Journal of Experimental Psychology:
Human Perception and Performance
2008, Vol. 34, No. 1, 205–223

0096-1523/08/$12.00 DOI: 10.1037/0096-1523.34.1.205

Eye Movement Control During Reading: Effects of Word Frequency and Orthographic Familiarity

Sarah J. White
University of Leicester

Word frequency and orthographic familiarity were independently manipulated as readers' eye movements were recorded. Word frequency influenced fixation durations and the probability of word skipping when orthographic familiarity was controlled. These results indicate that lexical processing of words can influence saccade programming (as shown by fixation durations and which words are fixated). Orthographic familiarity, but not word frequency, influenced the duration of prior fixations. These results provide evidence for orthographic, but not lexical, parafoveal-on-foveal effects. Overall, the findings have a crucial implication for models of eye movement control in reading: There must be sufficient time for lexical factors to influence saccade programming before saccade metrics and timing are finalized. The conclusions are critical for the fundamental architecture of models of eye movement control in reading—namely, how to reconcile long saccade programming times and complex linguistic influences on saccades during reading.

Keywords: reading, eye movements, word frequency, orthography, models of eye movement control in reading

As we read, the linguistic characteristics of words influence the duration of fixations and which words are fixated (Rayner, 1998). The present study provides a detailed examination of the influences of orthographic familiarity and word frequency on eye movements during reading. It thus provides a critical assessment of the relationship between linguistic text processing and the systems that control when and where the eyes move. Specifically, whether lexical processing can have an immediate influence on saccade programming is examined. The issues addressed here have crucial implications for the architecture of models of eye movement control in reading. This article adds to a growing number of recent studies specifically aiming to test and develop such accounts (Inhoff, Eiter, & Radach, 2005; Kliegl, Nuthmann, & Engbert, 2006; Rayner, Ashby, Pollatsek, & Reichle, 2004; Rayner, Juhasz, & Brown, 2007; Rayner, Liversedge, White, & Vergilino-Perez, 2003; Reingold & Rayner, 2006). Previous studies of the effects of word frequency and orthography are discussed first. Models of eye movements in reading, which may account for such effects, are summarized. Finally, the issue of whether processing of parafoveal information can influence prior fixations (parafoveal-on-foveal effects) and where words are fixated (saccade specification) is considered.

Word Frequency Effects

The influence of word frequency on word processing is an established finding both for isolated word response time tasks (Monsell, 1991) and sentence reading (Rayner, 1998). Inhoff and Rayner (1986; see also Rayner & Duffy, 1986) first demonstrated that for words in sentences with word length controlled, first fixation durations and gaze durations (the sum of fixations before leaving a word) are longer on infrequent than on frequent words. Word frequency effects during sentence reading are usually spatially localized to the word that induced those effects (Henderson & Ferreira, 1990, 1993; Raney & Rayner, 1995), and in other cases there are effects of word frequency both on the word itself and on subsequent spillover fixations (Kennison & Clifton, 1995; Kliegl et al., 2006; Rayner & Duffy, 1986). Frequent words are also more likely to be skipped than infrequent words (e.g., Rayner, Sereno, & Raney, 1996; see also Brysbaert, Drieghe, & Vitu, 2005; Brysbaert & Vitu, 1998). Note that other factors, such as age of acquisition and concreteness, have been shown to have independent influences on reading behavior even though they are correlated with word frequency (Juhasz & Rayner, 2003).

The influence of word frequency on eye movement behavior during reading suggests that lexical word recognition processes can influence when and where the eyes move. However, of the large number of studies that have manipulated word frequency, a very small proportion have attempted to control for the orthographic characteristics of the words. It is easy to confound word frequency with orthographic familiarity because frequent words are necessarily orthographically familiar, whereas many infrequent words are orthographically unfamiliar. A few studies have attempted to control for orthographic characteristics using the measure of type frequency, which is the number of words that contain a particular letter sequence. Rayner and Duffy (1986) undertook post hoc analyses that showed higher trigram-type frequencies for frequent than for infrequent target words, but they found that word frequency effects still held for those items in which differences in type frequency were reversed. Bertram and Hyönä (2003) showed word frequency effects on first fixation and gaze durations when

This research was supported by Biotechnology and Biological Sciences Research Council Grant 12/S19168. I thank Keith Rayner, Françoise Vitu, Reinhold Kliegl, Alan Kennedy, Erik D. Reichle and Simon P. Liversedge for their comments on earlier versions of this article.

Correspondence concerning this article should be addressed to Sarah J. White, School of Psychology, University of Leicester, Lancaster Road, Leicester LE1 9HN, United Kingdom. E-mail: s.j.white@dunelm.org.uk

bigram type frequency was controlled. Rayner et al. (1996) reported effects of word frequency on fixation durations and word skipping for items that had equal monogram- and bigram-type frequency counts.

Importantly, previous reading studies only attempted to control for orthography by using type frequency counts. As type frequency is simply the number of words that contain a particular letter sequence, it is effectively a measure of lexical informativeness or redundancy. For example, the trigram *pne* at the word beginning has a very low type frequency and is very informative because it highly constrains the number of possible word candidates (*pneumatic*, *pneumonia*). Importantly, type frequency does not reflect letter sequence familiarity. For example, there are a number of words that begin with the letter sequence *irr*, but very few of these are very frequent; hence, although *irr* has a relatively high type frequency, it actually has quite low orthographic familiarity. Manipulations of only type frequency or informativeness should therefore reflect processing at the level of lexical candidates.

A better measure of orthographic familiarity is token frequency, which is the sum of the frequencies of words that contain a particular letter sequence.[1] Critically, effects of orthographic familiarity may involve processing at a sublexical or even a visual level (see the Orthographic Effects section below). Note that other studies have tested for effects of word frequency, and the type and token frequency of word-initial letters, in multiple isolated word-processing tasks (Kennedy, 1998, 2000; Kennedy, Pynte, & Ducrot, 2002) and sentence reading (Kennedy & Pynte, 2005; Pynte & Kennedy, 2006). However, the orthographic characteristics beyond the word-initial letters were not controlled in these studies and, consequently, they did not test whether word frequency effects occur independently of differences in orthographic familiarity. To summarize, although previous studies of word frequency have attempted to control for orthography to some extent, these studies did not eliminate the possibility that differences in orthographic familiarity could have produced, or at least influenced, the word frequency effect.

The issue of whether orthographic familiarity may be contributing to the word frequency effect is of particular importance for the case of word skipping. Critically, the linguistic characteristics of skipped words must be processed in parafoveal vision (where stimuli are degraded due to acuity limitations), which reduces the speed of linguistic processing of those words (Rayner & Morrison, 1981; Schiepers, 1980). In addition, fixations prior to word skipping are likely to involve processing of the fixated word too, which may reduce the time (or resources) available within a fixation for processing of the parafoveal word (e.g., Morrison, 1984). Of the studies that have shown word frequency effects on word skipping, only one study controlled for type-bigram frequency (Rayner et al., 1996). Not only was orthographic familiarity not controlled but orthographic processing of trigrams, not just bigrams, could have contributed to the effect. Furthermore, the fact that some studies have not shown word frequency effects on word skipping (Calvo & Meseguer, 2002; Henderson & Ferreira, 1993) raises the possibility that other factors, such as orthographic familiarity, may be important. Visual familiarity may play an important role in word processing (Martin, 2004), and some models suggest that fixation durations (McDonald, Carpenter, & Shillcock, 2005) and especially word skipping (Engbert, Nuthmann, Richter, & Kliegl, 2005) are not necessarily driven by full word identification. Consequently, it is particularly feasible that processing of orthographic familiarity may have produced the previously reported effects of word frequency on word skipping.

To summarize, previous studies have not provided a proper test of whether word frequency influences fixation durations and word skipping when orthographic familiarity is fully controlled. Differences in orthographic familiarity may have caused, or at least inflated, effects that have been attributed to word frequency. Consequently, previous studies of word frequency do not categorically demonstrate lexical influences on word recognition and eye movement behavior. The issue of whether word frequency effects may be explained by differences in orthographic processing is crucial. If the effects are due to differences in orthography, this raises the critical question of whether lexical factors can have an immediate impact on when and where the eyes move during reading. Basically, given that this issue is so critical for models of eye movement control during reading, it is absolutely essential that a thorough analysis of the effects of word frequency and orthographic familiarity be undertaken. The present study did this by testing the effects of word frequency on eye movement behavior while controlling for monogram, bigram, and trigram token orthographic frequencies.

Orthographic Effects

Studies using isolated word tasks have investigated a wide range of factors related to orthographic processing of words (L. Henderson, 1982). A number of early studies were undertaken into the effects of bigram frequency and word frequency during reading (Gernsbacher, 1984). These studies used isolated word methods such as tachistoscopic presentation of words, naming, and lexical decision, and bigram frequency was controlled only by type frequency counts such as those reported by Mayzner and Tresselt (1965). However, the findings of such studies using low-frequency words have been contradictory, with some indicating that words with high-frequency bigrams are more difficult to process than those with low-frequency bigrams (Broadbent & Gregory, 1968; Rice & Robinson, 1975), while others have shown the opposite result (Biederman, 1966; Seidenberg, Waters, Barnes, & Tanenhaus, 1984; Waters & Seidenberg, 1985). However, as noted above, letter sequences can have different levels of informativeness and familiarity, and it is possible that such differences may be one explanation for the inconsistent results (Grainger & Dijkstra, 1996).

A number of studies using eye-tracking methodologies have examined the role of the informativeness of letter sequences (confounded with orthographic familiarity). Pynte, Kennedy, and Murray (1991) showed longer fixation durations on informative parts of words (see also Holmes & O'Regan, 1987). In sentence reading, Lima and Inhoff (1985) showed that first fixation durations were longer on words that began with constraining (e.g., *dwarf*) compared with less constraining (e.g., *clown*) letter sequences. Other

[1] Note that type and token frequency are often confounded such that the term *orthographic regularity* is used rather than *orthographic familiarity* (White & Liversedge, 2006b). The term *orthographic regularity* can also be used to infer the extent to which letter sequences follow orthographic rules. However, as the present article focuses only on orthographic familiarity, this terminology is not used.

experiments have shown that the orthographic familiarity of the initial letters of long words can influence where they are first fixated (Hyönä, 1995; Radach, Inhoff, & Heller, 2004; Vonk, Radach, & van Rijn, 2000; White & Liversedge, 2004, 2006a, 2006b).

Orthographic familiarity may affect visual, sublexical, or lexical levels of processing. Processing of text at a visual, rather than linguistic, level may modulate the familiarity of visual information such that frequent letter strings may develop higher visual familiarity than infrequent letter strings (Findlay & Walker, 1999). Therefore, any effects of orthographic familiarity must be interpreted as a reflection of processing at least at the level of visual familiarity. However, differences in orthographic familiarity may also be associated with differences in informativeness or constraint (type frequency), and orthographically unfamiliar words may also tend to have more irregular phonology and fewer orthographic neighbors. Consequently, any effects of orthographic familiarity could also be driven by sublexical or even lexical processes. The present study manipulated the orthographic familiarity of the entire word, and it examined whether orthographic familiarity influences fixation durations and word skipping.

Models of Eye Movement Control During Reading

Models of eye movement control vary in the extent to which they suggest that linguistic processing can influence eye movement behavior. Some suggest that eye movements are driven by linguistic processing, at least at the level of lexical access (Just & Carpenter, 1980; Morrison, 1984; Thibadeau, Just, & Carpenter, 1982). Others suggest that linguistic processing influences, or even determines, when and where the eyes move, but this may be indexed by an early stage of word processing (Engbert, Longtin, & Kliegl, 2002; Engbert et al., 2005; Feng, 2006; Kliegl & Engbert, 2003; Legge, Hooven, Klitz, Mansfield, & Tjan, 2002; Legge, Klitz, & Tjan, 1997; McDonald et al., 2005; Pollatsek, Reichle, & Rayner, 2006; Reichle, Pollatsek, Fisher, & Rayner, 1998; Reichle, Pollatsek, & Rayner, 2006; Reichle, Rayner, & Pollatsek, 1999, 2003; Reilly & Radach, 2003, 2006; Richter, Engbert, & Kliegl, 2006).

