspelled words, especially the very irregular misspellings, were more difficult to process than the correctly spelled words. Previous studies have also shown that misspelled words (Inhoff & Topolski, 1994; Rayner, Pollatsek, & Binder, 1998; Underwood, Bloomfield, & Clews, 1988), and words which are incorrect in the context of the sentence (Daneman, Reingold, & Davidson, 1995; Ehrlich & Rayner, 1981) produce longer fixation durations.

Landing positions. For the first fixation landing position analyses, the space before the critical string was classified as zero and the first letter of the string as one etc. Table 2 shows the mean landing positions on the critical string. The mean first fixation landing positions on the critical string were 0.5 to 0.3 characters nearer the word beginning for the misspelled strings compared to the correctly spelled words. There was a significant effect of spelling on the mean first fixation landing position on the critical string, $F_1(4, 176) = 3.08, p = .02, \underline{MSE} = 0.75$; $F_2(4, 116) = 2.91, p = .02, \underline{MSE} = 0.57$. Compared to the correctly spelled condition, mean landing positions were significantly nearer the beginning of the word in the high frequency, $F_1(1, 44) =$

7.46, $p < .01$, $\text{MSE} = 1.6$; $F_2(1, 29) = 15.14$, $p < .01$, $\text{MSE} = 0.69$, low frequency, $F_1(1, 44) = 8.21$, $p < .01$, $\text{MSE} = 1.01$; $F_2(1, 29) = 4.97$, $p = .03$, $\text{MSE} = 1.08$, illegal pronounceable, $F_1(1, 44) = 14$, $p < .01$, $\text{MSE} = 1.07$; $F_2(1, 29) = 5.7$, $p = .02$, $\text{MSE} = 1.54$, and the illegal unpronounceable, $F_1(1, 44) = 4.07$, $p = .05$, $\text{MSE} = 1.3$; $F_2(1, 29) = 6.1$, $p = .02$, $\text{MSE} = 1.17$ misspelled conditions. No other paired contrasts between the misspelled conditions were significant (t 's < 1.4). Figure 1 shows the distribution of landing positions for each condition. For all of the conditions, most fixations landed on the preferred viewing position (between the middle and the beginning of the word). The correctly spelled condition landing position distribution curve is shifted to the right of the misspelled condition curves. Clearly, readers processed the critical string prior to direct fixation and misspellings produced landing positions nearer to the beginning of the critical string compared to when it was spelled correctly.

Insert Figure 1 and Table 2 here

Incoming saccade extent and launch site. Table 2 shows the mean lengths of saccades into the critical string and mean launch sites. There was no significant effect of spelling on the length of the saccade into the critical string, $F_1(4, 176) = 1.35$, $p = .253$, $\text{MSE} = 1.06$; $F_2 < 1$. However, Table 2 shows that the mean saccade lengths into the critical string were longer for the correctly spelled condition than in any of the misspelled conditions. There was no effect of spelling on the position of the fixation prior to first fixating the critical string (F 's < 1) and, in contrast to the means for saccade lengths, Table 2 shows no consistent pattern of differences in launch site between the correctly spelled condition and the misspelled conditions. The probability

of skipping word n-1 before fixating the critical string (trials in which regressions were made from word n-1 were considered separately) was numerically greater for the misspelled conditions (high frequency: 0.17; low frequency: 0.11; illegal pronounceable: 0.14; illegal unpronounceable: 0.16) than for the correctly spelled condition (0.09). There was a significant main effect of spelling on the probability of skipping word n-1, $F_1(3.2, 141.8) = 3.55$, $p = .01$, $MSE = 202$; $F_2(4, 116) = 3.26$, $p = .01$, $MSE = 154$, and word n-1 was less likely to be skipped in the correctly spelled condition than the high frequency, $F_1(1,44) = 10.5$, $p < .01$, $MSE = 328$; $F_2(1,29) = 11.93$, $p < .01$, $MSE = 225$, and illegal unpronounceable $F_1(1,44) = 9.07$, $p < .01$, $MSE = 261$; $F_2(1,29) = 4.83$, $p = .04$, $MSE = 447$, misspelled conditions. There was no significant difference for the low frequency misspelling condition, F 's < 1.2 , and a significant difference across participants, $F_1(1,44) = 5.69$, $p = .02$, $MSE = 172$, but not items, $F_2(1,29) = 2.33$, $p = .138$, $MSE = 312$, for the illegal pronounceable misspelling condition. The finding that spelling influenced the probability of skipping the previous word suggests that the misspellings may have attracted saccades from distant launch sites. Figure 2 shows the distribution of launch sites for each condition. Note that there tend to be slightly more saccades launched from seven or more characters from the critical string for the high frequency and illegal unpronounceable misspelled conditions compared to the correctly spelled condition.