In contrast, it has been suggested (Deubel, O'Regan, & Radach, 2000; Nazir, 2000), and models have proposed (McConkie & Yang, 2003; O'Regan, 1990, 1992; Reilly & O'Regan, 1998; Suppes, 1990; Yang, 2006; Yang & McConkie, 2001), that eye movements are largely controlled by visual and oculomotor factors and that linguistic processes have a smaller influence, for example by delaying or cancelling programmed saccades. However, such models cannot necessarily account for some linguistic influences on reading behavior, such as the following frequency effects: (a) on the first of multiple first-pass fixations on a word (Rayner et al., 1996), (b) in the absence of visual information (Liversedge et al., 2004; Rayner, Liversedge, et al., 2003), (c) and on gaze durations that cannot be explained by a number of very long fixations or gaze durations (Rayner, 1995; Rayner, Liversedge, et al., 2003). Linguistic factors, therefore, have a critical role in influencing eye movement behavior during reading, and visual- and/or oculomotor-based models cannot fully account for reading eye movement behavior. However, the issue of precisely how linguistic processing influences when and where the eyes move during reading is far from resolved.

The most comprehensive implemented models of eye movement behavior during reading—the E-Z reader model (Pollatsek et al., 2006; Reichle et al., 1998, 1999, 2003, 2006) and the SWIFT ([Autonomous] **S**accade-Generation **W**ith **I**nhibition by **F**oveal **T**argets) model (Engbert et al., 2002, 2005; Kliegl & Engbert, 2003; Richter et al., 2006)—include a period of saccade programming during which the planned timing and metrics of the subsequent saccade are prepared (see also Salvucci, 2001). The time necessary to program a saccade has been estimated to be 175–200 ms (Rayner, Slowiaczek, Clifton, & Bertera, 1983), or 125 ms once 50 ms of mandatory visual processing has been taken into account (Pollatsek et al., 2006). Fixation durations in reading are on average 200–250 ms long (Rayner, 1998), and so a substantial portion of the time during a fixation could involve programming the next saccade. Although linguistic processing can continue during this period, it may not necessarily influence saccade programming.

Saccade programming is composed of a labile period, during which the saccade can be cancelled, and a nonlabile period, during which the saccade metrics are finalized and the saccade cannot be cancelled (Becker & Jürgens, 1979; Deubel et al., 2000). In the E-Z reader model, the mean durations of the labile and nonlabile stages are 100 ms and 25 ms, respectively (Pollatsek et al., 2006). In the SWIFT model, the labile stage is between 50 and 150 ms, and the nonlabile stage is between 5 and 50 ms (Engbert et al., 2005) or else these values are fixed at 150 ms and 50 ms, respectively (Richter et al., 2006). In the E-Z reader and SWIFT models, linguistic factors can determine, or influence, when the labile stage of saccade programming commences. In both cases, the time at which the saccade program is triggered effectively influences when the subsequent saccade is executed and, therefore, the duration of fixations. Critically, given the time required for saccade programming (~125 ms) and the average duration of fixations (~250 ms), such linguistic influences on when saccade programming is initiated would necessarily have to occur relatively early during fixations.

Linguistic processing during the labile stage of saccade programming may also influence current fixation durations or the next saccade target. In both the E-Z reader and SWIFT models, such mechanisms have been adopted to account for word skipping. In the E-Z reader model, the labile stage can be cancelled and restarted such that the word target is changed and a new saccade program can commence. In contrast, in the SWIFT model, the saccade target location is always specified at the end of the labile stage. Note that even when linguistic factors impact late during a fixation at the end of the labile stage of saccade programming, there will still be some delay before the saccade can be executed due to the subsequent nonlabile stage.

The issue of how linguistic processing can influence saccade programming, taking account of saccade programming times, is one of the most critical issues for the design of models of eye movements in reading. The present study tested whether lexical factors (word frequency) influence saccade programming (fixation durations and word skipping) independent of sublexical factors (orthographic familiarity). If the lexical factor of word frequency influences fixation durations or word skipping, this must be explained by either an early linguistic influence on when saccade programming is initiated or a later influence during, or at the end of, the labile stage of saccade programming.

Both the E-Z reader and SWIFT models suggest that word frequency affects saccade programming, and so they predict that this influences both fixation durations and word skipping. However, both models are vague about precisely how word frequency affects the difficulty of word processing. Given the timing constraints of the proposal that linguistic factors trigger the initiation of saccade programming, it is quite plausible that the sublexical factor of orthographic familiarity, and not the lexical factor of word frequency, might influence saccades within such a framework. Nevertheless, if the present study shows that word frequency does have an influence—for example, on how long words are first fixated—then this would suggest that the linguistic processes that occur prior to saccade programming in these models must be of a lexical nature.

Parafoveal-on-Foveal Effects of Word Frequency and Orthography

Many studies have shown that parafoveal processing of words to the right of fixation can influence the probability of word skipping and can also facilitate subsequent processing of those words when they are later fixated, a phenomenon known as *preview benefit* (Rayner & Pollatsek, 1981). However, the issue of whether parafoveal processing of words can influence fixations prior to fixation of those words (fixation $n - 1$)—a phenomenon known as *parafoveal-on-foveal effects*—is controversial. Previous research testing whether orthographic familiarity and word frequency produce parafoveal-on-foveal effects is reviewed below. The investigation of parafoveal-on-foveal effects is especially critical because it has important implications for models of eye movements in reading. Serial processing models suggest that words are lexically processed one at a time (Morrison, 1984; Pollatsek et al., 2006; Reichle et al., 1998, 1999, 2003, 2006). In contrast, parallel accounts suggest that multiple words can be processed at once (Engbert et al., 2002, 2005; Kennedy, 2000; Kliegl & Engbert, 2003; McDonald et al., 2005; Reilly & Radach, 2003, 2006; Richter et al., 2006). If the characteristics of a parafoveal word influence fixation $n - 1$, this could be indicative of parallel processing of words. There are alternative explanations for these effects, such as inaccurate saccade targeting, which are explained below and further in the Discussion. To be clear, parallel-based models predict both sublexical and lexical parafoveal-on-foveal effects, whereas the core assumptions of serial-based models do not predict such effects, although additional assumptions or explanations have been offered to account for these. Importantly, the present study provided an important opportunity to test for the presence of parafoveal-on-foveal effects in a carefully controlled experiment.

Some sentence reading studies suggest that parafoveal preprocessing, at least at the level of orthographic familiarity, can influence fixation $n - 1$ (Inhoff, Starr, & Shindler, 2000; Pynte, Kennedy, & Ducrot, 2004; Rayner, 1975; Starr & Inhoff, 2004; Underwood, Binns, & Walker, 2000), though other studies have shown no such effects (Rayner, Juhasz, & Brown, 2007; White & Liversedge, 2004, 2006b). In addition, a number of studies using multiple isolated word-processing tasks (Kennedy, 1998, 2000; Kennedy et al., 2002) and sentence reading (Kennedy & Pynte, 2005; Pynte & Kennedy, 2006) have suggested that the informativeness of the word-initial letters of a parafoveal word can influence fixation $n - 1$. Some studies using isolated word-processing (Kennedy, 1998, 2000; Kennedy et al., 2002) and sentence reading (Kennedy & Pynte, 2005; Kliegl et al., 2006; Pynte & Kennedy, 2006) tasks have suggested that word frequency can also produce such effects. However, other studies have shown inconsistent (Hyönä & Bertram, 2004) or no (Calvo & Meseguer, 2002; Henderson & Ferreira, 1993; Rayner, Fischer, & Pollatsek, 1998; Schroyens, Vitu, Brysbaert, & d'Ydewalle, 1999) parafoveal-on-foveal effects of word frequency, and other research has shown no evidence of other lexical parafoveal-on-foveal effects (Altarriba, Kambe, Pollatsek, & Rayner, 2001; Hyönä & Häikiö, 2005; Inhoff, Starr, & Shindler, 2000; Rayner, 1975; Rayner, Juhasz, & Brown, 2007; for reviews, see Rayner & Juhasz, 2004; Rayner, White, Kambe, Miller, & Liversedge, 2003).

Many fixations are mislocated during reading (McConkie, Kerr, Reddix, & Zola, 1988; Nuthmann, Engbert, & Kliegl, 2005), and it has been suggested that parafoveal-on-foveal effects may arise because of such inaccurately targeted saccades (Drieghe, Rayner, & Pollatsek, in press; Rayner, Warren, Juhasz, & Liversedge, 2004; Rayner, White, et al., 2003). That is, saccades intended to land on the critical word mistakenly land at the end of the previous word, but attention is still allocated to the originally intended location such that processing of the critical word influences the fixation duration on the previous word. Importantly, these effects would be expected to be in a conventional direction. For example, lower frequency and less familiar parafoveal words would produce longer fixations on foveal words than would higher frequency and more familiar parafoveal words. Reports of postlexical parafoveal-on-foveal effects have shown effects in a conventional direction that might, therefore, be explained by inaccurate saccade targeting (Inhoff, Radach, Starr, & Greenberg, 2000; Murray, 1998; Rayner, Warren, et al., 2004). Nevertheless, Starr and Inhoff (2004) showed that parafoveal-on-foveal effects of orthographic familiarity held even when prior fixations at the very end of the foveal word were eliminated from analysis. Furthermore, other studies that have shown that parafoveal information influences the probability of refixating on the foveal word, or that the parafoveal-on-foveal effects are opposite to the conventional direction, cannot be explained by the inaccurate saccade targeting account (Kennedy, 1998, 2000; Kennedy & Pynte, 2005; Kennedy et al., 2002).

The present study provided an additional test of whether sublexical (orthographic familiarity) and lexical (word frequency) characteristics of parafoveal words influence foveal fixations in the form of parafoveal-on-foveal effects. The question of whether there are lexical parafoveal-on-foveal effects in sentence reading under carefully controlled experimental conditions is particularly important because, so far, the only sentence reading studies to have shown parafoveal-on-foveal effects of word frequency have been based on a corpus of reading data (Kennedy & Pynte, 2005; Pynte & Kennedy, 2006) or data from a combination of different studies (Kliegl et al., 2006). It is important to assess whether lexical parafoveal-on-foveal effects arise under standard experimental conditions when the stimuli are designed to control for other variables. In the present study, sentence beginnings were identical across the conditions, and none of the critical words were predictable from the sentence context. In addition, both foveal and parafoveal words were short, therefore providing optimal conditions for parafoveal preview and, consequently, for parafoveal-on-foveal effects to occur.

Saccade Specification and Regressions

The current study also provided an opportunity to test whether orthographic familiarity and word frequency influence saccade length into short words or where short words are first fixated. As noted above, previous research suggests that long words with orthographically unfamiliar word beginnings are first fixated nearer to the beginning of the word than are long words with orthographically familiar beginnings (Hyönä, 1995; Radach et al., 2004; Vonk et al. 2000; White & Liversedge, 2004, 2006a, 2006b), whereas Rayner et al. (1996) showed no effect of word frequency on where words are first fixated. Importantly, previous studies have not tested whether orthographic familiarity can influence where short words are first fixated. Note that models of eye movement control during reading generally predict that the only parafoveal information used to influence saccade specification to word targets is word length; hence, they would predict no effects of orthographic familiarity or word frequency on initial fixation positions (e.g., Engbert et al., 2005; Reichle et al., 1999). Reichle et al. (2003) suggested that low spatial frequency information (such as ascenders and descenders) might influence saccade programming; however, they did not specify exactly what influence this information would have on where words are fixated (Liversedge & White, 2003).

Finally, the experiment reported here also tested whether word frequency and orthographic familiarity influence the probability of making regressions out of, or into, words. Some models of eye movement control do not attempt to account for interword regressions (e.g., McDonald et al., 2005; Pollatsek et al., 2006; Reichle et al., 1998, 1999, 2003, 2006), whereas others suggest that regressions are made to words with incomplete lexical processing (Engbert et al., 2002, 2005; Kliegl & Engbert, 2003; Richter et al., 2006; see also Reilly & Radach, 2003, 2006). The present study investigated the relative influences of sublexical (orthographic familiarity) and lexical (word frequency) influences on interword regressions.

Summary

The present study provided the first comprehensive test of the independent effects of word frequency and (whole word) orthographic familiarity on word recognition processes, as shown by eye movement behavior during reading. The main focus of the study was to test whether lexical processes affect saccade programming such that fixation durations and word skipping are influenced by the lexical characteristics of words. The study also provided an opportunity to test whether the orthographic or lexical characteristics of parafoveal words might be processed in parallel with the fixated word, or at least produce parafoveal-on-foveal effects. Measures of saccade specification, such as where words are initially fixated, are also reported, as are analyses of whether orthographic familiarity or word frequency influence regressions out of, or into, words.

To investigate the independent effects of word frequency and orthographic familiarity, an eye movement experiment was undertaken with three conditions. Word frequency effects were examined by comparing frequent (e.g., *town*) and infrequent (e.g., *cove*) words that were equally orthographically familiar. Orthographic familiarity effects were examined by comparing orthographically familiar (e.g., *cove*) and unfamiliar (e.g., *quay*) words that were equally infrequent. That is, the orthographically familiar low word frequency condition was used for both analyses. It was not possible to orthogonally manipulate the variables, because words with high frequencies cannot be orthographically unfamiliar.

Method

Participants

Thirty students at the University of Durham, Durham, United Kingdom, participated in the experiment. They all had normal or corrected-to-normal vision and were naive regarding the purpose of the experiment.

Materials and Design

The critical words were (a) frequent and orthographically familiar, (b) infrequent and orthographically familiar, or (c) infrequent and orthographically unfamiliar. These three conditions were manipulated within participants and items.

Word frequencies and *n*-gram frequencies were calculated in counts per million using the CELEX English word form corpus (Baayen, Piepenbrock, & Gulikers, 1995). The word form, rather than lemma, corpus was selected to ensure inclusion of letter sequences within all words. For example, the word form corpus includes words such as *went*, whereas in the lemma corpus, frequencies for such words would be associated instead with the base form (e.g., *go*). For the orthographically familiar words, the frequent words had higher word frequencies (M = 297, SD = 166) than the infrequent words (M = 1.7, SD = 0.9), $t(38) = 11.1$, $p < .001$. For the infrequent words, there were no differences in word frequency between the orthographically unfamiliar (M = 1.5, SD = 1.0) and familiar (M = 1.7, SD = 0.9) conditions ($t < 1$).

Previous research indicates that letter-position coding is quite flexible (e.g., Humphreys, Evett, & Quinlan, 1990). Consequently *n*-gram frequencies were calculated both specific to position and nonposition specific regardless of word length. Orthographic familiarity was measured using *n*-gram token frequencies, which represent the sum of the frequencies of the words that contain a particular letter sequence. Token frequencies for each of the *n*-grams within the word (e.g., for a four-letter word, there are two trigrams, three bigrams, and four monograms) were summed together. Table 1 shows the mean monogram, bigram, and trigram summed frequencies for each of the conditions. The table shows that *n*-gram frequencies in the two orthographically familiar conditions were the same (or even slightly higher in the infrequent condition). For the infrequent words, *n*-gram frequencies were always significantly lower in the orthographically unfamiliar condition than in the orthographically familiar condition. The initial trigram is most important in preprocessing of words (Rayner, Well, Pollatsek, & Bertera, 1982). In line with the summed *n*-gram data, position-specific token-initial trigram frequencies of the critical words were significantly smaller for the unfamiliar (M = 166, SD = 303) than for the familiar (M = 1,307, SD = 3,087) infrequent words, $t(39) = 2.28$, $p < .05$, whereas there was no difference for the familiar frequent (M = 992, SD = 903) and

Table 1
Non-Position-Specific (NPS) and Position-Specific (PS) Summed Token n-Gram Frequency Counts (per Million) for Each of the Conditions, With Differences in Mean Frequency Counts for the Orthographically Familiar and Infrequent Conditions

n-gram	Frequent, orthographically familiar		Infrequent, orthographically familiar		Difference: Orthographically familiar words		Infrequent, orthographically unfamiliar		Difference: Infrequent words	
	NPS	PS	NPS	PS	NPS	PS	NPS	PS	NPS	PS
Trigram	5,654 (3,842)	2,905 (2,135)	7,369 (6,513)	2,668 (3,173)	1,715	−237	541 (573)	231 (310)	−6,828***	−2,437***
Bigram	65,315 (30,237)	21,798 (11,593)	84,564 (41,470)	23,246 (9,713)	19,249**	1,448	33,422 (22,788)	10,109 (8,767)	−51,142***	−13,137***
Monogram	1,154,817 (227,950)	250,301 (66,055)	1,181,874 (245,519)	242,741 (49,672)	27,057	−7,560	989,524 (247,410)	205,336 (68,417)	−192,350**	−37,405*

Note. Standard deviations are shown in parentheses.
* $p < .05$. ** $p < .01$. *** $p < .001$.

infrequent (M = 1,307, SD = 3,087) words ($t < 1$). Type frequencies followed similar patterns to token frequencies for all of the measures described above.

Orthographic familiarity is also associated with differences in the number of orthographic neighbors. The number of orthographic neighbors was calculated using the entire English Lexicon Project database (Balota et al., 2002). There was no difference in the number of orthographic neighbors between the frequent (M = 7.5, SD = 4.5) and infrequent (M = 8.1, SD = 4.8) orthographically familiar words ($t < 1$), but there were more orthographic neighbors for the orthographically familiar (M = 8.1, SD = 4.8) than for the orthographically unfamiliar (M = 2.2, SD = 2.7) infrequent words, $t(38) = 7.37$, $p < .001$. The number of higher frequency neighbors for each of the items was also calculated for the frequent and infrequent orthographically familiar words (as noted above, the orthographically unfamiliar infrequent words had very few neighbors). The infrequent orthographically familiar words had significantly more higher frequency neighbors (M = 4.8, SD = 3.8) than the frequent words (M = 0.7, SD = 0.8), $t(38) = 6.66$, $p < .001$. These differences reflect the fact that the frequent words are so highly frequent that there are few words that are more frequent than they are (compared with the infrequent words).[2]

To ensure that the critical words were not predictable within the context of the sentence, sentence completion norms were obtained. Twelve participants were given the beginning portions of the sentence up to the critical word and were asked to provide a single word that they felt could fit as the next word in the sentence. Of all of the completions, only two (0.4%) were correct. Therefore, none of the critical words were predictable from the sentence context.

There were 39 critical words in each condition; all were either 4 or 5 letters long and matched for length across the three conditions, with a mean word length of 4.5 characters (SD = 0.5). Each set of critical words was embedded in the same neutral sentential frame up to and including the word after the critical word. Each of the sentences was no longer than one line of text (80 characters). The word preceding the critical word (word $n - 1$) was either 5 or 6 letters long, with a mean word frequency of 147 counts per million (SD = 170). A full list of materials is provided in the Appendix.

Three lists of 123 sentences were constructed, and 10 participants were randomly allocated to each list. Each list included all 117 experimental sentences with an additional 6 practice sentences at the beginning. For each third of the lists, the

[2] Previous studies that have manipulated the number of higher frequency neighbors during sentence reading have shown either no effects (Sears, Campbell, & Luper, 2006) or late effects (Perea & Pollatsek, 1998; but see Pollatsek, Perea, & Binder, 1999; Sears et al., 2006). It is therefore unlikely that differences in the number of higher frequency neighbors could have produced the differences between the frequent and infrequent word conditions reported here. Nevertheless, any effects of the number of higher frequency neighbors would reflect a lexical level of processing, consistent with the reported conclusions related to effects of word frequency.

conditions were rotated across the three lists.[3] The order of the items within each third of the list was different, but overall the sentences were presented in a fixed, pseudorandom order, ensuring that repeated items were widely distributed throughout the experiment. Thirty-eight of the sentences were followed by a comprehension question.

Procedure

Eye movements were monitored using a Dual-Purkinje-Image eye tracker. Viewing was binocular, but only the movements of one eye were monitored (the right eye was monitored for 18 participants, and the left eye was monitored for 12 participants).[4] The sentences were presented in light cyan on a black background, with characters presented in Courier font. The viewing distance was 80 cm, and 3.7 characters subtended 1° of visual angle. The resolution of the eye tracker was 10 min of arc, and the sampling rate was every millisecond.

Participants were instructed to understand the sentences to the best of their ability. A bite bar and head restraint were used to minimize head movements. The accuracy of the eye tracker was checked (and recalibrated when necessary) before each trial. After each sentence, participants pressed a button box to continue and to respond *yes* or *no* to comprehension questions. The entire experiment lasted approximately 30 min.

Analyses

Fixations shorter than 80 ms that were within 1 character of the next or previous fixation were incorporated into that fixation. Any remaining fixations shorter than 80 ms or longer than 1,200 ms were discarded; 3.7% 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 word.

Results

The influence of orthographic familiarity and word frequency on saccade programming was assessed by examining fixation durations on, and the probability of skipping, the critical word. The duration of the first fixation, single fixation durations, 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. Parafoveal-on-foveal effects were assessed by examining the duration of the fixation directly before fixation of the critical word. In addition, analyses of saccade targeting to the critical word and the effect of the critical word on interword regressions are reported.

Repeated measures analyses of variance (ANOVAs) were undertaken across the three conditions for both participants' (F_1) and items' (F_2) means. Note that the items are the sentences, such that the sentence beginnings were identical for each item, and the three word conditions were manipulated using a repeated measures design. Such a design not only provides control over sentence context across the conditions, it also enables the items' statistical analyses to be undertaken with the more powerful repeated measures procedures.[5] For cases in which the ANOVAs showed a main effect across the three conditions, paired-samples *t* tests were undertaken. Comparisons between the frequent and infrequent orthographically familiar conditions were used to test for an effect of word frequency. Comparisons between the orthographically familiar and unfamiliar infrequent conditions were used to test for an effect of orthographic familiarity. The mean error rate on the comprehension questions was 4%, indicating that participants properly read and understood the sentences; trials were included regardless of question responses.

Parafoveal-on-Foveal Effects

Table 2 shows mean reading times on word $n - 1$ and fixation durations prior to fixating the critical word. There were no effects of the condition of the critical word on first fixation durations, single fixation durations, or gaze durations on word $n - 1$ (Fs < 1). Because of acuity limitations, the characteristics of a parafoveal word are only likely to influence processing on previous fixations for saccades launched from near launch sites (Kennison & Clifton, 1995; Lavigne, Vitu, & d'Ydewalle, 2000; Rayner, 1975; Rayner, Binder, Ashby, & Pollatsek, 2001; White & Liversedge, 2006b). Therefore, influences of the critical word on the fixation duration prior to fixation of it were calculated for all of the data and for only the 88% of cases in which saccades were launched from word $n - 1$.

There was a main effect of condition on the duration of the fixation prior to fixation of the critical word for all data, $F_1(2, 58) = 3.24$, $MSE = 174$, $p < .05$, partial $\eta^2 = .101$; $F_2(2, 76) = 3.19$, $MSE = 148$, $p < .05$, partial $\eta^2 = .077$, and for saccades launched from word $n - 1$, $F_1(2, 58) = 4.55$, $MSE = 162$, $p < .05$,

[3] The effects of linguistic variables on word skipping are often quite small. Therefore, to increase the power of the analyses, each participant was shown all three versions of each experimental item. Consequently, the repeated sentence beginnings were specifically designed to be very bland, and counterbalancing procedures ensured that the repeated items were spaced throughout the stimuli lists. The order in which the participants saw the different conditions for each item was also counterbalanced across the three lists. After the experiment, participants were asked if they noticed any kind of repetition between the sentences, and none of them did.

[4] The measures were also calculated separately for participants for whom the left and right eyes were recorded; the two groups showed the same patterns of results.

[5] There is an issue about whether within-item or between-items designs should be adopted when the critical words are different across conditions. A between-items design is used when there are no controls for matching other variables across the conditions. In contrast, when an experiment has a within-item design, the different items are matched across the conditions—for example, by using the same sentence frame and matching for other variables such as length of the critical words. In the present study, the overall pattern of results was similar when the items analyses were undertaken with between-items tests. For example, for orthographically familiar words, reading times on the critical word were significantly longer for infrequent compared with frequent words for first fixation durations, $t_2(76) = 5.55$, $p < .001$; single fixation durations, $t_2(76) = 6.14$, $p < .001$; gaze durations, $t_2(76) = 7.30$, $p < .001$; and total time, $t_2(76) = 6.24$, $p < .001$. Other analyses (such as the main effects of condition on word skipping, $F_2(2, 114) = 2.23$, $MSE = 0.014$, $p = .112$, partial $\eta^2 = .038$, and fixation durations prior to fixating the critical word launched from word $n - 1$, F_2 (2, 114) $= 2.40$, $MSE = 227$, $p = .095$, partial $\eta^2 = .04$) did not reach significance for the between-items analyses, though the same patterns of effects as for the within-item tests clearly held. Overall, the between-items analyses have larger *p* values because of the less powerful design (i.e., because between-items analyses do not take account of the controls within the repeated measures design). These analyses highlight the importance of adopting careful matching procedures in studies of word recognition in natural reading.