Therefore, although there were no significant effects of incoming saccade extent or launch site, the results suggest that differences in both these factors may have contributed to the landing position effect. That is, non-significant differences in the mean incoming saccade extent and differences in the probability of skipping word n-1 may both have influenced first fixation positions on the critical string.

Insert Table 3 here

Frequency of refixations. Table 3 shows the probability of skipping or making one or more than one fixation on the critical string on first pass. There was a significant effect of spelling on the probability of refixating the critical string on first pass, $F_1(4, 176) = 8.21$, $p < .01$, $MSE = 307$; $F_2(4, 116) = 6.73$, $p < .01$, $MSE = 287$. The correctly spelled condition was significantly less likely to be refixated than any of the four misspelled conditions (F 's > 4.6 , $ps < .05$). Similar to the reading time measures, these results suggest that the misspelled words were more difficult to process than the correctly spelled words because they produced more first pass refixations on the critical string.

Table 3 shows the probability of making a refixation to the left of the initial fixation on the critical string for those trials in which multiple first pass fixations occurred on the critical word. There was a significant effect of spelling on the probability of making a refixation to the left of the initial fixation⁶, $F_1(4, 104) = 2.77$, $p = .03$, $MSE = 1003$; $F_2(4, 88) = 5.91$, $p < .01$, $MSE = 666$. Compared to the correctly spelled condition, refixations were more likely to be to the left of the initial fixation in the low frequency, $F_1(1, 26) = 5.81$, $p = .02$, $MSE = 2308$; $F_2(1, 22) = 7.6$, $p = .01$, $MSE = 1434$, and the illegal unpronounceable, $F_1(1, 26) = 8.03$, $p < .01$, $MSE = 2134$; $F_2(1, 22) = 18.02$, $p < .01$, $MSE = 1255$, misspelled conditions. For the illegal pronounceable misspelled condition the effect was significant across participants but not items, $F_1(1, 26) = 4.27$, $p = .05$, $MSE = 1412$; $F_2(1, 22) = 2.82$, $p = .107$, $MSE = 1490$. There was no significant difference in the probability of refixating to the left of the initial fixation for the correct and high frequency misspelled words, $F_1(1, 26) = 1.27$, $p = .27$, $MSE = 1848$; $F_2 < 1$. The results suggest that the more irregular

misspelled items were more likely to produce regressive refixations than the correctly spelled condition.

Discussion

Both the position of the first fixation and the direction of refixations were influenced by the presence of misspellings. Therefore the results show that non-foveal processing at least at the level of orthographic familiarity can influence where words are fixated. It is also interesting that the word before the critical word was more likely to be skipped if the critical word was misspelled. These results suggest that misspellings can attract saccades from distant launch sites. However, note that in contrast to these results, Pynte et al. (2003) found that irregular misspellings reduce the probability of skipping the previous word.

The effects of the misspellings on landing positions clearly show that they must have been processed during the previous fixation. However importantly, there was no effect of the misspellings on prior fixation durations or refixation probabilities. That is, there were no parafoveal-on-foveal effects.

First fixation landing positions were also significantly nearer the word beginning for the high frequency misspelled condition compared to the correctly spelled condition. There were no differences between initial trigram frequencies in the correct and high frequency misspelling conditions and, as mentioned above, the position in the word at which the high frequency misspelled words became illegal was uncontrolled. Therefore letter sequences up to at least the first four letters of the high frequency misspelled strings had to be processed in order for the word initial letter sequence to be detected as irregular. Importantly, although the string would have to be processed up to at least the fourth letter, shorter infrequent or illegal letter sequences may have been detected (for example “quc” in “equation”). Nevertheless, this result

is surprising because Beauvillain and Doré (1998) showed that the letter sequence frequency of the second and third letters of a letter string did not influence fixation positions. The high frequency misspelling result suggests that letter sequences that are positioned further into the word than those tested by Beauvillain & Doré can influence fixation positions. The high frequency misspelling result is even more surprising because it appears to be at least partly determined by saccades being attracted from distant launch sites. That is, word $n-1$ is more likely to be skipped when there is a high frequency misspelling than when the critical string is spelled correctly. Note that saccades launched from distant launch sites tend to land nearer the beginning of words (McConkie et al., 1988), hence the numerically larger number of fixations on the space before the word for the high frequency misspellings (see Figure 1). These results imply that processing beyond the level of the orthographic familiarity of the word initial trigram can be undertaken on text presented more than one word from fixation, which is beyond or certainly towards the far edge of the region of text from which letter information can be processed (McConkie & Rayner, 1975; Rayner, 1975; Rayner, 1998).

There are three possible explanations for the high frequency misspelling landing position result. First, the high frequency misspelled strings, or letter sequences within these strings, might have been identified as illegal. Secondly, the stimuli were chosen primarily on the basis of token, rather than type, frequency. Although there were no significant differences in type frequency, the high frequency misspelling condition had initial trigrams with a greater range and variation (range: 1-679, $SD = 115$) than the correctly spelled condition (range: 8 - 421, $SD = 88$) and therefore differences in type frequency (i.e. informativeness) might have influenced

fixation positions. Thirdly, given that the high frequency misspelling result was a surprising finding in relation to previous research, it may be spurious.

Experiment 2

Experiment 2 was designed to distinguish between the three alternative explanations for the high frequency misspelling result in Experiment 1. In order to do this, we constructed a set of materials in which a critical string was spelled correctly with an uninformative initial trigram, misspelled with an uninformative initial trigram, or misspelled with an informative initial trigram. Each of the three explanations for the results of Experiment 1 described above generate different predictions for Experiment 2. First, if fixation positions are influenced by any kind of misspelling then landing positions should be nearer the beginning of the critical string in both of the misspelled conditions, compared to the correctly spelled condition. Secondly, if lexical preprocessing of a non-fixated word influences where words are first fixated then the informativeness of word beginnings might affect landing positions. Consequently, we might expect fixation positions to be nearer the beginning of the informative misspelled strings compared to the uninformative misspelled and correctly spelled strings. Thirdly, if processing beyond the level of the orthographic familiarity of word initial trigrams does not influence where words are first fixated then there should be no difference in landing positions for letter strings with equally familiar initial letter sequences. That is to say, there should be no effect of spelling on landing positions.

Previous studies of the effects of orthographic regularity on landing positions (Beauvillain & Doré, 1998; Beauvillain et al., 1996; Doré & Beauvillain, 1997; Everatt & Underwood, 1992; Hyönä, 1995; Hyönä et al., 1989; Radach et al., 2003; Underwood et al., 1990; Underwood et al., 1987; Vonk et al., 2000) have confounded

the variables of orthographic familiarity and informativeness. Kennedy (2000) did carefully manipulate these, and other, variables in artificial task experiments but found no effects of letter sequence frequency on landing positions. Experiment 2 provides a test of the hypothesis that informativeness of the word initial trigram, independent of the orthographic familiarity of the word initial trigram, influences fixation positions.

Method

Participants. Twenty-four native English speakers at the University of Durham were paid to participate in the experiment. The participants all had normal or corrected to normal vision and were naïve in relation to the purpose of the experiment.

Materials. Word frequencies and n-gram frequencies were calculated using the CELEX English word form corpus (Baayen, et al, 1995). All of the critical words were eight or nine characters long ($\underline{M} = 8.5$, $\underline{SD} = 0.5$) and the mean word frequency in counts per million was 17 ($\underline{SD} = 29.5$). There were three conditions that were manipulated within participants and items. The critical words were spelled correctly or the second letter was misspelled to create either an uninformative or informative initial trigram.