Table 2

First Fixation Durations, Single Fixation Durations, and Gaze Durations on Word n − 1, With Mean Fixation Durations Prior to Fixation of the Critical Word for All Data, for Only Saccades Launched From Word n − 1, and for Only Saccades Launched From n − 1 Except From the Final Three Characters of the Word

Reading time measure (word $n - 1$)	Frequent, orthographically familiar	Infrequent, orthographically familiar	Frequency effect	Infrequent, orthographically unfamiliar	Orthographic familiarity effect
First fixation duration	243 (60)	242 (59)	−1	244 (63)	2
Single fixation duration	245 (59)	246 (58)	1	248 (63)	2
Gaze duration	263 (82)	264 (78)	1	265 (85)	1
Prior fixation duration (all)	233 (62)	233 (64)	0	239 (65)	6
Prior fixation duration ($n - 1$)	238 (60)	238 (60)	0	244 (63)	6
Prior fixation duration ($n - 1$, except final 3 characters)	240 (58)	239 (55)	−1	246 (60)	7

Note. All values represent milliseconds. Standard deviations are shown in parentheses.

partial $\eta^2 = .136$; $F_2(2, 76) = 3.13$, $MSE = 174$, $p < .05$, partial $\eta^2 = .076$. For infrequent critical words, there was a small (6-ms) parafoveal-on-foveal effect such that prior fixation durations were longer when the critical word was orthographically unfamiliar compared with when it was orthographically familiar, and these effects were significant for saccades launched from word $n - 1$, $t_1(29) = 2.37$, $p < .05$; $t_2(38) = 2.49$, $p < .05$, but significant only across items, $t_2(38) = 2.33$, $p < .05$, and not participants, $t_1(29) = 1.85$, $p = .075$, for all of the data. In contrast, for both sets of analyses, for orthographically familiar words there was no difference in prior fixation duration between the frequent and infrequent conditions (*t*s < 1).[6]

It has been suggested that parafoveal-on-foveal effects can sometimes occur as a result of inaccurate saccade targeting (Drieghe et al., in press; Rayner, Warren, et al., 2004; Rayner, White, et al., 2003). However, if the parafoveal-on-foveal effects reported above had arisen because of mistargeting of saccades, there perhaps also should have been a parafoveal-on-foveal effect of word frequency. The following analysis is aimed at identifying whether parafoveal-on-foveal effects occurred when cases in which there were most likely to have been mistargeted saccades were eliminated. Saccades that were intended to land on the critical word but that undershot it were most likely to have landed on the three final characters of word $n - 1$. For fixations launched from word $n - 1$, but not from the three final characters of word $n - 1$, the main effect of condition was marginal, $F_1(2, 58) = 2.84$, $MSE = 223$, $p = .067$, partial $\eta^2 = .089$; $F_2(2, 76) = 2.70$, $MSE = 266$, $p = .074$, partial $\eta^2 = .066$. Although there was no effect of parafoveal word frequency on these fixation durations (*t*s < 1), the results indicate that prior fixation durations in this region were longer prior to orthographically unfamiliar compared with orthographically familiar infrequent words, $t_1(29) = 2.22$, $p < .05$; $t_2(38) = 2.74$, $p < .01$.

Together, the absence of a parafoveal-on-foveal effect of word frequency and the indication of a parafoveal-on-foveal effect of orthography more than three characters from the critical words suggest that the orthographic parafoveal-on-foveal effects shown here may not simply be explained by inaccurate saccade targeting (see Starr & Inhoff, 2004, for a similar finding). Importantly, the present study may have provided very favorable conditions for parafoveal-on-foveal effects to arise. That is, both the foveal (word $n - 1$) and parafoveal (critical) words were short, and the orthographic familiarity of the entire parafoveal word was strongly manipulated. (Note, however, that it could be that only the familiarity of some of the letters, such as those at the word beginning, could have produced the effect.) Consequently, the parafoveal-on-foveal effects shown here may not hold under less favorable conditions—for example, when there are long parafoveal words or only the orthographic familiarity of the word beginning is manipulated (White & Liversedge, 2004, 2006b). Critically, despite the favorable conditions, and consistent with prior research (Rayner et al., 1998), there was no effect of word frequency on prior fixation durations for orthographically familiar words.[7]

Reading Measures for the Critical Word

The mean reading times, refixation probabilities, and spillover fixation durations for the critical word are shown in Table 3. There were significant main effects of condition for all of the reading measures on the critical word (*F*s > 15, *p*s < .001). For orthographically familiar words, reading times for the critical word were shorter on frequent than on infrequent words for first fixation durations ($t_1(29) = 8.96$, $p < .001$; $t_2(38) = 5.34$, $p < .001$), single fixation durations ($t_1(29) = 8.01$, $p < .001$; $t_2(38) = 6.01$, $p <$

[6] In an additional analysis, prior fixations were divided into those with near ($M = 3.0$, $SD = 1.4$) and far ($M = 6.7$, $SD = 3$) launch sites prior to fixation of the critical word for each participant. There was no difference between the frequent and infrequent conditions for either near (frequent: $M = 237$, $SD = 58$; infrequent: $M = 238$, $SD = 64$) or far (frequent: $M = 231$, $SD = 64$; infrequent: $M = 231$, $SD = 61$) launch sites. Similar to the data for saccades launched from word $n - 1$, prior-fixation durations were numerically longer prior to orthographically unfamiliar (near: $M = 242$, $SD = 65$; far: $M = 238$, $SD = 63$) than orthographically familiar (near: $M = 238$, $SD = 64$; far: $M = 231$, $SD = 61$) words, but none of the effects were statistically reliable. There was also no significant effect of condition on prior fixation durations launched three or fewer characters from the critical word (*F*s < 1.43, *p*s > .24).

[7] A 2 (skip or fixate critical word) × 3 (condition) ANOVA was undertaken to assess whether skipping the critical word influenced prior fixation durations. There was no effect of whether the critical word was fixated ($M = 240$) or skipped ($M = 239$) on the duration of the fixation prior to the critical word launched from word $n - 1$, $F_1 < 1$; $F_2(1, 37) = 1.34$, $p = .254$, partial $\eta^2 = .035$. There was no effect of condition, $F_1(2, 52) = 1.43$, $MSE = 479$, $p = .248$, partial $\eta^2 = .052$; $F_2 < 1$, or Skipping × Condition interaction, $F_1(2, 52) = 2.48$, $MSE = 577$, $p = .094$, partial $\eta^2 = .087$, $F_2(2, 74) = 1.90$, $MSE = 724$, $p = .157$, partial $\eta^2 = .049$. The hint of an interaction is likely attributable to the significant parafoveal-on-foveal effect of orthographic familiarity for cases in which the critical word is fixated (as detailed in the Results section). See Kliegl and Engbert (2005) for further discussion of this issue.

Table 3
Mean Reading Times on the Critical Word for Each Condition, Probabilities of Refixating the Critical Word on First Pass, and Mean Duration of the Spillover Fixation

Reading measure	Frequent, orthographically familiar	Infrequent, orthographically familiar	Frequency effect	Infrequent, orthographically unfamiliar	Orthographic familiarity effect
First fixation duration	253 (77)	280 (89)	27	286 (93)	6
Single fixation duration	255 (78)	284 (88)	29	294 (92)	10
Gaze duration	265 (88)	309 (117)	44	324 (135)	15
Total time	289 (123)	356 (168)	67	365 (181)	9
Refixation (probability)	.06	.11	.05	.15	.04
Spillover fixation duration	234 (66)	245 (83)	11	241 (77)	−4

Note. Except for the probabilities, all values represent milliseconds. Standard deviations are shown in parentheses.

.001), gaze durations ($t_1(29) = 10.18$, $p < .001$; $t_2(38) = 7.25$, $p < .001$), and total time ($t_1(29) = 8.8$, $p < .001$; $t_2(38) = 5.98$, $p < .001$). There were also significantly more refixations on the infrequent compared with the frequent orthographically familiar words, $t_1(29) = 4.6$, $p < .001$; $t_2(38) = 4.05$, $p < .001$. These results clearly demonstrate that even when orthographic familiarity is carefully controlled, the lexical variable of word frequency influences word processing, even for the first fixation on the word.

For infrequent words, reading times for the critical word were consistently numerically longer, and there were numerically more refixations on the orthographically unfamiliar than on the orthographically familiar critical words, though these effects were much smaller than those for word frequency. The effect of orthographic familiarity was significant for single fixation durations ($t_1(29) = 2.27$, $p < .05$; $t_2(38) = 2.46$, $p < .05$); significant across participants, $t_1(29) = 2.02$, $p = .05$, but not items, $t_2(38) = 1.5$, $p = .143$, for first fixation durations; significant across participants, $t_1(29) = 2.87$, $p < .01$, and marginal across items, $t_2(38) = 1.93$, $p = .061$, for gaze durations; significant across participants, $t_1(29) = 2.54$, $p < .05$, but not items, $t_2(38) = 1.7$, $p = .098$, for refixation probability; and nonsignificant for total time, $t_1(29) = 1.4$, $p = .171$; $t_2 < 1$. The direction of these orthographic familiarity effects is consistent with previous evidence from sentence reading (Lima & Inhoff, 1985) and consistent with some (Biederman, 1966; Seidenberg et al., 1984; Waters & Seidenberg, 1985) but not other (Broadbent & Gregory, 1968; Rice & Robinson, 1975) studies using isolated word-processing tasks.

There was also a main effect of condition on the duration of the spillover fixation, after leaving the critical word either to the right or left, $F_1(2, 58) = 3.83$, $MSE = 209$, $p < .05$, partial $\eta^2 = .117$; $F_2(2, 76) = 3.68$, $MSE = 299$, $p < .05$, partial $\eta^2 = .088$. For orthographically familiar words, fixations were longer following fixation of the infrequent compared with the frequent words, $t_1(29) = 2.44$, $p < .05$; $t_2(38) = 2.75$, $p < .01$. In contrast, for the infrequent words, there was no difference in the duration of the fixation following the orthographically unfamiliar compared with the familiar words, $t_1 < 1$; $t_2(38) = 1.24$, $p = .223$. The results are consistent with previous studies showing spillover effects of word frequency (Kennison & Clifton, 1995; Kliegl et al., 2006; Rayner & Duffy, 1986), though note that such effects do not always occur (White & Liversedge, 2006a).

The distribution of single fixation durations on the critical word is shown in Figure 1. Note that the longer fixation durations in the infrequent compared with the frequent word conditions are characterized by a rightward shift in the distribution, consistent with previous studies (Rayner, 1995; Rayner, Liversedge, et al., 2003). Numerical differences in the distributions between the frequent and infrequent orthographically familiar conditions occur no earlier than differences in the distributions between the orthographically familiar and unfamiliar infrequent conditions. These numerical patterns indicate that the effect of word frequency during single fixation durations occurs no later than that of orthographic familiarity.

Overall, the results show that word frequency has a robust and long-lasting effect on word processing. In contrast, orthographic familiarity has a numerically smaller influence for all of the reading time measures on the critical word. The absence of significant orthographic familiarity effects in later measures such as spillover indicates that orthographic familiarity exerts a relatively small and short-lived influence on word processing compared with effects of word frequency.

Critical Word Skipping Probabilities

Table 4 shows the probability of skipping the critical word in each of the conditions. Because of acuity limitations, effects of word skipping are calculated for all of the data and for only the 88% of cases in which saccades were launched from word $n - 1$. There was a main effect of condition on the probability of skipping the critical word both for all of the data, $F_1(2, 58) = 3.2$, $MSE = 0.014$, $p < .05$, partial $\eta^2 = .099$; $F_2(2, 76) = 3.8$, $MSE = 0.019$, $p < .05$, partial $\eta^2 = .091$, and for saccades launched from word $n - 1$, $F_1(2, 58) = 5.07$, $MSE = 0.006$, $p < .01$, partial $\eta^2 = .149$; $F_2(2, 76) = 5.55$, $MSE = 0.006$, $p < .01$, partial $\eta^2 = .127$. For all of the data, there were no significant effects of either word frequency, $t_1(29) = 1.79$, $p = .084$; $t_2(38) = 1.83$, $p = .075$, or orthographic familiarity (ts < 1) on word skipping. For saccades launched from word $n - 1$, there was no effect of orthographic familiarity on word skipping for the infrequent words (ts < 1). However, for saccades launched from word $n - 1$ for orthographically familiar critical words, frequent words were more likely to be skipped than infrequent words, $t_1(29) = 2.19$, $p < .05$; $t_2(38) = 2.17$, $p < .05$.