Position specific n-gram frequencies were calculated in counts per 17.9 million. The initial trigram token frequencies tended to be higher in the uninformative ($\underline{M} = 8696$, $\underline{SD} = 10545$) and informative ($\underline{M} = 6879$, $\underline{SD} = 10974$) misspelled conditions compared to the correctly spelled condition ($\underline{M} = 4325$, $\underline{SD} = 5262$) although these differences were not significant (t 's < -1.8 , $ps > 0.9$). The uninformative misspelled condition also tended to have higher type frequency initial trigrams ($\underline{M} = 47$, $\underline{SD} = 26$) compared to the correctly spelled condition ($\underline{M} = 32$, $\underline{SD}$

= 29) although this was not significant, $t(23) = -1.72$, $p = 0.1$. Importantly, the informative misspelled condition had significantly lower type frequency initial trigrams ($M = 6$, $SD = 3$) than both the correctly spelled condition, $t(23) = 4.45$, $p < 0.01$ and the uninformative misspelled condition, $t(23) = 7.51$, $p < 0.01$. The type and token frequencies of the initial bigrams followed a similar pattern. The type and token monogram frequencies of the misspelled second letter were significantly higher in the misspelled condition compared to the correctly spelled condition ($t's > 2$). Importantly, the initial trigrams of the misspelled conditions were not more orthographically unfamiliar than the correctly spelled condition.

The 24 critical words were embedded in identical sentence frames for each condition. Each of the sentences was no longer than one line of text (78 characters) and the critical word appeared approximately in the middle of the sentence. The words before and after the critical word were either five or six letters long and had medium to high frequencies. Most of the sentences included context relevant to the critical word at the beginning of the sentence. See Appendix for example experimental sentences and critical words.

Three lists of 96 items were constructed and eight participants were randomly allocated to each list. Each list included 24 experimental items of which 8 items were from each of the three misspelling conditions. The conditions were rotated following a Latin square design. There were 16 misspelled filler items with misspellings in a variety of word lengths and in a variety of positions within the word and the sentence. There were also 56 filler items that were spelled correctly. Therefore of the 96 items, 32 contained a misspelling. Thirty-two of the sentences were followed by a comprehension question to ensure that participants concentrated on understanding the

sentences. The sentences were presented in a fixed random order with six filler sentences at the beginning.

Procedure. The experimental procedure was the same as in Experiment 1. The entire experiment lasted approximately 30 minutes and participants were given one break.

Analyses. The analyses were the same as in Experiment 1. 1.4 percent of trials were excluded due to either no first pass fixations on the sentence prior to word $n-1$ or tracker loss or blinks on first pass reading of word $n-1$ or the critical string.

Results

The results were analysed in the same manner as for Experiment 1. The mean error rate on the comprehension questions was 2.3 percent.

Parafoveal-on-foveal effects. Table 1 shows the mean fixation durations prior to fixating the critical string. There were no significant effects of spelling on first fixation, gaze duration or total time for word $n-1$ (F 's < 1.1). There was also no difference in the probability of refixating word $n-1$ (F 's < 1). There were no significant effects of spelling on the duration of the fixation prior to first fixating the critical word for all of the data, for saccades launched from word $n-1$ and for saccades launched from three or less characters from the critical word (F 's < 1). Once again, the results show no evidence of parafoveal-on-foveal effects.

Reading time measures. Table 1 shows the mean reading time measures on the critical string and word $n+1$. For the critical string there were significant effects of spelling on first fixation, $F_1(2,46) = 8.75$, $p < 0.01$, $MSE = 19235$; $F_2(2,46) = 6.59$, $p < 0.01$, $MSE = 19378$, gaze duration, $F_1(2,46) = 19.56$, $p < 0.01$, $MSE = 207245$; $F_2(2,46) = 18.96$, $p < 0.01$, $MSE = 205442$, and total time, $F_1(2,46) = 54.42$, $p < 0.01$, $MSE = 17476$; $F_2(2,46) = 24.98$, $p < 0.01$, $MSE = 38297$. For all measures reading

times were longer on the two misspelled conditions compared to the correctly spelled condition ($F's > 6.5$, $ps < 0.05$). There were no significant differences in reading time between the uninformative and informative misspelling conditions ($t's < 1.6$, $ps > 0.1$).

Table 1 shows the mean reading times after leaving the critical string. There was no effect of spelling on the duration of the fixation after leaving the critical string or on first fixation durations on word n+1 ($F's < 1.2$). There were also no effects of spelling on gaze duration on word n+1, $F_1(2,46) = 2.31$, $p = 0.11$, $MSE = 7719$; $F_2 < 1$, or across items for total time ($F_2 < 1$) although there was a significant effect of spelling across participants for total time on word n+1, $F_1(2,46) = 3.8$, $p < 0.05$, $MSE = 28584$.

Reading times were longer on the misspelled words than the correctly spelled words and there were no reliable spillover effects. These data indicate that misspelled words were more difficult to process than the correctly spelled words.

Landing position. Table 2 shows the mean first fixation positions on the critical string in each of the conditions. There were no significant effects of spelling on landing position ($F's < 1$). Figure 3 shows the distribution of landing positions for each of the conditions, note that most fixations landed on the preferred viewing position.

Insert Figure 3 here

Incoming saccade extent and launch site. Table 2 shows the mean saccade extents and launch sites for each condition. There were no effects of spelling on the launch site or incoming saccade extent prior to fixating the critical string ($F's < 1$).

There was no effect of spelling on the probability of skipping word $n-1$ before fixating the critical string (trials in which regressions were made from word $n-1$ were considered separately) (F 's < 1).

Frequency of refixations. Table 3 shows the probability of skipping or making one or more than one fixation on the critical string on first pass. There was a significant effect of spelling on the probability of refixating the critical string on first pass, $\underline{F}_1(2,46) = 9.7$, $p < 0.01$, $MSE = 211$; $\underline{F}_2(2,46) = 6.69$, $p < 0.01$, $MSE = 316$. The correctly spelled condition was significantly less likely to be refixated on first pass than the uninformative misspelling condition, $\underline{F}_1(1,23) = 9.88$, $p < 0.01$, $MSE = 508$; $\underline{F}_2(1,23) = 11.51$, $p < 0.01$, $MSE = 471$, or the informative misspelling condition, $\underline{F}_1(1,23) = 16$, $p < 0.01$, $MSE = 443$; $\underline{F}_2(1,23) = 10.65$, $p < 0.01$, $MSE = 672$. Similar to the reading time measures, these results suggest that the misspelled words were more difficult to process because they produced more first pass refixations.

There was also a significant effect of spelling on the probability of first refixating to the left of the initial fixation position⁷, $\underline{F}_1(2,38) = 3.33$, $p < 0.05$, $MSE = 2835$; $\underline{F}_2(2,36) = 4.95$, $p < 0.05$, $MSE = 3202$. Refixations to the left of the initial fixation position were significantly more likely in the informative misspelled condition compared to the correctly spelled condition, $\underline{F}_1(1,19) = 8.71$, $p < 0.05$, $MSE = 10945$; $\underline{F}_2(1,18) = 7.85$, $p < 0.05$, $MSE = 11299$. Leftward refixations also tended to be more likely in the uninformative misspelled condition compared to the correctly spelled condition but this effect was significant across items, $\underline{F}_2(1,18) = 9.1$, $p < 0.05$, $MSE = 7533$, but not participants, $\underline{F}_1(1,19) = 2.53$, $p = 0.129$, $MSE = 4835$. There was no difference in the probability of refixating to the left between the

uninformative and informative conditions (t 's < 1.2). The results again show that misspellings increase the probability of making regressive refixations.

Discussion.

Experiment 2 clearly showed that neither the presence of a misspelling nor the informativeness of word initial letters reliably influenced where words were first fixated. The results do not support the suggestion that lexical factors influence first fixation positions on words. There is a clear inconsistency between the high frequency misspelling effect in Experiment 1 and the results of Experiment 2. It must be concluded that influences on landing positions beyond the level of the orthographic familiarity of the initial trigrams are, at best, unreliable. However, the results do show that misspellings influence the directions of refixations.

Similar to Experiment 1, the results also provide no support for the notion that non-fixated text influences fixation durations. There was also no difference in reading times on words that were misspelled with an informative or uninformative initial trigram. These results suggest that the time to process a misspelled word is not influenced by the number of possible candidates that are generated by the initial trigram.