Compared with the results for saccades launched from word $n - 1$, a similar pattern of effects held for saccades launched from three or fewer characters from the critical word. There was

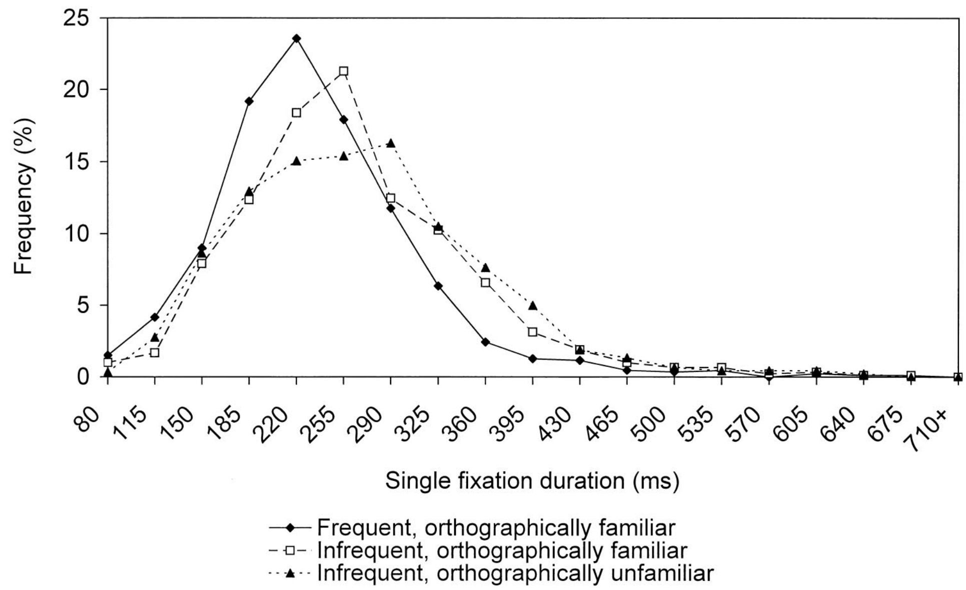

Figure 1. The distribution of single fixation durations on the critical word for each of the three experimental conditions (35-ms bins).

a main effect of condition, $F_1(2, 58) = 7.01$, $MSE = 0.019$, $p < .01$, partial $\eta^2 = .195$; $F_2(2, 76) = 6.74$, $MSE = 0.017$, $p < .01$, partial $\eta^2 = .151$, which was characterized by a greater probability of skipping frequent compared with infrequent orthographically familiar words, $t_1(29) = 2.22$, $p < .05$; $t_2(38) = 2.08$, $p < .05$. However, there was no significant difference in the probability of skipping orthographically familiar compared with orthographically unfamiliar infrequent words, $t_1(29) = 1.78$, $p = .086$; $t_2(38) = 1.31$, $p = .20$. These results show that word frequency, but not orthographic familiarity, significantly influences saccade programming such that this determines whether words are skipped.[8] Critically, the effect of word frequency on word skipping indicates that the lexical characteristics of words are processed in the parafovea and that they can have an early influence on word processing and eye movement behavior. Furthermore, the fact that orthographic familiarity produces a parafoveal-on-foveal effect, but does not influence word skipping, indicates that although these two measures both reflect early parafoveal processing of words, they may be determined by qualitatively different aspects of eye movement control.

Saccade Metrics for the Initial First Pass Fixation on the Critical Word

Mean landing positions, launch positions, and saccade lengths for first-pass saccades launched from word $n - 1$ to the critical word are shown in Table 4. There were no effects of condition on landing positions (Fs < 1); launch positions, $F_1(2, 58) = 2.25$, $MSE = 0.174$, $p = .114$, partial $\eta^2 = .072$; $F_2(2, 76) = 1.87$, $MSE = 0.095$, $p = .162$, partial $\eta^2 = .047$; or saccade lengths, $F_1(2, 58) = 1.88$, $MSE = 0.16$, $p = .162$, partial $\eta^2 = .061$; $F_2(2, 76) = 2.25$, $MSE = 0.09$, $p = .113$, partial $\eta^2 = .056$.

These findings suggest that neither the orthographic familiarity nor the word frequency of four- and five-letter words influences saccade targeting to words. These results contrast with evidence showing that orthographic familiarity does influence where longer words are first fixated (Hyönä, 1995; Radach et al., 2004; Vonk et al. 2000; White & Liversedge, 2004, 2006a, 2006b). However, note that initial trigrams used in experiments with longer words were often much more infrequent than those used here. Therefore, it is possible that the orthographic familiarity of shorter words may influence saccade targeting with much stronger manipulations of orthographic familiarity. It is also possible that orthographic influences on saccade targeting have no, or much smaller, effects for shorter words.

Regressions

Regression probabilities out of and into the critical word are presented in Table 4. There was no effect of condition on the

[8] Note that there were no differences in launch site between the three conditions prior to skipping or fixating the critical word, both for saccades launched from word $n - 1$ (Fs < 1) and for saccades launched from three or fewer characters away (Fs < 1.3). In an additional analysis, fixations were divided into those with near ($M = 2.5$, $SD = 1.1$) and far ($M = 6.3$, $SD = 2.9$) launch sites for each participant, prior to the first pass of the critical word. There was no effect of condition on skipping probabilities for far launch sites (Fs < 1.9, ps $> .17$), but there was an effect for near launch sites, $F_1(2, 58) = 3.13$, $MSE = 0.004$, $p = .05$, partial $\eta^2 = .097$; $F_2(2, 76) = 3.74$, $MSE = 0.005$, $p < .05$, partial $\eta^2 = .09$. Saccades launched from near launch sites were numerically more likely to skip the frequent (0.40) than the equally orthographically familiar infrequent words (0.35), though the effect was not significant, $t_1(29) = 1.61$, $p = .118$; $t_2(38) = 1.73$, $p = .091$. There was no significant difference in skipping probability between the orthographically familiar (0.35) and unfamiliar (0.32) infrequent words (ts < 1).

Table 4
Probabilities of Skipping the Critical Word for All Data, for Only Saccades Launched From Word n − 1, and for Only Saccades Launched From Three or Fewer Characters From the Critical Word; Mean Landing Positions, Launch Positions, and Saccade Lengths for the Critical Word; and Probabilities of First-Pass Regressions Out of the Critical Word and Into the Critical Word When the Critical Word Was Fixated (Fix n) and Skipped (Skip n) on First Pass

Reading measure	Frequent, orthographically familiar	Infrequent, orthographically familiar	Frequency effect	Infrequent, orthographically unfamiliar	Orthographic familiarity effect
Skip (all data)	.23	.20	−.03	.19	−.01
Skip (launch $n - 1$)	.26	.22	−.04	.20	−.02
Skip (launch ≤3 characters)	.41	.34	−.07	.30	−.04
Landing position (characters)	3.0 (1.3)	3.0 (1.3)	0	3.0 (1.3)	0
Launch position (characters)	4.0 (1.6)	3.9 (1.6)	−0.1	3.9 (1.7)	0
Saccade length (characters)	7.1 (1.5)	7.0 (1.6)	−0.1	6.9 (1.5)	−0.1
First-pass regression out	.08	.09	.01	.09	0
First-pass regression in (Fix *n*)	.09	.12	.03	.11	−.01
First-pass regression in (Skip *n*)	.26	.45	.19	.52	.07

Note. Except as indicated, all values represent probabilities. Standard deviations are shown in parentheses.

probability of making a first-pass regression out of the critical word (Fs < 1). The probability of making a regression into the critical word was investigated as a function of whether the critical word was fixated on first pass.[9] A 2 (skip vs. fixate) × 3 (condition) ANOVA showed a significant main effect of skipping, $F_1(1, 27) = 70.36$, $MSE = 0.054$, $p < .001$, partial $\eta^2 = .723$, $F_2(1, 37) = 194.14$, $MSE = 0.031$, $p < .001$, partial $\eta^2 = .84$, such that there were more regressions into the critical word when it was skipped (0.41) compared with when it was fixated (0.11) on first pass. There was also a main effect of condition, $F_1(2, 54) = 9.92$, $MSE = 0.032$, $p < .001$, partial $\eta^2 = .269$; $F_2(2, 74) = 10.85$, $MSE = 0.049$, $p < .001$, partial $\eta^2 = .227$, and a Skipping × Condition interaction, $F_1(2, 54) = 7.07$, $MSE = 0.029$, $p < .01$, partial $\eta^2 = .208$; $F_2(2, 74) = 7.86$, $MSE = 0.042$, $p < .01$, partial $\eta^2 = .175$.

For cases in which the critical word was fixated on first pass, there was no effect of condition on the probability of making a regression into the critical word, $F_1(2, 58) = 2.16$, $MSE = 0.004$, $p = .124$, partial $\eta^2 = .069$; $F_2(2, 76) = 1.65$, $MSE = 0.006$, $p = .199$, partial $\eta^2 = .042$. In contrast, for cases in which the critical word was skipped on first pass, there was a main effect of condition on the proportion of regressions made into the critical word, $F_1(2, 54) = 9.09$, $MSE = 0.056$, $p < .001$, partial $\eta^2 = .252$; $F_2(2, 74) = 10.01$, $MSE = 0.085$, $p < .001$, partial $\eta^2 = .213$. For cases in which the critical word was skipped on first pass, for orthographically familiar words there were more regressions into infrequent than into frequent critical words, $t_1(27) = 2.92$, $p < .01$; $t_2(37) = 3.5$, $p < .01$. However, there was no difference in the proportion of regressions made into the critical word for infrequent orthographically unfamiliar compared with familiar words (ts $<$ 1.1). The finding that word frequency influences the probability of making a regression back to a skipped word supports results reported by Vitu and McConkie (2000). It is particularly interesting that the present findings show that word frequency, but not orthographic familiarity, significantly influenced regressions. The results suggest that the linguistic influence on regressions is at a lexical rather than a sublexical level. The effect of lexical processing difficulty on regressions supports the suggestion made by Engbert et al. (2005) that interword regressions can be caused by incomplete lexical access. However, note that processing difficulty related to postlexical semantic integration may also be related to such an effect of word frequency. The present findings are also consistent with previous research suggesting that regressive saccades can target areas of processing difficulty quite accurately (Frazier & Rayner, 1982; Kennedy, Brooks, Flynn, & Prophet, 2003; Meseguer, Carreiras, & Clifton, 2002).

Discussion

The results clearly show that word frequency, independent of orthographic familiarity, influences the probability of skipping words and fixation durations on words. However, there were no effects of word frequency on prior fixation durations. In contrast, orthographic familiarity had a small effect on prior fixation durations and fixation durations on words but no influence on the probability of word skipping. The key implications are, therefore, that lexical processing of fixated words can influence saccade programming, as shown by fixation durations, and that lexical processing of parafoveal words can influence saccade programming, as shown by word skipping. The results have important implications for models of eye movement control in reading, and these are discussed below. In addition, there was a small orthographic parafoveal-on-foveal effect but no evidence of lexical parafoveal-on-foveal effects. The implications of these findings are considered at the end of this Discussion.

Saccade Programming: Fixation Durations and Word Targeting

The findings reported here demonstrate that models of eye movement control in reading should include a saccade-programming mechanism that is sensitive to lexical (or even

[9] The analysis of the probability of making a regression into the critical word was based on 28 participants in the analyses across participants, and 38 items in the analyses across items for the main 2 × 3 ANOVA and for the three-way ANOVA for cases in which the critical word was skipped on first pass.

postlexical) processing of word frequency. Therefore, there must be sufficient time during a fixation for both lexical processing and saccade programming to occur, before the metrics and timing of the subsequent saccade are finalized. The present findings are particularly crucial for models in which linguistic factors modulate when saccade programming is initiated because, due to the time required for saccade programming, such linguistic influences may have to occur early during fixations (Engbert et al., 2002, 2005; Kliegl & Engbert, 2003; Pollatsek et al., 2006; Reichle et al., 1998, 1999, 2003, 2006; Richter et al., 2006).

In the E-Z reader model (Pollatsek et al., 2006; Reichle et al., 1998, 1999, 2003, 2006), completion of an initial stage of word processing (L_1) triggers the initiation of a saccade program, which subsequently takes approximately 125 ms to complete. Therefore, the time at which this first stage of word processing is completed effectively produces the linguistic influence on the duration of fixations. For a word to be skipped, both the fixated word and the parafoveal word would have to have reached the L_1 stage before the skipping program could be finalized. In the SWIFT model, a random stochastic process influences when saccade programming begins, and this is delayed or cancelled by linguistic processing using a mechanism referred to as *foveal inhibition* (Engbert et al., 2002, 2005; Kliegl & Engbert, 2003; Richter et al., 2006). Therefore, similar to the E-Z reader model, in the SWIFT model, linguistic influences on fixation durations must also occur prior to saccade programming. Crucially, for such accounts to explain the results reported here, the lexical variable of word frequency must have an influence early during a fixation, before saccade programming commences. For example, for a fixation lasting 250 ms with 125 ms of saccade programming, lexical influences on saccade programming would have to occur in the initial 125 ms of the fixation. Given such an account, either lexical processing must be very fast or a significant amount of this processing may be undertaken on previous fixations (Findlay & White, 2003).

An alternative possibility is that linguistic factors may influence the saccade program later during a fixation but before the nonlabile stage of saccade programming. For example, in the SWIFT model, determination of the saccade target (which word is fixated) occurs at the end of the labile stage of saccade programming. If linguistic processing could influence saccade programming during the labile stage, there would be more time during the fixation for lexical processing to occur such that it could then influence when or where the eyes moved. For example, for a fixation lasting 250 ms with 50 ms for the nonlabile stage of saccade programming, 200 ms of linguistic processing time may be available before the linguistic influence on the saccade program is finalized at the end of the labile stage.

In the E-Z reader model, once the first stage of word processing is complete (L_1) and saccade programming has been initiated, a second stage of word processing (L_2) is achieved before attention shifts to the following word (Pollatsek et al., 2006; Reichle et al., 1998, 1999, 2003, 2006). Because saccade-programming time is relatively constant, the duration of L_2 determines the time between the attention shift and when the eyes move, during which the following word can be preprocessed. For the E-Z reader model, the influence of L_2 on the degree of parafoveal processing is crucial to explaining both spillover effects (e.g., Rayner & Duffy, 1986) and modulation of parafoveal processing by foveal load (Henderson & Ferreira, 1990; Kennison & Clifton, 1995; White, Rayner, & Liversedge, 2005). If L_1 is of a lexical nature, this raises the question of exactly how L_2 is different from L_1. Future models based on multiple word-processing stages may need to specify the types of processing entailed in each stage more precisely. For a more detailed discussion of how even postlexical factors may possibly influence the first stage of word processing, see Reichle, Pollatsek, and Rayner (2007).

The present study also raises the issue of precisely how the orthographic familiarity of words influences fixation durations on those words. In the E-Z reader model (Pollatsek et al., 2006; Reichle et al., 1998, 1999, 2003, 2006), it could be argued that orthographic familiarity may influence the initial stage of word processing (L_1), which influences the current fixation duration, but not the second stage of word processing (L_2), which can influence subsequent fixation durations. Such a suggestion would be consistent with the finding that orthographic familiarity had a short-lived effect on reading times on the critical word in the present study (for similar reasoning, see Reingold, 2003; Reingold & Rayner, 2006).

The results also showed that the lexical characteristics of words influenced the probability of making a regression back to words if they were skipped on first pass. In line with these findings, the SWIFT model of eye movement control is unique in that it predicts that regressions are directed to words that are not completely processed on first pass (Engbert et al., 2002, 2005; Kliegl & Engbert, 2003; Richter et al., 2006; see also Reilly & Radach, 2003, 2006). It seems especially noteworthy that orthographic familiarity did not significantly influence word skipping or regression probabilities, while word frequency did influence these measures. These results suggest that lexical factors have a more critical role than sublexical factors in determining which words are fixated and refixated. However, note that although lexical factors have been shown here to influence both when and where the eyes move, research suggests that these two processes may in fact be controlled in qualitatively different ways. For example, while fixation durations are influenced by both foveal and parafoveal linguistic information, word skipping may be influenced by linguistic information only in the parafovea (White, 2007; see also Drieghe, Rayner, & Pollatsek, 2005).

Parafoveal-on-Foveal Effects

The present study also has important implications for the contentious issue of parafoveal-on-foveal effects. The results show that, at least when both foveal and parafoveal words are short and the orthographic familiarity of the entire parafoveal word is manipulated, the orthographic characteristics of the critical word have a small (6-ms) influence on prior fixation durations. These results are in line with previous sentence reading studies showing parafoveal-on-foveal effects at least at the level of orthographic familiarity (Inhoff, Starr, & Shindler, 2000; Pynte et al., 2004; Rayner, 1975; Starr & Inhoff, 2004; Underwood et al., 2000). It could be that only the orthographic familiarity of the initial letters of the word is critical. Furthermore, other characteristics associated with orthographic familiarity, such as the informativeness of the component letter sequences, may have driven the effects. Fixations are often mislocated (McConkie et al., 1988; Nuthmann et al., 2005), and some parafoveal-on-foveal effects may be explained by such mislocated fixations (Drieghe et al., 2005, 2007;

Rayner, Warren, et al., 2004; Rayner, White, et al., 2003). However, the present results indicate that the orthographic parafoveal-on-foveal effects shown here are not simply isolated to fixations three or fewer characters from the critical word. Therefore, either a substantial proportion of mislocated fixations must land more than three characters from the critical word or, as concluded by Starr and Inhoff (2004), there are parafoveal-on-foveal effects of orthography that are not caused by mislocated fixations.

Given that the explanation of mislocated fixations does not seem feasible in this case, there are two alternative accounts for the small orthographic parafoveal-on-foveal effects shown here. First, attention may be allocated to multiple words in parallel such that processing of the foveal word may occur simultaneously with processing of the orthographic characteristics of the parafoveal word (Engbert et al., 2002, 2005; Kennedy, 2000; Kliegl & Engbert, 2003; McDonald et al., 2005; Reilly & Radach, 2003, 2006; Richter et al., 2006). Second, attention may be allocated to words one at a time (as in serial models), but the orthographic characteristics of the parafoveal words may be concurrently processed in a manner that does not require attention. Such early preattentive visual processing of the parafoveal word may affect processing of the foveal word to generate orthographic parafoveal-on-foveal effects (Pollatsek et al., 2006; Reichle et al., 2003, 2006). Note that in the E-Z reader model, preattentive processes that may induce parafoveal-on-foveal effects are quite separate from the linguistic processes associated with the L_1 and L_2 stages of word recognition, which have a more primary role in influencing saccade programming during reading.

To be clear, the parafoveal-on-foveal effects shown here were not necessarily mediated by the same attention-based processes that are generally allocated for reading of words. That is, parafoveal-on-foveal effects may not necessarily affect the reading process (see Drieghe et al., in press). Therefore, although there may be temporal overlap between processing of the foveal word and processing related to the orthographic characteristics of the parafoveal word, these separate processes may be independent and perhaps even qualitatively different. For example, the orthographic parafoveal-on-foveal effects may be mediated by visual, not linguistic, processes. Overall, the orthographic parafoveal-on-foveal effects reported here cannot distinguish between the parallel attention (Engbert et al., 2002, 2005; Kennedy, 2000; Kliegl & Engbert, 2003; McDonald et al., 2005; Reilly & Radach, 2003, 2006; Richter et al., 2006) and preattentive (Pollatsek et al., 2006; Reichle et al., 2003, 2006) explanations provided by the models.

The present study revealed no effect of word frequency on prior fixation durations. This was despite the study providing favorable conditions for lexical parafoveal-on-foveal effects to occur by using short foveal and parafoveal words. Note that the foveal words $n - 1$ were frequent words (see the Method section), so there should have been sufficient time or processing resources to process the parafoveal word (Henderson & Ferreira, 1990; Kennison & Clifton, 1995; White et al., 2005). The results are in line with previous experimental studies showing no evidence of lexical parafoveal-on-foveal effects (Altarriba et al., 2001; Calvo & Meseguer, 2002; Henderson & Ferreira, 1993; Inhoff, Starr, & Shindler, 2000; Rayner, 1975; Rayner et al., 1998; Rayner et al., 2007; Schroyens et al., 1999), but they contrast with studies that have shown lexical parafoveal-on-foveal effects using very large data sets across a corpus of data or a combination of different studies (Kennedy & Pynte, 2005; Kliegl et al., 2006; Pynte & Kennedy, 2006). It is not clear why standard experimental studies consistently show such a different pattern of results than do studies based on larger datasets. At the very least, the data suggest that if lexical parafoveal-on-foveal effects do occur, then these must be of a small or specific nature such that they are very elusive in experimental studies. Given that experimental studies provide much greater control over other variables than do corpus-based studies, it is important that findings that are shown in corpus studies, but not in sentence-based experimental studies, be treated with caution (Rayner, Pollatsek, Drieghe, Slattery, & Reichle, 2007). Overall, perhaps in the vast majority of cases, the lexical characteristics of words are processed serially (Morrison, 1984; Pollatsek et al., 2006; Reichle et al., 1998, 1999, 2003, 2006), but with very large samples of data it can be shown that lexical parafoveal-on-foveal effects do occur, though it is still not entirely clear whether such effects are due to parallel processing of words, mislocated fixations, or other variables.

References

Altarriba, J., Kambe, G., Pollatsek, A., & Rayner, K. (2001). Semantic codes are not used in integrating information across eye fixations in reading: Evidence from fluent Spanish–English bilinguals. *Perception & Psychophysics, 63,* 875–890.

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

Balota, D. A., Cortese, M. J., Hutchison, K. A., Neely, J. H., Nelson, D., Simpson, G. B., & Treiman, R. (2002). *The English lexicon project: A Web-based repository of descriptive and behavioral measures for 40,481 English words and nonwords.* Retrieved July 12, 2007, from Washington University's English Lexicon Project Web site: http://elexicon.wustl.edu/

Becker, W., & Jürgens, R. (1979). An analysis of the saccadic system by means of double step stimuli. *Vision Research, 19,* 967–983.

Bertram, R., & Hyönä, J. (2003). The length of a complex word modifies the role of morphological structure: Evidence from eye movements when reading short and long Finnish compounds. *Journal of Memory & Language, 48,* 615–634.

Biederman, G. B. (1966). The recognition of tachistoscopically presented five-letter words as a function of digram frequency. *Journal of Verbal Learning and Verbal Behavior, 5,* 208–209.

Broadbent, D. E., & Gregory, M. (1968). Visual perception of words differing in letter digram frequency. *Journal of Verbal Learning and Verbal Behavior, 7,* 569–571.

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. 53–77). Oxford, England: 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, England: Elsevier.

Calvo, M. G., & Meseguer, E. (2002). Eye movements and processing stages in reading: Relative contribution of visual, lexical, and contextual factors. *Spanish Journal of Psychology, 5,* 66–77.

Deubel, H., O'Regan, J. K., & Radach, R. (2000). Attention, information processing and eye movement control. In A. Kennedy, R. Radach, D. Heller, & J. Pynte (Eds.), *Reading as a perceptual process* (pp. 355–374). Oxford, England: Elsevier.

Drieghe, D., Rayner, K., & Pollatsek, A. (2005). Eye movements and word skipping during reading revisited. *Journal of Experimental Psychology: Human Perception and Performance, 31,* 954–969.

Drieghe, D., Rayner, K., & Pollatsek, A. (in press). Mislocated fixations can account for parafoveal-on-foveal effects in eye movements during reading. *Quarterly Journal of Experimental Psychology.*

Engbert, R., Longtin, A., & Kliegl, R. (2002). A dynamical model of saccade generation in reading based on spatially distributed lexical processing. *Vision Research, 42,* 621–636.

Engbert, R., Nuthmann, A., Richter, E. M., & Kliegl, R. (2005). SWIFT: A dynamical model of saccade generation during reading. *Psychological Review, 112,* 777–813.

Feng, G. (2006). Eye movements as time-series random variables: A stochastic model of eye movement control in reading. *Cognitive Systems Research, 7,* 70–95.

Findlay, J. M., & Walker, R. (1999). A model of saccade generation based on parallel processing and competitive inhibition. *Behavioural and Brain Sciences, 22,* 661–674.

Findlay, J. M., & White, S. J. (2003). Serial programming for saccades: Does it all add up? *Behavioral and Brain Sciences, 26,* 483–484.

Frazier, L., & Rayner, K. (1982). Making and correcting errors during sentence comprehension: Eye movements in the analysis of structurally ambiguous sentences. *Cognitive Psychology, 14,* 178–210.

Gernsbacher, M. A. (1984). Resolving 20 years of inconsistent interactions between lexical familiarity and orthography, concreteness, and polysemy. *Journal of Experimental Psychology: General, 113,* 256–281.

Grainger, J., & Dijkstra, T. (1996). Visual word recognition: Models and experiments. In T. Dijkstra & K. de Smedt (Eds.), *Computational psycholinguistics: AI and connectionist models of human language processing* (pp. 139–165). London: Taylor & Francis.

Henderson, J. M., & Ferreira, F. (1990). Effects of foveal processing difficulty on the perceptual span in reading: Implications for attention and eye movement control. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 16,* 417–429.

Henderson, J. M., & Ferreira, F. (1993). Eye movement control during reading: Fixation measures reflect foveal but not parafoveal processing difficulty. *Canadian Journal of Experimental Psychology, 47,* 201–221.

Henderson, L. (1982). *Orthography and word recognition in reading.* London: Academic Press.

Holmes, V. M., & O'Regan, J. K. (1987). Decomposing French words. In J. K. O'Regan & A. Lévy-Schoen (Eds.), *Eye movements: From physiology to cognition* (pp. 459–466). Amsterdam: Elsevier.

Humphreys, G. W., Evett, L. J., & Quinlan, P. T. (1990). Orthographic processing in visual word recognition. *Cognitive Psychology, 22,* 517–560.

Hyönä, J. (1995). Do irregular letter combinations attract readers' attention? Evidence from fixation locations in words. *Journal of Experimental Psychology: Human Perception and Performance, 21,* 68–81.

Hyönä, J., & Bertram, R. (2004). Do frequency characteristics of nonfixated words influence the processing of fixated words during reading? *European Journal of Cognitive Psychology, 16,* 104–127.

Hyönä, J., & Häikiö, T. (2005). Is emotional content obtained from parafoveal words during reading? An eye movement analysis. *Scandinavian Journal of Psychology, 46,* 475–483.

Inhoff, A. W., Eiter, B. M., & Radach, R. (2005). Time course of linguistic information extraction from consecutive words during eye fixations in reading. *Journal of Experimental Psychology: Human Perception and Performance, 31,* 979–995.

Inhoff, A. W., Radach, R., Starr, M., & Greenberg, S. (2000). Allocation of visuo-spatial attention and saccade programming during reading. In A. Kennedy, R. Radach, D. Heller, & J. Pynte (Eds.), *Reading as a perceptual process* (pp. 221–246). Oxford, England: Elsevier.

Inhoff, A. W., & Rayner, K. (1986). Parafoveal word processing during eye fixations in reading: Effects of word frequency. *Perception & Psychophysics, 40,* 431–439.

Inhoff, A. W., Starr, M., & Shindler, K. L. (2000). Is the processing of words during eye fixations in reading strictly serial? *Perception & Psychophysics, 62,* 1474–1484.

Juhasz, B. J., & Rayner, K. (2003). Investigating the effects of a set of intercorrelated variables on eye fixation durations in reading. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 29,* 1312–1318.

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

Kennedy, A. (1998). The influence of parafoveal words on foveal inspection time: Evidence for a processing trade off. In G. Underwood (Ed.), *Eye guidance in reading and scene perception* (pp. 149–179). Oxford, England: Elsevier.

Kennedy, A. (2000). Parafoveal processing in word recognition. *Quarterly Journal of Experimental Psychology: Human Experimental Psychology, 53*(A), 429–455.

Kennedy, A., Brooks, R., Flynn, L.-A., & Prophet, C. (2003). The reader's spatial code. In J. Hyönä, R. Radach, & H. Deubel (Eds.), *The mind's eye: Cognitive and applied aspects of eye movement research* (pp. 193–212). Amsterdam: Elsevier.

Kennedy, A., & Pynte, J. (2005). Parafoveal-on-foveal effects in normal reading. *Vision Research, 45,* 153–168.

Kennedy, A., Pynte, J., & Ducrot, S. (2002). Parafoveal-on-foveal interactions in word recognition. *Quarterly Journal of Experimental Psychology: Human Experimental Psychology, 55*(A), 1307–1337.

Kennison, S. M., & Clifton, C. (1995). Determinants of parafoveal preview benefit in high and low working memory capacity readers: Implications for eye movement control. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 21,* 68–81.

Kliegl, R., & Engbert, R. (2003). SWIFT explorations. In J. Hyönä, R. Radach, & H. Deubel (Eds). *The mind's eye: Cognitive and applied aspects of eye movement research* (pp. 391–411). Amsterdam: Elsevier.

Kliegl, R., & Engbert, R. (2005). Fixation durations before word skipping in reading. *Psychonomic Bulletin & Review, 12,* 132–138.

Kliegl, R., Nuthmann, A., & Engbert, R. (2006). Tracking the mind during reading: The influence of past, present, and future words on fixation durations. *Journal of Experimental Psychology: General, 135,* 12–35.

Lavigne, F., Vitu, F., & d'Ydewalle, G. (2000). The influence of semantic context on initial eye landing sites in words. *Acta Psychologica, 104,* 191–214.

Legge, G. E., Hooven, T. A., Klitz, T. S., Mansfield, J. S., & Tjan, B. S. (2002). Mr. Chips 2002: New insights from an ideal-observer model of reading. *Vision Research, 42,* 2219–2234.

Legge, G. E., Klitz, T. S., & Tjan, B. S. (1997). Mr. Chips: An ideal-observer model of reading. *Psychological Review, 104,* 524–553.

Lima, S. D., & Inhoff, A. W. (1985). Lexical access during eye fixations in reading: Effects of word initial letter sequence. *Journal of Experimental Psychology: Human Perception and Performance, 11,* 272–285.

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,* 1013, 1024.

Liversedge, S. P., & White, S. J. (2003). Psycholinguistic processes affect fixation durations and orthographic information affects fixation locations: Can E-Z Reader cope? *Behavioural and Brain Sciences, 26,* 492–493.

Martin, G. L. (2004). Encoder: A connectionist model of how learning to visually encode fixated text images improves reading fluency. *Psychological Review, 111,* 617–639.

Mayzner, M. S., & Tresselt, M. E. (1965). Tables of single-letter and digram frequency counts for various word-length and letter-position combinations. *Psychonomic Monograph Supplements, 1,* 13–32.

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

McConkie, G. W., & Yang, S.-N., (2003). How cognition affects eye movements during reading. In J. Hyönä, R. Radach, & H. Deubel (Eds.), *The mind's eye: Cognitive and applied aspects of eye movement research* (pp. 413–427). Amsterdam: Elsevier.

McDonald, S. A., Carpenter, R. H. S., & Shillcock, R. C. (2005). An anatomically constrained, stochastic model of eye movement control in reading. *Psychological Review, 112,* 814–840.

Meseguer, E., Carreiras, M., & Clifton, C. (2002). Overt reanalysis strategies and eye movements during the reading of mild garden path sentences. *Memory & Cognition, 30,* 551–561.

Monsell, S. (1991). The nature and locus of word frequency effects in reading. In D. Besner & G. W. Humphreys (Eds.), *Basic processes in reading: Visual word recognition* (pp. 148–197). Hillsdale, NJ: Erlbaum.

Morrison, R. E. (1984). Manipulation of stimulus onset delay in reading: Evidence for parallel programming of saccades. *Journal of Experimental Psychology: Human Perception and Performance, 10,* 667–682.

Murray, W. S. (1998). Parafoveal pragmatics. In G. Underwood (Ed.), *Eye guidance in reading and scene perception* (pp. 181–200). Oxford, England: Elsevier.

Nazir, T. A. (2000). Traces of print along the visual pathway. In A. Kennedy, R. Radach, D. Heller, & J. Pynte (Eds.), *Reading as a perceptual process* (pp. 3–22). Oxford, England: Elsevier.

Nuthmann, A., Engbert, R., & Kliegl, R. (2005). Mislocated fixations during reading and the inverted optimal viewing position effect. *Vision Research, 45,* 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. 395–453). Amsterdam: Elsevier.

O'Regan, J. K. (1992). Optimal viewing position in words and the strategy–tactics theory of eye movements in reading. In K. Rayner (Ed.), *Eye movements and visual cognition: Scene perception and reading* (pp. 333–354). New York: Springer-Verlag.

Perea, M., & Pollatsek, A. (1998). The effects of neighborhood frequency in reading and lexical decision. *Journal of Experimental Psychology: Human Perception and Performance, 24,* 767–779.

Pollatsek, A., Perea, M., & Binder, K. S. (1999). The effects of "neighborhood size" in reading and lexical decision. *Journal of Experimental Psychology: Human Perception and Performance, 25,* 1142–1158.

Pollatsek, A., Reichle, E., & Rayner, K. (2006). Tests of the E-Z reader model: Exploring the interface between cognition and eye-movement control. *Cognitive Psychology, 52,* 1–56.

Pynte, J., & Kennedy, A. (2006). An influence over eye movements in reading exerted from beyond the level of the word: Evidence from reading English and French. *Vision Research, 46,* 3786–3801.

Pynte, J., Kennedy, A., & Ducrot, S. (2004). The influence of parafoveal typographical errors in eye movements in reading. *European Journal of Cognitive Psychology, 16,* 178–202.

Pynte, J., Kennedy, A., & Murray, W. S. (1991). Within-word inspection strategies in continuous reading: Time course of perceptual, lexical, and contextual processes. *Journal of Experimental Psychology: Human Perception and Performance, 17,* 458–470.

Radach, R., Inhoff, A., & Heller, D. (2004). Orthographic regularity gradually modulates saccade amplitudes in reading. *European Journal of Cognitive Psychology, 16,* 27–51.

Raney, G. E., & Rayner, K. (1995). Word frequency effects and eye movements during two readings of a text. *Canadian Journal of Experimental Psychology, 49,* 151–173.

Rayner, K. (1975). The perceptual span and peripheral cues in reading. *Cognitive Psychology, 7,* 65–81.

Rayner, K. (1995). Eye movements and cognitive processes in reading, visual search, and scene perception. In J. M. Findlay, R. Walker, & R. W. Kentridge (Eds.), *Eye movement research: Mechanisms, processes and applications* (pp. 3–12). Amsterdam: North-Holland.

Rayner, K. (1998). Eye movements in reading and information processing: 20 years of research. *Psychological Bulletin, 124,* 372–422.

Rayner, K., Ashby, J., Pollatsek, A., & Reichle, E. D. (2004). The effects of frequency and predictability on eye fixations in reading: Implications for the E-Z reader model. *Journal of Experimental Psychology: Human Perception and Performance, 30,* 720–732.

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,* 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,* 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., & Juhasz, B. J. (2004). Eye movements in reading: Old questions and new directions. *European Journal of Cognitive Psychology, 16,* 340–352.

Rayner, K., Juhasz, B. J., & Brown, S. J. (2007). Do readers obtain preview benefit from word $n + 2$? A test of serial attention shift versus distributed lexical processing models of eye movement control in reading. *Journal of Experimental Psychology: Human Perception and Performance, 33,* 230–245.

Rayner, K., Liversedge, S. P., White, S. J., & Vergilino-Perez, D. (2003). Reading disappearing text: Cognitive control of eye movements. *Psychological Science, 14,* 385–388.

Rayner, K., & Morrison, R. M. (1981). Eye movements and identifying words in parafoveal vision. *Bulletin of the Psychonomic Society, 17,* 135–138.

Rayner, K., & Pollatsek, A. (1981). Eye movement control during reading: Evidence for direct control. *Quarterly Journal of Experimental Psychology: Human Experimental Psychology, 33*(A), 351–373.

Rayner, K., Pollatsek, A., Drieghe, D., Slattery, T. J., & Reichle, E. D. (in press). Tracking the mind during reading via eye movements: Comments on Kliegl, Nuthmann, and Engbert (2006). *Journal of Experimental Psychology: General.*

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,* 1188–1200.

Rayner, K., Slowiaczek, M. L., Clifton, C., Jr., & Bertera, J. H. (1983). Latency of sequential eye movements: Implications for reading. *Journal of Experimental Psychology: Human Perception and Performance, 9,* 912–922.

Rayner, K., Warren, T., Juhasz, B. J., & Liversedge, S. P. (2004). The effect of plausibility on eye movements in reading. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 30,* 1290–1301.

Rayner, K., Well, A. D., Pollatsek, A., & Bertera, J. H. (1982). The availability of useful information to the right of fixation in reading. *Perception & Psychophysics, 31,* 537–550.

Rayner, K., White, S. J., Kambe, G., Miller, B., & Liversedge, S. P. (2003). On the processing of meaning from parafoveal vision during eye fixations in reading. In J. Hyönä, R. Radach, & H. Deubel (Eds.), *The mind's eye: Cognitive and applied aspects of eye movement research* (pp. 213–234). Amsterdam: Elsevier.

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

Reichle, E. D., Pollatsek, A., & Rayner, K. (2006). E-Z reader: A cognitive-control, serial-attention model of eye-movement behavior during reading. *Cognitive Systems Research, 7,* 4–22.

Reichle, E. D., Pollatsek, A., & Rayner, K. (2007). Modeling the effects of lexical ambiguity on eye movements during reading. In R. van Gompel, M. Fischer, W. Murray, & R. Hill (Eds). *Eye movements: A window on mind and brain* (pp. 271–292). Amsterdam: Elsevier.

Reichle, E. D., Rayner, K., & Pollatsek, A. (1999). Eye movement control in reading: Accounting for initial fixation locations and refixations within the E-Z reader model. *Vision Research, 39,* 4403–4411.

Reichle, E. D., Rayner, K., & Pollatsek, A. (2003). The E-Z reader model of eye movement control in reading: Comparisons to other models. *Behavioural and Brain Sciences, 26,* 445–526.

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

Reilly, R. G., & Radach, R. (2003). Foundations of an interactive activation model of eye movement control in reading. In J. Hyönä, R. Radach, & H. Deubel (Eds.), *The mind's eye: Cognitive and applied aspects of eye movement research* (pp. 429–455). Amsterdam: Elsevier.

Reilly, R. G., & Radach, R. (2006). Some empirical tests of an interactive activation model of eye movement control in reading. *Cognitive Systems Research, 7,* 34–55.

Reingold, E. M. (2003). Eye-movement control in reading: Model and predictions. *Behavioural and Brain Sciences, 26,* 500–501.

Reingold, E. M., & Rayner, K. (2006). Examining the word identification stages hypothesized by the E-Z reader model. *Psychological Science, 17,* 742–746.

Rice, G. A., & Robinson, D. O. (1975). The role of bigram frequency in the perception of words and nonwords. *Memory & Cognition, 3,* 513–518.

Richter, E. M., Engbert, R., & Kliegl, R. (2006). Current advances in SWIFT. *Cognitive Systems Research, 7,* 23–33.

Salvucci, D. D. (2001). An integrated model of eye movements and visual encoding. *Journal of Cognitive Systems Research, 1,* 201–220.

Schiepers, C. (1980). Response latency and accuracy in visual word recognition. *Perception & Psychophysics, 27,* 71–91.

Schroyens, W., Vitu, F., Brysbaert, M., & d'Ydewalle, G. (1999). Eye movement control during reading: Foveal load and parafoveal processing. *Quarterly Journal of Experimental Psychology: Human Experimental Psychology, 52*(A), 1021–1046.

Sears, C. R., Campbell, C. R., & Lupker, S. J. (2006). Is there a neighborhood frequency effect in English? Evidence from reading and lexical decision. *Journal of Experimental Psychology: Human Perception and Performance, 32,* 1040–1062.

Seidenberg, M. S., Waters, G. S., Barnes, M. A., & Tanenhaus, M. K. (1984). When does irregular spelling or pronunciation influence word recognition. *Journal of Verbal Learning and Verbal Behaviour, 23,* 383–404.

Starr, M. S., & Inhoff, A. W. (2004). Attention allocation to the right and left of a fixated word: Use of orthographic information from multiple words during reading. *European Journal of Cognitive Psychology, 16,* 203–225.

Suppes, P. (1990). Eye-movement models for arithmetic and reading performance. In E. Kowler (Ed.), *Eye movements and their role in visual and cognitive processes* (pp. 455–477). Amsterdam: Elsevier.

Thibadeau, R., Just, M. A., & Carpenter, P. A. (1982). A model of the time course and content of reading. *Cognitive Science, 6,* 157–203.

Underwood, G., Binns, A., & Walker, S. (2000). Attentional demands on the processing of neighbouring words. In A. Kennedy, R. Radach, D. Heller, & J. Pynte (Eds.), *Reading as a perceptual process* (pp. 247–268). Oxford, England: Elsevier.

Vitu, F., & McConkie, G. W. (2000). Regressive saccades and word perception in adult reading. In A. Kennedy, R. Radach, D. Heller, & J. Pynte (Eds.), *Reading as a perceptual process* (pp. 301–326). Oxford, England: Elsevier.

Vonk, W., Radach, R., & van Rijn, H. (2000). Eye guidance and the saliency of word beginnings in reading text. In A. Kennedy, R. Radach, D. Heller, & J. Pynte (Eds.), *Reading as a perceptual process* (pp. 269–299). Oxford, England: Elsevier.

Waters, G. S., & Seidenberg, M. S. (1985). Spelling-sound effects in reading: Time-course and decision criteria. *Memory & Cognition, 13,* 557–572.

White, S. J. (2007). Foveal load and parafoveal processing: The case of word skipping. In R. van Gompel, M. Fischer, W. Murray, & R. Hill (Eds.), *Eye movements: A window on mind and brain* (pp. 409–424). Amsterdam: Elsevier.

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

White, S. J., & Liversedge, S. P. (2006a). Foveal processing difficulty does not modulate non-foveal orthographic influences on fixation positions. *Vision Research, 46,* 426–437.

White, S. J., & Liversedge, S. P. (2006b). Linguistic and non-linguistic influences on the eyes' landing positions during reading. *Quarterly Journal of Experimental Psychology, 59,* 760–782.

White, S. J., Rayner, K., & Liversedge, S. P. (2005). Eye movements and the modulation of parafoveal processing by foveal processing difficulty: A re-examination. *Psychonomic Bulletin & Review, 12,* 891–896.

Yang, S.-N. (2006). An oculomotor-based model of eye movements in reading: The competition/interaction model. *Cognitive Systems Research, 7,* 56–69.

Yang, S.-N., & McConkie, G. W. (2001). Eye movements during reading: A theory of saccade initiation time. *Vision Research, 41,* 3567–3585.

Appendix

Experimental Sentences

The critical word is shown in italics. Sentences a, b, and c refer to the frequent and orthographically familiar, infrequent and orthographically familiar, and infrequent and orthographically unfamiliar conditions, respectively.

1a. He loved to visit the local *town* near to where his grandparents lived.

1b. He loved to visit the local *cove* near to where he learnt to swim.

1c. He loved to visit the local *quay* near to his father's fish shop.

2a. He thought the awful *party* was a waste of time.

2b. He thought the awful *lager* was really not good enough.

2c. He thought the awful *vinyl* was a lot worse than the old carpet.

3a. He tried to lift the heavy *door* onto its hinges but he needed more help.

3b. He tried to lift the heavy *gong* onto the table without it making a noise.

3c. He tried to lift the heavy *tusk* onto the truck but it was just too awkward.

4a. She thought the dusty *glass* might be very valuable.

4b. She thought the dusty *cello* might need re-tuning.

4c. She thought the dusty *yucca* might need watering.

5a. He saw the famous *place* in the city where the pop star was born.

5b. He saw the famous *adder* in the reptile section of the zoo.

5c. He saw the famous *crypt* in the old church.

6a. The photograph showed the young *child* sitting on top of the climbing frame.

6b. The photograph showed the young *heron* sitting on its nest.

6c. The photograph showed the young *koala* sitting in the eucalyptus tree.

7a. She liked the basic *home* because it was practical and well designed.

7b. She liked the basic *loom* because she could easily weave beautiful fabrics.

7c. She liked the basic *yoga* because it provided good but gentle exercise.

8a. She admired the unique *city* before she found out about the drug problem.

8b. She admired the unique *dart* before she aimed it at the dartboard.

8c. She admired the unique *oboe* before she began to play her favourite composition.

9a. Eventually the strong *wife* managed to move the concrete slab.

9b. Eventually the strong *lout* managed to push his way to the bar.

9c. Eventually the strong *oxen* managed to finish ploughing the field.

10a. She laughed at the funny *sound* that was coming from the radiator.

10b. She laughed at the funny *hound* that was bounding across the field.

10c. She laughed at the funny *scowl* that the child was making.

11a. She knew that the modern *chair* was perfect for her bedroom.

11b. She knew that the modern *grate* was of very poor quality.

11c. She knew that the modern *kiosk* was not suitable for the business.

12a. She looked at the awful *fire* which was spreading across the forest.

12b. She looked at the awful *lice* which were causing so many problems.

12c. She looked at the awful *acne* which she desperately wanted to be better.

13a. He used the decent *table* for the dinner party at his house.

13b. He used the decent *plank* for the building work on the garage.

13c. He used the decent *opium* for the very last time.

(*Appendix continues*)

14a. He knew that the cheap *paper* might not be acceptable for the office.

14b. He knew that the cheap *crate* might not be strong enough to hold the bottles.

14c. He knew that the cheap *khaki* might not be quite the right colour.

15a. She chose the normal *bank* for the new business account.

15b. She chose the normal *sari* for her daughter to wear for the visit.

15c. She chose the normal *kiln* for the pots to be fired in.

16a. She liked the pretty *hair* that her sister had always had.

16b. She liked the pretty *glen* that she saw with her family in Scotland.

16c. She liked the pretty *loch* that was so quiet and peaceful.

17a. He gave the spare *money* to his brother after school.

17b. He gave the spare *cress* to his mother for the recipe.

17c. He gave the spare *myrrh* to the chemist at the university.

18a. She wanted the clean *room* ready for when her parents visited.

18b. She wanted the clean *lint* ready for the first aid session.

18c. She wanted the clean *toga* ready for the big party at the start of term.

19a. She liked the clever *idea* despite the expensive cost of the project.

19b. She liked the clever *dame* despite the annoying high pitched voice.

19c. She liked the clever *guru* despite his rather extreme beliefs.

20a. She worried about the major *case* that she had been asked to work on.

20b. She worried about the major *ford* that she would have to cross tomorrow.

20c. She worried about the major *feud* that had arisen within the family.

21a. She hated the awful *view* which she looked out on from her window.

21b. She hated the awful *lisp* which she had had since she was a child.

21c. She hated the awful *levy* which the society had decided to charge.

22a. He needed some normal *water* for the special mixture.

22b. He needed some normal *mince* for the special meal that he was cooking.

22c. He needed some normal *gauze* for the machine he was constructing.

23a. He disliked the boring *woman* despite her admirable achievements.

23b. He disliked the boring *chime* despite his love of clocks.

23c. He disliked the boring *polka* despite the fact that he was winning.

24a. The doctor looked at the unique *blood* under the microscope.

24b. The doctor looked at the unique *finch* under the old tree.

24c. The doctor looked at the unique *algae* under the water.

25a. She hated the yellow *house* which belonged to the dentist.

25b. She hated the yellow *froth* which clung to the edge of the bowl.

25c. She hated the yellow *fudge* which her grandmother gave her to eat.

26a. She admired the great *work* that the charity had done for the homeless.

26b. She admired the great *lark* that sang so beautifully in the tree.

26c. She admired the great *judo* that she saw the children doing in the arena.

27a. He planned the entire *story* before he spoke to the publisher.

27b. He planned the entire *prank* before he told his friends what to do.

27c. He planned the entire *haiku* before he wrote it for his girlfriend.

28a. He was impressed by the great *game* that everyone wanted to play.

28b. He was impressed by the great *solo* that the singer had performed.

28c. He was impressed by the great *hoax* that they had managed to pull off.

29a. He examined the clean *stage* before the performance.

29b. He examined the clean *quill* before he began to write.

29c. He examined the clean *anvil* before the smith used it to shape the metal.

30a. He wanted the quiet *night* to last forever because it was so peaceful.

30b. He wanted the quiet *tramp* to move away from the shop entrance.

30c. He wanted the quiet *hyena* to come back so that he could see him again.

31a. He thought the simple *light* was perfect for the office.

31b. He thought the simple *plait* was very appropriate on the little girl.

31c. He thought the simple *humus* was a bit boring for the special sandwiches.

32a. He cleaned the dirty *food* before giving it to the animals.

32b. He cleaned the dirty *leek* before he chopped it up for the stew.

32c. He cleaned the dirty *ruby* before he took it to the jewellers.

33a. She knew that the modern *road* would be safest in the winter conditions.

33b. She knew that the modern *cork* would keep the wine in good condition.

33c. She knew that the modern *tyre* would last a long time.

34a. She found the small *book* under the bed in her room.

34b. She found the small *dice* under the board game and cards.

34c. She found the small *kiwi* under the oranges and apples in the fridge.

35a. He watched the quiet *class* whilst they worked on the project.

35b. He watched the quiet *panda* whilst he hid amongst the bamboo bushes.

35c. He watched the quiet *waltz* whilst he waited at the dance hall.

36a. He knew that the single *girl* would not want his phone number.

36b. He knew that the single *pear* would be good for the fruit crumble.

36c. He knew that the single *buoy* would be positioned near the stranded ship.

37a. She wanted a decent *world* for the poor people in the developing countries.

37b. She wanted a decent *puree* for the fantastic meal she was trying to prepare.

37c. She wanted a decent *dowry* for herself and her husband after the marriage.

38a. She used the fresh *fish* for the family dinner.

38b. She used the fresh *lard* for frying the meatballs.

38c. She used the fresh *suet* for making the dumplings.

39a. He examined the small *group* using a basic written test for each child.

39b. He examined the small *louse* using a special microscope.

39c. He examined the small *ulcer* using key-hole surgery.

Received May 30, 2006
Revision received May 29, 2007
Accepted June 5, 2007 ■