General Discussion

The aim of this study was to investigate whether orthographic familiarity and informativeness influence landing positions in the reading of English sentences. In accordance with previous evidence, our results clearly show that most fixations land left of the word centre on the preferred viewing position (Dunn-Rankin, 1978; McConkie et al., 1988; Rayner, 1979) and that more distant launch sites are associated with landing positions nearer the beginning of words (Hyönä, 1995; McConkie, Kerr,

& Dyre, 1994; McConkie et al., 1988; Radach & Kempe, 1993; Radach & McConkie, 1998; Rayner et al., 1996). The results of the present study provide no reliable support for the influence of lexical processing on fixation positions. The most important finding is that first fixation landing positions were nearer the beginning of words with unfamiliar orthography. To our knowledge, this is the first study to find an effect of orthographic familiarity on landing positions for English language sentences. The results are supported by other recent experiments that have shown that orthographic processing influences where words are first fixated in the reading of correctly spelled English sentences (White & Liversedge, in prep). These results are particularly striking since current models of eye movements in reading make no attempt to account for the influence of orthography on first fixation landing positions (O'Regan, 1990; Reichle et al., 1998, 1999; Reilly & O'Regan, 1998). Our experiments are a clear demonstration that these effects do occur and any complete model of oculomotor control in reading must account for them.

The results of Experiment 1 support a number of studies in languages other than English that have shown that word initial orthographic regularity influences where words are first fixated (Beauvillain & Doré, 1998; Beauvillain et al., 1996; Doré & Beauvillain, 1997; Hyönä, 1995; Radach et al., 2003; Vonk et al., 2000). However, in support of Rayner and Morris (1992), and against the claims of Underwood and colleagues (Everatt & Underwood, 1992; Hyönä et al., 1989; Underwood et al., 1990; Underwood et al., 1987), the results provide no reliable support for the suggestion that informativeness, or the number of potential lexical candidates, can influence where words are first fixated.

Experiment 1 provided a strong test of the possibility that orthographic familiarity produces parafoveal-on-foveal effects and Experiment 2 provided a strong

test of the possibility that informativeness produces parafoveal-on-foveal effects. However both Experiments showed no evidence of such effects. Previous studies using artificial tasks (Kennedy, 1998, 2000; Murray, 1998; Murray & Rowan, 1998), and sentence reading studies (Inhoff, Radach et al., 2000; Inhoff, Starr et al., 2000; Pynte et al., 2003; Kennedy et al., 2002; Underwood et al., 2000) have suggested that the characteristics of a word can influence fixation times on the previous word. However, as also reported in Rayner et al. (2003), in both the experiments reported here, there were no effects of the spelling of the critical string on the fixation duration prior to fixating the critical string, even when the prior fixation was three or less characters from the beginning of the critical string. Furthermore, the landing position effects in Experiment 1 show that the initial letter sequences were processed before the critical strings were fixated and yet there was no effect of the initial letter sequence on the prior fixation duration. Importantly, the absence of such effects in the present study at least suggests that there is no strong consistent parafoveal-on-foveal processing in normal sentence reading. That is, the results provide no support for the hypothesis that words are processed in parallel such that the sub-lexical and lexical characteristics of a non-fixated word can influence fixation durations or refixation probabilities on the previous word. Clearly, these data indicate that non-foveal processing influences where the eyes move but does not influence when the eyes move to fixate a non-foveal string.

Three types of possible explanations have been proposed to account for the effects of orthographic familiarity on fixation positions found in Experiment 1. First, Hyönä (1993) and Beauvillain and Doré (1998) suggested that irregular letter sequences “pop out” and attract saccades towards them. Secondly, Findlay and Walker (1999) proposed that visually unfamiliar (intrinsically salient) letter sequences

could influence saccade computation within a salience map. The third possible explanation is that non-foveal processing difficulty reduces the perceptual span and consequently shortens saccades (Hyönä, 1995; Hyönä & Pollatsek, 1998, 2000). In order for the processing difficulty hypothesis to explain the results of Experiment 2, it must be assumed that the uninformative and informative misspellings did not induce sufficient non-foveal processing difficulty to influence saccades.

A further important question is whether the effects of orthography on landing positions form part of a strategy that is efficient for word recognition, or whether they are simply due to mandatory processes that function in all types of visual processing such as scene viewing or visual search. Legge, Klitz, and Tjan (1997) suggested that an ideal reader would use all available information to determine the length of a saccade in order to minimise uncertainty for word recognition. However, if this was the case then it is not clear why a number of studies have failed to find effects of within word characteristics on first fixation positions. The landing position differences in Experiment 1 were very small and one might reasonably assume that such differences would be much greater if landing positions were central to visual word recognition. Also, landing position effects such as increasing the probability of landing on the space before the word are not necessarily optimal for word recognition (McConkie, Kerr, Reddix, Zola, & Jacobs, 1989; Vitu, O'Regan, & Mittau, 1990). If the influence of orthography on landing positions is not a strategy for efficient word recognition then an alternative possibility is that the effects might simply result from standard visual processes, as suggested by Findlay and Walker (1999).

The current experiments also yielded interesting results regarding the nature of refixations. O'Regan (1990) argued that the locations of refixations are determined by the position of the first fixation on a word in relation to the word length. However in

both Experiments 1 and 2 there were more refixations to the left for misspelled critical strings. In support of previous studies (Hyönä, 1995; Hyönä & Pollatsek, 1998; Pynte, Kennedy, & Murray, 1991; Pynte, 1996; Pynte, 2000) the results suggest that the characteristics of a word influence the location of refixations. Once again, current models of eye movements in reading make no attempt to explain these effects.

In conclusion the results show that the orthographic familiarity, but not informativeness, of non-fixated words influences where words are first fixated and refixated. However importantly the results provide no evidence for parafoveal-on-foveal effects.

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Appendix

Examples of experimental sentence frames and critical strings for Experiments 1 and 2. A full set of materials is available from the first author on request.

Experiment 1, the slashes denote the correctly spelled, high frequency misspelled, low frequency misspelled, legal pronounceable misspelled and illegal unpronounceable misspelled condition respectively.

Farmers complained when local agricultural / acricultural / aoricultural / akricultural / ngricultural ground was contaminated.

The gallery presented great exhibitions / ethibitions / ephibitions / ebhibitions / dxhibitions during the school holidays.

The scientist worked in the large laboratory / liboratory / luboratory / lyboratory / lwboratory every day of the week.

Experiment 2, the slashes denote the correctly spelled, uninformative misspelled and the informative misspelled condition respectively.

Pip hated stairs and he even used the short escalator / encalator / eacalator down to the first floor.

The builder gave a cheap estimate / entimate / eitimate before he realised the tiles were expensive.

The musicians enjoyed playing in the small orchestra / occhestra / onchestra every Monday night.

Footnotes

¹ Artificial tasks do not involve the measurement of normal reading. However, advocates of such tasks usually argue that they are intended to generalise to reading. Such tasks often provide a greater degree of control over the location from which saccades are launched. Typically, two or three adjacent words are presented and participants then make a categorical decision.

² In Experiment 1, five critical words did not have illegal pronounceable misspellings because there were no suitable letters that could meet the necessary constraints. Therefore the items analyses were based on 30 items and the participants analyses were based on 30 items in the illegal pronounceable condition and 35 items in each of the other four spelling conditions.

³ For Experiment 1, the analysis of saccades launched from three or less characters away was based on data from 37 participants due to failure to fixate these characters or excluded data.

⁴ If a Mauchly test of sphericity was significant, the Greenhouse-Geisser Epsilon adjustment was used. Unless otherwise indicated, if the degrees of freedom do not correspond to the number of conditions and participants or items then the results were corrected for sphericity.

⁵ In Experiment 1, the E_1 analysis of first pass reading time on word $n+1$ was based on data from 43 participants due to skipping and excluded data.

⁶ In Experiment 1, for the analyses of the probability of refixating to the left, only participants and items that produced refixations in all of the conditions were

included. Consequently the $\underline{E}_1$ analysis was based on 27 participants and the $\underline{E}_2$ analysis was based on 23 items.

⁷ In Experiment 2, for the analyses of the probability of refixating to the left, only participants and items that produced refixations in all of the conditions were included. Consequently the $\underline{E}_1$ analysis was based on 20 participants and the $\underline{E}_2$ analysis was based on 19 items.

Author Note

The order of authors is arbitrary. Sarah J. White acknowledges the support of a University of Durham Studentship. The experiments reported here form part of the first author's PhD thesis. The authors would like to thank Ralph Radach and Joel Pynte for helpful comments on this manuscript.

Tables

Table 1: Reading Time Measures for Each Condition in Experiments (Exp) 1 and 2. Mean First Fixation Duration (FF) and Gaze Duration (GD) on Word n-1, Word n and Word n+1. Total Time (TT) on Word n and Word n+1. Fixation Duration Prior to Fixating the Critical String (Prior Fixation) for All the Data (All), for Saccades Launched from Word n-1 (Word n-1) and Saccades Launched from Three or Less Characters from the Beginning of the Critical String (≤ 3). Fixation Duration After Leaving the Critical String (Fixation n+1).

Exp	Condition	Word n-1		Fixation n-1			Word n		Fixation n+1		Word n+1		
		FF	GD	All	Word n-1	≤ 3	FF	GD	TT		FF	GD	TT
1	Correct	267	291	257	264	267	276	339	381	263	271	279	312
	High frequency misspelling	267	291	256	267	261	297	428	610	264	278	302	380
	Low frequency misspelling	260	281	253	255	245	301	478	632	269	285	314	366
	Illegal pronounceable misspelling	272	298	257	268	257	301	478	637	266	282	310	367
	Illegal unpronounceable misspelling	269	298	262	270	255	318	507	675	276	280	302	363
2	Correct	271	305	260	260	252	302	360	434	277	286	306	353
	Uninformative misspelling	261	292	256	261	257	340	518	785	280	292	321	405
	Informative misspelling	263	294	264	259	259	358	525	771	291	298	333	429

Table 2: Mean Landing Positions, Incoming Saccade Extents and Launch Sites for Experiments (Exp) 1 and 2. Standard Deviations in Parentheses.

Exp	Condition	Landing position	Saccade extent	Launch site
1	Correct	4.4 (2.2)	9.1 (3.2)	4.7 (3.4)
	High frequency misspelling	4.0 (2.3)	8.9 (2.6)	4.9 (3.4)
	Low frequency misspelling	4.0 (2.1)	8.7 (2.6)	4.7 (3.1)
	Illegal pronounceable misspelling	3.9 (2.2)	8.8 (3.1)	4.9 (3.5)
	Illegal unpronounceable misspelling	4.1 (2.3)	8.8 (2.9)	4.7 (3.2)
2	Correct	3.5 (2.1)	8.4 (2.3)	4.9 (2.7)
	Uninformative misspelling	3.5 (2.1)	8.4 (2.5)	4.9 (2.9)
	Informative misspelling	3.6 (2.2)	8.3 (2.8)	4.8 (2.8)

Table 3: Frequency of Number of First Pass Fixations on the Critical String for Experiments (Exp) 1 and 2. Frequency of First Refixating to the Left of the Initial Fixation on the Critical String for Multiple First Pass Fixation Cases.

Exp	Condition	Fixation frequency			Leftward refixation
		Skip	One	$\geq$ Two	
1	Correct	.03	.72	.25	.34
	High frequency misspelling	.02	.64	.34	.34
	Low frequency misspelling	.02	.56	.42	.49
	Illegal pronounceable misspelling	.01	.58	.41	.46
	Illegal unpronounceable misspelling	.02	.55	.43	.56
2	Correct	.03	.74	.23	.16
	Uninformative misspelling	.02	.6	.38	.29
	Informative misspelling	.01	.59	.4	.39

Figure captions

Figure 1: First fixation landing position distributions on the critical string for Experiment 1. Landing position zero is the space before the word and landing position one is the first letter of the word.

Figure 2: Launch site distributions for each condition for Experiment 1.

Figure 3: First fixation landing position distributions on the critical string for Experiment 2. Landing position zero is the space before the word and landing position one is the first letter of the word.

Figures

Figure 1:

Figure 2:

Figure 3: