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Coordination of Word Recognition and Oculomotor Control During Reading: The Role of Implicit Lexical Decisions

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Abstract

The coordination of word-recognition and oculomotor processes during reading was evaluated in two eye-tracking experiments that examined how word skipping, where a word is not fixated during first-pass reading, is affected by the lexical status of a letter string in the parafovea and ease of recognizing that string. Ease of lexical recognition was manipulated through target-word frequency (Experiment 1) and through repetition priming between prime-target pairs embedded in a sentence (Experiment 2). Using the gaze-contingent boundary technique the target word appeared in the parafovea either with full preview or with transposed-letter (TL) preview. The TL preview strings were nonwords in Experiment 1 (e.g., *bilnk* created from the target *blink*), but were words in Experiment 2 (e.g., *sacred* created from the target *scared*). Experiment 1 showed greater skipping for high-frequency than low-frequency target words in the full preview condition but not in the TL preview (nonword) condition. Experiment 2 showed greater skipping for target words that repeated an earlier prime word than for those that did not, with this repetition priming occurring both with preview of the full target and with preview of the target's TL neighbor word. However, time to progress from the word after the target was greater following skips of the TL preview word, whose meaning was anomalous in the sentence context, than following skips of the full preview word whose meaning fit sensibly into the sentence context. Together, the results support the idea that coordination between word-recognition and oculomotor processes occurs at the level of implicit lexical decisions.

Recognizing words so that their meanings can be retrieved is critical to successful reading comprehension. These lexical processes must be coordinated with other perceptual, motor, and attentive processes in order for eye movements during reading to be controlled efficiently. During reading the eyes alternate between fixations (periods when the eyes are nearly stationary) and saccades (rapid ballistic movements); for skilled readers saccades typically occur four to five times per second with most words receiving only a single first-pass fixation (Rayner, 1998). Oculomotor processes, which are constrained by differential acuity across the retina and by the nature of ocular motor control, are major determinants of eye movements during reading. The contribution of these processes can be seen in how physical characteristics of text, such as the length of words, influence the pattern of fixations and saccades. Language-based processes that relate to comprehension of the text also exert a strong influence on when – and occasionally where – the eyes move during reading. The contribution of these processes can be seen in how eye movements are influenced by non-physical aspects of the text such as word frequency or the predictability of a word in context. Very different explanations have been advanced for how oculomotor and language-based processes are coordinated. At one extreme it is argued that language-based effects on eye-movements lead to only slight modulation of a more basic oculomotor process that generates forward saccades of a standard length at a regular rhythm (McConkie, Kerr, Reddix, & Zola,

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1988; O'Regan, 1990; Yang & McConkie, 2001). At the other extreme it is argued that, while oculomotor processes determine most characteristics of the targeting of forward saccades, word recognition determines when saccades are initiated and in some instances their targeting (Morrison, 1984; Pollatsek, Reichle & Rayner, 2006; Reichle, Pollatsek, Fisher, & Rayner, 1998). Other models take more intermediate positions (Engbert, Nuthmann, Richter, & Kliegl, 2005; Reichle, Rayner, & Pollatsek, 2003).

The phenomenon of skipping, where a word is not directly fixated during the first pass of the eyes over the text, has been central to the evaluation of these alternative models. Word length has a very strong effect on skipping, with short words skipped more frequently than long words (Kerr, 1992; Vitu, O'Regan, Inhoff, & Topolski, 1995; for a review see Brysbaert, Drieghe, & Vitu, 2005). This effect can be readily understood as resulting from visual and motor processes. A short word to the right of the fixated word is seen more clearly than a long word because it is more likely to fit within the fovea. Further, having the eyes land on short words tends to require shorter saccades than having them land on long words, which increases the likelihood that short words will be skipped because motor error in saccade targeting takes the form of overshoot for short saccades and undershoot for long saccades (McConkie, Kerr, & Dyre, 1994; McConkie et al., 1988). Language-based factors also affect skipping, such that frequent and predictable words are more likely to be skipped than infrequent or unpredictable words (Ehrlich & Rayner, 1981; Rayner & Fisher, 1996; Rayner & Raney, 1996; Rayner & Well, 1996; Schilling, Rayner, & Chumbley, 1998; White, 2008). Skipping effects are interesting in part because they are the only case where language factors related to word recognition affect the targeting of forward saccades rather than just their timing (Drieghe, Rayner, & Pollatsek, 2005). As such, skipping has been an important arena for addressing the manner in which lexical processing is coordinated with processes of attention, vision and motor control during reading.

Models of eye movement control that attribute only a small role to language-based processing relative to oculomotor processing account for language effects on skipping in a number of ways. For example, according to the Extended Optimal Viewing Position (EOVP) model, language-based skips are in essence an educated guess based on factors such as word length and very partial word identification (Brysbaert & Vitu, 1998). The main determinants of the decision to skip a word are the length of the word in the parafovea and the experience the system has built up with how often a word of a certain length at a certain distance can be skipped without hindering overall text comprehension. Consequently that decision is made with very limited information about the identity of the skipped word. Models of eye-movement control that attribute a more substantial role to language-based (or cognitive) factors have gone through a number of iterations and refinements, but have retained a core set of mechanisms to account for language-based skipping as described by the EZ Reader model (Morrison, 1984; Pollatsek et al., 2006; Reichle et al., 1998). These models posit a serial-attention-shifting mechanism where words in the text are processed one at a time (though recognition of a word is achieved by matching the stimulus to multiple lexical and sublexical representations in parallel). Once the fixated word is recognized, attention shifts to processing parafoveal information about the next word. Attention shifts prior to movement of the eyes because of limits on the rate at which saccades can be generated. In the majority of cases the oculomotor system then executes a planned saccade which has been targeted to the next word on the basis of a parallel process of visual analysis that locates word boundaries. The processing that occurs prior to fixation on that word provides a parafoveal-preview benefit that facilitates recognition, a *spillover* effect that can be observed in first-pass reading times (Henderson & Ferreira, 1990; Kennison & Clifton, 1995; White, Rayner, & Liversedge, 2005). In a minority of cases, recognition of the word in the parafovea occurs quickly enough that the planned saccade to that word can be cancelled and a new saccade can be programmed to a more distant word resulting in a skip of the word in the parafovea. Thus, according to the EZ Reader model the ease of recognizing the current word affects both the amount of parafoveal-preview benefit on the next word and, together with the ease of recognizing the next word, determines whether that next word is skipped. A strong association between ease of word recognition, parafoveal preview benefit and skipping has been found for word frequency and predictability (e.g., Drieghe et al. 2005; Rayner & Fisher, 1996) though manipulations of the visual characteristics of text (Drieghe, 2008) and the phonological length of words (Fitzsimmons & Drieghe, 2011) have shown dissociations between these factors.

An essential feature of the serial-attention-shifting models is that the same mechanisms are used for recognizing words in the fovea and parafovea. In both cases the initiation of saccadic processes is linked to processing words to a level where the words are highly likely to be fully recognized soon (Pollatsek et al., 2006). Gordon, Plummer and Choi (in press) tested this model by using repetition to manipulate the ease of recognizing a target word while using the boundary technique (Rayner, 1975) to manipulate the information about that word available during parafoveal preview. The boundary technique is a gaze-contingent method where the stimulus word changes when the eyes cross an invisible boundary on the screen, thereby allowing manipulation of the relationship between parafoveal and foveal information about a word. In Gordon et al. the string in the parafovea could either be the target word itself (e.g., the name Herman) or a nonword created by transposing two internal letters of the target word (e.g., Hreman). When used as primes in masked-priming studies or as preview strings in eye-movement studies, such *transposed letter* (TL) nonwords produce substantial facilitation in the subsequent processing of the target word as compared to substituted letter (SL) nonwords that have the same number of letter-in-position differences with the target word (Johnson, Perea, & Rayner, 2007; Perea & Lupker, 2003a, 2003b;). However, when TL nonwords are directly fixated they disrupt reading (causing longer first-pass reading times and greater likelihood of refixation) because they are not words (Rayner, White, Johnson, & Liversedge, 2006; White, Johnson, Liversedge, & Rayner, 2008). Gordon et al. found that facilitating lexical access through repetition increased skipping when the parafoveal preview string was the target word itself, but that repetition had no effect on skipping when the parafoveal preview string was a highly-similar TL nonword. This pattern supports serial-attention-shifting models, such as EZ Reader, by showing that the letter string in the parafovea must be recognized as a word in order for lexical priming to increase skipping above the baseline rate that occurs due to oculomotor processes. Thus, it is not the case that contextual facilitation due to repetition priming constitutes a bias that combines with partial visual information from the periphery to increase skipping (see Engbert et al., 2005; Rayner, Slattery, Drieghe & Liversedge, 2011 for advocacy of such a mechanism in the case of word predictability). The Gordon et al. findings are consistent with models of eye-movement control during reading where the key link between language-based and oculomotor processes is an *implicit lexical decision* about whether the letter string in the parafovea will be successfully recognized as a word.

Experiment 1

This experiment tests the hypothesis that language-based word skipping depends on an implicit decision that the letter string in parafoveal preview will be recognized as a word by seeing whether the increased skipping rate observed for high-frequency (HF) versus low-frequency (LF) words depends on the type of preview (full vs. TL nonword) that readers have for that word. The four conditions are illustrated in 1a–1d below, with the parafoveal preview string and target word shown in brackets and separated by a colon.

1a HF-full The visitors saw that the base was slightly [north:north] of their current location.

1b HF-TL The visitors saw that the base was slightly [nroth:north] of their current location.

1c LF-full The only sign of life was the momentary [blink: blink] of his left eye.

1d LF-TL The only sign of life was the momentary [bilnk: blink] of his left eye.

Skipping is produced both by oculomotor and language-based processes and therefore overall skipping rates reflect a mixture of skips generated by oculomotor and language-based processes. The design of the study holds oculomotor factors constant by equating word length so that any effect of the stimulus conditions should provide evidence about the nature of the mechanisms of language-based skipping. If language-based skipping involves a decision that the letter string in parafoveal preview is likely to be recognized as a word (Gordon et al., in press; Pollatsek et al., 2006), then increased skipping due to lexical frequency should occur when readers have full preview of the parafoveal letter string but it should not occur when the preview string is a TL nonword. Such a pattern would be consistent with models in which the initiation of forward saccades is based on an implicit decision that the letter string being processed will be successfully recognized as a word. Alternatively, if skipping is based on a partial word identification process, then increased skipping due to lexical frequency should not depend on preview type because TL nonwords cause greater activation of their base word when that base word is high frequency as compared to low frequency, a pattern that has been found both in masked-priming research on word recognition (O'Conner & Foster, 1981) and in neighborhood effects on eye movements during reading (Williams, Perea, Pollatsek, & Rayner, 2006).

The experiment follows the general strategy of the Gordon et al. (in press) study in that it examines whether the skipping rate for a TL nonword seen only in the parafovea is affected by the ease of recognizing the base word from which the TL nonword is generated. Extending this strategy to word frequency is important because research on language-based skipping has focused much more on word frequency than on word repetition (Pollatsek et al., 2006; Reichle et al., 2003;); therefore, examination of how frequency effects on skipping are modulated by parafoveal information relates directly to the substantial body of empirical and theoretical work on how language and eye-movement control processes interact during reading. In addition, Gordon et al. manipulated within-sentence repetition using proper names. This was done because proper names can be placed in different sentence positions without the lexical-semantic constraints that affect the placement of content words. This allowed Gordon et al. to counterbalance fully the assignment of names to the repeated and new conditions, a level of control that would have been difficult to achieve when manipulating within-sentence repetition of content words. While a variety of evidence suggests that proper names and content words are processed similarly (e.g., Hollis & Valentine, 2001), some evidence suggests differences (e.g., Moxey, Sanford, Sturt, & Morrow, 2004; Van Petten, Kutas, Kluender, Mitchiner, & McIsaac, 1991), making it important to determine whether the ease of recognizing a content word affects skipping rate when it is used as a base word to generate a TL nonword in parafoveal preview.

Method

Participants—Twenty-eight undergraduates at the University of North Carolina at Chapel Hill participated for $10 or for course credit. All participants were native English speakers with normal or corrected-to-normal vision and were naïve about the goals of the experiment.

Materials and Design—One hundred twenty words (five letters in length) were used as targets, with each embedded in a single-line sentence. Some target words were selected from Johnson et al. (2007), and others from the CELEX corpus (Baayen, Piepenbrock, & Gulikers, 1995). Sixty targets were high-frequency words (mean word frequency of 251 per million) and 60 were low-frequency words (mean word frequency of 2.72 per million). Orthographic familiarity of the target words was balanced by equating the average letter n-gram frequencies in the high- and low- target-word frequency conditions, as calculated by N-Watch (Davis, 2005) using the default CELEX English word-form corpus (Baayen et al. 1995). This was done because orthographic familiarity can influence lexical or sub-lexical processing of words during reading (Lima & Inhoff, 1985; Plummer & Rayner, 2012; White, 2008; White & Liversedge, 2004, 2006a, 2006b). Type and token frequency were assessed for letter bigrams and trigrams. The results of these orthographic analyses of the target words are shown in Table 1. No significant differences were found between high-frequency and low-frequency target words on any n-gram measures ($t < 1$, $p > .05$ for all comparisons).

The preview strings for the TL condition were created by transposing the second and the third letter of each target word (*huose* as the preview of *house*), which in all cases resulted in a letter string that was not an English word. Analysis of these TL nonword preview strings showed that they were balanced in high- and low-frequency base word conditions on two dimensions of similarity to real words that might plausibly affect their processing. The pronounceability of the initial three letters of the TL strings and of the entire TL string, as rated by two native English speakers, did not differ across the two conditions (pronounceability for the first three letters: 75% for TL nonwords with high frequency base words vs. 68% for TL nonwords with low frequency base words; pronounceability for the whole letter nonwords: 50% for TL nonwords with high frequency base words vs. 61% for TL nonwords with low frequency base words). In addition their average number of orthographic neighbors, which might affect skipping rates (Pollatsek, Perea, & Binder, 1999) did not differ between TL nonwords in the two conditions as measured by N-Watch (Davis, 2005), $t < 1$, $p > .5$.

A measure of the predictability of the target words in context (corpus-based measures of transitional probability from the previous word) was obtained because predictability affects where and when the eyes move during reading (Calvo & Meseguer, 2002; Rayner & Well, 1996). Following previous research (McDonald & Shillcock, 2003a; 2003b), transitional probability was calculated as the ratio of joint and marginal frequencies of the target word. Frequency information was obtained from the online version of The Corpus of Contemporary American English (COCA; released in 2008). COCA is a large, diverse corpus of American English which includes more than 385 million words produced from 1990 – 2008 (20 million words each year), balanced between spoken language and written language of several genres: fiction, magazines, newspapers, academic journals (Davies, 2008). Table 2 shows average transitional probabilities for each frequency condition. There were no significant differences on any of these measures of transitional probability for high-frequency target words and low-frequency target words ($p > 0.15$).

The word in the context sentence that immediately preceded the target word was 5 to 11 letters long; length and word frequency were not significantly different across the two frequency conditions (ts < 1.2). Limiting the minimum length of the preceding word increases the likelihood that it is fixated, which in turn increases the likelihood that the target word is seen in the parafovea, and the frequency of the preceding word may influence the processing resources available for the target word in the parafovea (Henderson & Ferreira, 1990).

Four counterbalanced lists were created, each containing 30 sentences with target words in each of the four conditions defined by the combination of base word frequency (high vs. low) and preview type (full vs. TL), as shown in 1a–1d. Equal numbers of participants were tested with each list.

After completion of the eye-tracking experiment, a separate group of 20 participants performed a modified Cloze test (Taylor, 1953) where they were presented with the sentence context preceding the target word and were asked to write a natural-sounding completion of the sentence. This was done in order to provide an additional measure of contextual predictability of the target words beyond that provided by the corpus-based transitional probability measure. The results showed that 5 target words were predictable from preceding context (over 40%), so these items were excluded from statistical analyses of the eye-movement data from the main experiment. The mean predictability scores for the remaining target words was less than 5% and the difference between high-frequency (5.9%) and low-frequency (3.6%) condition was not statistically significant ($t(118) = 1.3$, $p > .19$).

Procedure—Trials began with a fixation point presented near the left edge of the monitor and centered vertically. Upon subject's fixation of the point, the stimulus sentence appeared with its first word overwriting the fixation point. Participants were asked to read the sentence in a natural way and to press a button when finished. Then participants were presented with a true-false comprehension question about the content of the sentence.

An Eyelink 1000 model (SR Research, Ontario, Canada) was used to record eye movements from the reader's dominant eye at a sampling rate of 1000 Hz, with a headrest used to minimize head movement. Sentences were presented in black on a white background using a Courier mono-spaced font. They were displayed on a 21 inch ViewSonic G225f Monitor with resolution set to 1024 × 768 and refresh rate set to 120Hz. The distance between the participant and the display monitor was 61cm; 3.8 characters subtended 1° of visual angle. An invisible boundary (Rayner, 1975) in the center of the space immediately before the target word was used to manipulate the preview condition (full vs. TL) of the target word. When the reader's eyes crossed the boundary a display change was triggered where the preview string was replaced with the target string.

Results

Analysis of eye movements—First-pass skipping rates on the target word were calculated as the proportion of trials in which the target word was not fixated at all or was only fixated after a subsequent word had been fixated. Reading-time measures were calculated after substituting outliers with durations less than 80 ms or greater than 700 ms with those boundaries[1]. First-pass fixations were those after the eyes fixated on a word until they moved off the word, given that they had not progressed beyond that word before the first fixation. *Single-fixation duration* (SFD) was the average of the duration of the initial, first-pass fixation on a word given that the word received only one first-pass fixation. *First-fixation duration* (FFD) was the average of the duration of the initial, first-pass fixation on a word regardless of whether there were subsequent first-pass fixations on the word. *Gaze duration* (GZD) was the average of the sum of the durations of all first-pass fixations on a word.

All trials in which the subject blinked during first-pass reading of the pre-target, target or post-target word were excluded from the analysis as were all trials in which the display change occurred prior to the first saccade that crossed the invisible boundary. For the final analysis 4.8% of trials were excluded by these criteria. Four of 28 subjects and 2 of 120 sentences that each lost more than 15% of data by these criteria were eliminated from further

[1]This method of handling outliers is consistent with our previous research (Gordon et al. in press; Gordon, Hendrick, Johnson & Lee, 2006; Kwon, Lee, Gordon, Kluender & Polinsky, 2010; Lee, Lee & Gordon, 2007). Different criteria have been used in other labs. For example, Rayner et al. (2004) excluded fixations in cases where they were more than 2.5 standard deviations from the mean while Drieghe et al. (2005) eliminated outliers that were longer or shorter than the fixed-criterion (e.g. less than 100 ms, more than 1200 ms). The patterns of statistical significance in this experiment and the next did not depend on the specific criteria reported here.

analyses. Together with the elimination of five sentences based on the sentence completion data, this meant that 24 subjects and 113 experimental sentences (54 high frequency target words and 59 low frequency target words) were included in the analyses.

Target-word skipping—Figure 1 shows the mean skipping rate for the target word as a function of preview type (full vs. TL) and target-word frequency (high vs. low). Four conditions were analyzed with a 2 (type of preview) by 2 (word frequency) analysis of variance (ANOVA). Skipping rates were greater for high-frequency than for low-frequency target words, $F_1(1,23) = 6.55$, $p < 0.05$, $F_2(1,111) = 10.24$, $p < 0.005$. Skipping rates were also greater for full preview than for TL preview of the target word, $F_1(1,23) = 12.13$, $p < 0.005$, $F_2(1,111) = 19.06$, $p < 0.001$. Critically, there was a significant interaction of word frequency and preview type, $F_1(1,23) = 7.35$, $p < 0.05$, $F_2(1,111) = 5.47$, $p < 0.05$. Planned comparisons showed that in the full preview condition skipping rates were elevated for high-frequency targets (.15) as compared to low-frequency targets (.07), $t_1(23) = 2.92$, $p < 0.05$, $t_2(111) = 3.64$, $p < 0.05$, but that in the TL-preview condition skipping rates did not differ as a function of target word frequency (.08 vs. .06) (*t*s < 1, n.s.).[2] This pattern is consistent with the idea that language-based skipping involves an implicit decision that the letter string in parafoveal preview is likely to be recognized as a word, as claimed by serial-attention models of eye-movement control during reading (Reichle et al., 1998; Pollatsek et al. 2006), but not with models in which language-based skipping is based on an educated guess about word identification, as claimed by some parallel attention models (e.g. Brysbaert & Vitu, 1998, EOVP model).

Reading time on word preceding target—Table 3 shows mean first-pass reading times on the word preceding the target word. There were no main effects or interactions of target-word frequency or preview type. The absence of such effects is consistent with the view that the processing of the currently-fixated word is not influenced by the word in parafoveal preview (i.e., no parafoveal-on-foveal effects; Rayner, White, Kambe, Miller, & Liversedge, 2003; cf. Kennedy & Pynte, 2005). In addition, SFDs on the word preceding the target were analyzed as a function of whether the target word was subsequently skipped. In the subject analysis, SFDs were slightly longer when the target word was subsequently skipped (230 ms) as compared to when it was subsequently fixated (224 ms), a difference that was not close to significant, $F_1(1,23) = 0.6$, $p = 0.448$. In the item analysis, this difference was larger (245 ms vs. 223ms) and statistically significant, $F_2(1,111) = 4.24$, $p < .05$.[3] This result provides very modest support for serial-attention-shift models (such as

[2]As a supplementary measure, restricted skipping rate was calculated after reclassifying as non-skips instances where the target word was skipped but there was an immediate regression back to that word. This pattern of movement is thought to represent motor programming error in the targeting of the saccade rather than skipping based on lexical processing (Drieghe, et al., 2005). Skip reclassification affected 1.7% of the valid trials. Restricted skipping rates were greater for high-frequency than for low-frequency target words, $F_1(1,23) = 4.91$, $p < 0.05$; $F_2(1,111) = 9.28$, $p < 0.05$, and were also greater for full preview than for TL preview of the target word, $F_1(1,23) = 15.13$, $p < 0.05$; $F_2(1,111) = 28.36$, $p < 0.05$. The interaction of word frequency and preview type was significant by subjects and marginally significant by items, $F_1(1,23) = 6.56$, $p < 0.05$, $F_2(1,116) = 3.78$, $p = 0.054$. Planned comparisons showed that in the full preview condition restricted skipping rates were elevated for high-frequency as compared to low-frequency target ($t_1(23) = 2.60$, $p < 0.05$; $t_2(111) = 3.13$, $p < 0.05$) but that in the TL-preview condition restricted skipping rates did not differ as a function of target word frequency (*t*s < 1, n.s.). The pattern of effects observed for restricted skipping rates corroborates the pattern observed for raw skipping rates.

[3]The statistical significance of the skipping cost was further assessed using linear mixed effects (lme) modeling (Baayen, Davidson & Bates, 2008) as calculated by the lmer4 package in R (R Development Core Team, 2011). In a model with random intercepts but not random slopes the effect of skipping on the duration of the preceding single-fixation duration was significant (t = 2.31, with p = .021 as estimated using Monte Carlo Markov Chain (MCMC) sampling). Proponents of lme analyses argue that random slopes should only be included in the model used to test effects if their inclusion leads to significantly better model fit, which was not the case for this analysis. However, it has been argued that omitting random slopes, even when they do not significantly improve model fit, leads to inflation of Type 1 error rates (Barr, Levy, Scheepers & Tily, under review) because of the potentially problematic assumption that observations in different conditions from the same subject are independent. In an lme model with random slopes the skipping cost was not significant, just as it was not significant in the by-subjects repeated-measures ANOVA which similarly does not assume independence of observations from the same subject.

EZ Reader) in which longer fixations before skipping are the consequences of saccade cancelation and reprogramming (Reichle et al., 2003; cf. Kliegl & Engbert, 2005). The absence of statistical significance is a challenge to serial-attention-shifting models but it may be due to difficulties measuring the duration of an infrequent event (fixations prior to skips).

Reading times on target word—Table 4 shows reading times on the target word as a function of word frequency and preview type. For all three first-pass reading-time measures, times were shorter for high-frequency as compared to low-frequency target words: SFD, $F_1(1,23) = 31.25$, $p < 0.001$, $F_2(1,111) = 37.42$, $p < 0.001$, FFD, $F_1(1,23) = 23.43$, $p < 0.001$, $F_2(1,111) = 36.49$, $p < 0.001$, and GZD, $F_1(1,23) = 72.73$, $p < 0.001$, $F_2(1,111) = 37.45$, $p < 0.001$. In addition, all three measures showed shorter times for target words seen with full preview as compared to target words seen with TL preview: SFD, $F_1(1,23) = 20.7$, $p < 0.001$, $F_2(1,111) = 18.7$, $p < 0.001$, FFD, $F_1(1,23) = 14.86$, $p < 0.001$, $F_2(1,111) = 13.81$, $p < 0.001$, and GZD, $F_1(1,23) = 28.83$, $p < 0.001$, $F_2(1,111) = 16.54$, $p < 0.001$. These results indicate that recognition of the target word received more benefit from the processing of parafoveal information on the preceding fixation when the full word was available in preview than when preview consisted of a TL nonword. Finally, there was a numerical tendency across all three first-pass measures for the word frequency effect to be larger following TL preview than full preview, though this interaction was marginally significant for SFD, $F_1(1,23) = 3.94$, $p = 0.059$, $F_2(1,111) = 1.15$, $p < 0.285$, and non-significant for FFD, $F_1(1,23) = 0.584$, $p =0.452$, $F_2(1,111) = 0.083$, $p = 0.774$, and GZD, $F_1(1,23) = 2.69$, $p =0.115$, $F_2(1,111) = 1.38$, $p = 0.242$[4].

Reading times on word after target—Table 5 shows the first-pass reading times on the word immediately after the target word, selected for those trials where first-pass reading of the target was followed by a saccade to that word. Previous studies have shown that the ease of processing a word is modulated by the ease of processing the previous word on the immediately preceding fixation, a finding that has been interpreted as indicating that more time was available for parafoveal processing of the word during the preceding fixation on an easily recognized word (Kennison & Clifton, 1995; Rayner & Duffy, 1986). This spillover effect of word frequency was significant for the first-pass reading time measures in the subject analysis: SFD, $F_1(1, 23) = 7.27$, $p < 0.05$, FFD, $F_1(1, 23) = 5.69$, $p < 0.05$, and GZD, $F_1(1, 23) = 11.09$, $p < 0.01$, but only significant for SFD in the item analysis: SFD, $F_2(1, 23) = 4.19$, $p < 0.05$, FFD, $F_2(1, 23) = 1.84$, $p = 0.18$, and GZD, $F_2(1, 23) = 1.43$, $p = 0.24$. Preview type did not have a significant spillover effect on any reading time measure (all *F*s < 1) nor did it interact significantly with word frequency (all *F*s < 1).

Discussion

The central finding of Experiment 1 was that higher skipping rates were observed for high-frequency compared to low-frequency words when there was full preview of the target word but that this frequency effect on skipping was not observed when preview consisted of a TL nonword generated from the target word. This finding is consistent with models of reading in which the critical link between language-based (cognitive) processes and oculomotor processes consists of an implicit lexical decision that a letter string will be recognized as a

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[4]Two later measures of reading time – regression-path duration and total reading time – were also calculated. Regression-path duration is defined as the sum of the duration of all fixations from the time when the eyes first fixate on a word until the eyes move beyond the word given that the eyes have not progressed beyond the word. Total time is the sum of the duration of all fixations on a word. Reading times were shorter for high-frequency target words as compared to low-frequency target words on both measures: regression-path duration, $F_1(1,23) = 16.68$, $p < 0.001$, $F_2(1,111) = 15.95$, $p < 0.001$, and total time $F_1(1,23) = 33.79$, $p < 0.001$, $F_2(1,111) = 13.79$, $p < 0.001$. In addition, there was a significant main effect of preview type (significant in regression-path duration and marginally significant in total time), showing shorter fixation duration for the full preview as compared to the TL preview: regression-path duration, $F_1(1,23) = 8.83$, $p < 0.01$, $F_2(1,111) = 4.43$, $p < 0.05$, and total time, $F_1(1,23) = 3.73$, $p = 0.066$, $F_2(1,111) = 3.15$, $p = 0.07$. In contrast, there were no suggestions of interactions between word frequency and preview type (*F*s <1).

word (Pollatsek et al, 2006). It is not consistent with models in which language-based skipping amounts to an educated guess based on partial word recognition (Brysbaert & Vitu, 1998). The experiment showed that the effect of the lexical status of the preview string interacted with ease of recognizing the target word to affect skipping rates in the same way for word frequency as it has been found to do for word repetition (Gordon et al., in press).

There is some evidence that target words that are predictable from context or have higher-frequency neighbor words may be misperceived during normal sentence reading (Drieghe, Rayner, & Pollatsek, 2005; Slattery, 2009). The results of Experiment 1 showed no evidence that word frequency contributes to the misperception of the letter string in parafoveal preview. If the base-word activation of a TL nonword string is modulated by the frequency of the base word (O'Conner & Foster, 1981), then skipping rates for TL nonwords with high-frequency base words should have been greater than skipping rates for TL nonwords with low-frequency base words. Instead, Experiment 1 found no difference between skipping rates for TL non-words with high- and low-frequency base words.

Experiment 2

This experiment further examines how the ease of processing lexical information in parafoveal preview affects the targeting of eye movements during reading. As in Experiment 1 and in Gordon et al. (in press), this experiment manipulates both the ease of lexical processing of a target word and whether there is full parafoveal preview of the target word or preview of a highly similar TL letter string derived from the target word. Unlike those two experiments, the target words in this experiment were selected so that transposing two word-internal letters produced a word rather than a nonword, as in the pairs *scared – sacred* and *calm – clam*. Example sentences for the four conditions are shown in 2a–2d.

2a Rept-full Zach isn't <u>scared</u> of bugs, but he is definitely [*scared*:**scared**] of the snakes in the forest.

2b Rept-TL Zach isn't <u>scared</u> of bugs, but he is definitely [*sacred*:**scared**] of the snakes in the forest.

2c New-full Zach isn't <u>afraid</u> of bugs, but he is definitely [*scared*:**scared**] of the snakes in the forest.

2d New-TL Zach isn't <u>afraid</u> of bugs, but he is definitely [*sacred*:**scared**] of the snakes in the forest.

TL words have been used to study lexical confusability, orthographic coding and neighborhood effects (Acha & Perea, 2008; Chambers, 1979; Johnson, 2009); they are fairly rare in English but occur more frequently in some other languages (Duñabeitia, Molinaro, Laka, Estévez, & Carreiras, 2009). In a boundary study, Johnson and Dunne (2012) found that TL words caused greater parafoveal preview benefit on the target word than did SL words or SL nonwords; they did not manipulate the ease of recognizing the parafoveal letter strings, nor did they report skipping rates.

In this experiment, the ease of lexical processing of the target word was manipulated by repetition as was done by Gordon et al (in press). A target word (e.g., *scared*) could be presented following an earlier presentation of the same word, or following an earlier presentation of a synonym of the target word (e.g., *afraid*; see 2a–2d). The results of Gordon et al. predict that with full preview higher skipping rates should be observed when the target word is repeated rather than new, with such a finding showing that lexical repetition effects on skipping are not limited to proper names. However, the idea that language-based skipping involves an implicit lexical decision predicts that with TL preview, repetition will also increase skipping rates in the current experiment because it uses TL words rather than the

TL nonwords used in Gordon et al. (and in Experiment 1). More specifically, in the repeated condition the first occurrence of the target word (e.g., *scared*) should facilitate recognition of the TL word in parafoveal preview (e.g., *sacred*), given the substantial priming that occurs between TL letter strings. In the experiments with TL nonword preview strings, such priming would not support the decision that the string in parafoveal preview is likely to be recognized as a word, but with TL word preview, this priming should facilitate the decision that the string in parafoveal preview is likely to be recognized as a word.

An additional prediction arises from a practical constraint on designing and implementing the experiment. English has a very limited set of TL word pairs, and most of them show a very substantial imbalance in the frequency of the words in a pair (e.g., *calm* is much more frequent than *clam*). Because it is very difficult to construct natural-sounding sentences that have two occurrences of a low-frequency word such as *clam*, all stimulus sentences were written using the high-frequency member of the pair as the target word, with the low-frequency member used as the TL word preview string. Accordingly, a higher rate of skipping is predicted for the full preview condition as compared to the TL preview condition, irrespective of the repetition manipulation, because skipping rates are greater when the letter string in parafoveal preview is a high-frequency word as compared to when it is a low frequency word (Rayner, Ashby, Pollatsek, & Reichle, 2004; Rayner & Fisher, 1996; Rayner & Raney, 1996; White, 2008; Experiment 1).

Finally, the idea that language-based (cognitive) processing is linked to forward saccades through an implicit lexical decision specifies a level of word recognition that does not include integrating the meaning of the word into the overall meaning of the sentence. All of the sentences used in this experiment become semantically anomalous if the TL word is substituted for the target word (see 2a–2d). Accordingly, when skipping is based on the TL word in parafoveal preview there should be some downstream disruption of comprehension because the meaning of the TL word is anomalous in relation to the sentence meaning.

Method

Participants—Forty undergraduates at the University of North Carolina at Chapel Hill participated for course credit. All were native English speakers with normal or corrected-to-normal vision and were naïve about the goals of the experiment.

Materials and Design—Forty target words that have a TL neighbor word were selected from materials presented in Johnson (2009), Andrews (1996), and Chambers (1979). Length of target words ranged from 3 to 7 letter words, with 85% of the target words having 4 or 5 letters. Forty control prime words for the *New* condition were selected from the CELEX English word-form corpus (Baayen et al., 1995); their average frequency and length did not differ from those of the target words (word frequency: 49 per million (Repeated) vs. 49 per million (New), word length: 4.7 letters (Repeated) vs. 5.1 letters (New), ts < 1).

As seen in 2a–2d, prime and target pairs were inserted into identical sentence frames with manipulation of the prime determining whether the target occurred in the repeated condition, where the prime and target word were the same (*calm* and *calm*), or the new condition, where the prime differed from the target but was semantically similar (*quiet* and *calm*). The target word was presented either with full preview, where the preview string was identical to the target word (*calm* as the preview of *calm*) or with transposed letter (TL) preview, where the preview string was created by transposing two consecutive internal letters of the target word (*clam* as the preview of *calm*). The higher-frequency member of the TL pair (*calm*) was used as the target word in every sentence frame. Four counterbalanced lists of 40 sentence frames were generated based on the four experimental conditions (repetition by preview type), with equal numbers of subjects tested on each counterbalanced list. A complete list of the experimental materials is given in Appendix 2. After four practice trials, subjects read the experimental sentences along with 80 filler sentences in a pseudo-random order.

Procedure—The procedure of the Experiment 2 was exactly the same as that of Experiment 1.

Results

Analysis of eye movements—Procedures for analysis of the eye tracks followed those of Experiment 1, with the restrictions leading to exclusion of 7.6% of the data points.

Target-word skipping—As seen in Figure 2, skipping rates were higher in the repeated condition, where the target was also the prime, than in the new condition, where the target differed from the prime, $F_1(1,39) = 6.89$, $p < 0.05$, $F_2(1,39) = 4.73$, $p < 0.05$. Skipping rates were also higher in the full preview condition, where the higher-frequency target word was seen in the parafovea, than in the TL preview condition, where the lower-frequency TL word was seen in preview, $F_1(1,39) = 29.97$, $p < 0.001$, $F_2(1,39) = 19.6$, $p < 0.001$. The effects of repetition and preview type were additive, with no evidence of an interaction (*F*s < 1).[5] It should also be noted that higher overall skipping rates were observed in Experiment 2 than for previewed words in Experiment 1 (19.6% vs. 11.6%, $t(66) = 2.47$, p < .05). We believe that this difference occurred because the TL neighbor pairs used as target words in Experiment 2 were shorter than the targets used in Experiment 1 (average of 4.7 vs. 5, $t(158) = 4.18$, p < .001). Greater skipping of short versus long words is a well-established finding in studies of reading (e.g., Brysbaert et al. 2005; Rayner, 1998;) and constitutes basic evidence about oculomotor contributions to eye-movement control during reading as described by a range of theories (e.g., EOVP, Brysbaert & Vitu, 1998; EZ Reader, Reichle et al. 1998).

Reading times on word preceding target—Table 6 shows mean first-pass reading times on the word preceding the target word. There were no main effects or interactions of experimental factors (word repetition and preview type). The absence of such effects is consistent with the view that processing of the currently-fixated word is not influenced by the word in parafoveal preview (i.e., no parafoveal-on-foveal effects, Rayner et al., 2003; cf. Kennedy & Pynte, 2005). In addition, there was a numerical trend for single-fixation durations on the word preceding the target to be longer when the target word was subsequently skipped than when it was subsequently fixated, $F_1(1,39) = 2.74$, $p = 0.106$, $F_2(1,39) = 2.41$, $p = 0.128$.[6]

Reading times on target word—Table 7 shows reading times on the target word as a function of word repetition and preview type. Reading times were shorter for repeated target words as compared to new target words on first-pass measures: GZD, $F_1(1,39) = 4.23$, $p < 0.05$, $F_2(1,39) = 5.74$, $p < 0.05$, FFD, $F_1(1,39) = 6.86$, $p < 0.05$, $F_2(1,39) = 7.1$, $p < 0.05$, and SFD, $F_1(1,39) = 3.08$, $p = 0.087$, $F_2(1,39) = 4.68$, $p < 0.05$. In addition, GZD showed shorter times for target words seen with full preview as compared to target words seen with TL preview, a pattern that was significant in the subject analysis and marginally so in the item analysis, $F_1(1,39) = 4.59$, $p < 0.05$, $F_2(1,39) = 3.9$, $p = 0.055$. FFD and SFD showed a trend

[5]As in Experiment 1, supplementary analyses of restricted skipping rates showed the same statistical pattern found for raw skipping, a main effect of repetition, $F_1(1,39) = 11.03$, $p < 0.05$; $F_2(1,39) = 8.47$, $p < 0.05$ and of preview type, $F_1(1,39) = 34.12$, p < 0.001; $F_2(1,39) = 14.33$, $p < 0.001$, with no interaction between these factors (*F*s < 1). The main effect of repetition was significant in both the full preview ($t_1(39) = 2.49$, $p < 0.05$; $t_2(39) = 2.4$, $p < 0.05$) and the TL preview ($t_1(39) = 2.73$, $p < 0.05$; $t_2(39) = 2.25$, $p < 0.05$).

[6]As in Experiment 1, the statistical significance of the skipping cost was assessed further using lme models. In the random-intercept model the skipping penalty fell short of significance (t = 1.61, p = .11 as estimated using MCMC sampling).

toward shorter fixation durations in full preview than in TL preview: FFD, $F_1(1,39) = 2.68$, $p = 0.11$, $F_2(1,39) = 1.73$, $p = 0.196$, and SFD, $F_1(1,39) = 1.64$, $p = 0.207$, $F_2(1,39) = 2.92$, $p = 0.095$. Finally, there was no interaction effect between word repetition and preview type (all *F*s <1, ns).[7]

Consequences of skipping different preview types—Regression-path duration on the word following the target was used as a measure of whether skipping the target word on the basis of a TL word in parafoveal preview disrupts downstream processing as compared to skipping it with full parafoveal preview. Disruption would be expected if the TL preview word is recognized accurately (e.g., *clam* is recognized as *clam*) because the TL preview words are anomalous in the context of the sentence, but would not be expected if the TL preview word is mistakenly recognized as the target word (e.g., *clam* is recognized as *calm*) because this leads to no difference in meaning as compared to full preview (e.g., *calm* is recognized as *calm*). Regression-path duration captures two possible manifestations of such a disruption: increased processing time on the word after the target as might occur from trying to process the semantic anomaly and regression back to the target word as a check on whether it was accurately recognized. Of course, when the eyes cross the invisible boundary, the preview string is replaced by the target word so if the reader executes a regressive saccade back to the target word or simply switches attention back to it, the TL word preview string will have been replaced by the target and therefore cannot be a further cause of processing difficulty. Regression-path duration on the word following the target word was longer following skips of the TL word preview string (480 ms) than following skips of the full word preview string (304ms), $F_1(1,29) = 7.99$, $p < .01$, $F_2(1,38) = 7.94$, $p < .01$. This difference supports the conclusion that accurate recognition of the TL word preview strings contributed to the processes controlling eye movement targeting during reading.

Discussion

The skipping results of Experiment 2 are very clear, showing that skipping rates were higher for targets with full preview (high-frequency words) as compared to those with TL preview (low-frequency words) and for repeated as compared to new targets, with no indication of an interaction between the repetition and preview manipulations. This pattern corroborates and extends findings on how word frequency and repetition affect the use of parafoveal information to prompt word skipping.

The finding that higher skipping rates occurred for full preview as compared to TL word preview is consistent with the finding from Experiment 1, and from many other studies (Rayner et al., 2004; Rayner & Fisher, 1996; Rayner & Raney, 1996; White, 2008), showing that the incidence of skipping is greater when the word in parafoveal preview is high frequency rather than low frequency. Because of constraints on constructing stimulus materials, the target words in this experiment were always the high frequency members of the TL word pairs (e.g., *scared* from the pair *scared-sacred*), and for this reason the full preview word was always higher frequency than the TL preview word. Higher frequency increases the chance that the word in parafoveal preview is recognized and can be skipped.

The finding that higher skipping occurred in the repeated as compared to the new condition provides important new evidence that the level of processing associated with language-based

[7]Reading-time measures of later processing were shorter for repeated target words as compared to new target words on both measures: regression-path duration, $F_1(1,39) = 14.58$, $p < 0.05$, $F_2(1,39) = 11.9$, $p < 0.05$, and total time, $F_1(1,39) = 6.32$, $p < 0.05$, $F_2(1,39) = 9.96$, $p < 0.05$. In addition, there was a significant main effect of preview type (significant in total time and numerical trend in regression path duration), showing shorter fixation duration for the full preview as compared to the TL preview: regression-path duration, $F_1(1,39) = 2.17$, $p = 0.149$, $F_2(1,39) = 2.38$, $p = 0.131$, and total time, $F_1(1,39) = 3.08$, $p = 0.087$, $F_2(1,39) = 5.49$, $p < 0.05$. In contrast, there were no suggestions of interactions between word frequency and preview type (*F*s < 1, ns).

skipping involves an implicit lexical decision. Target-word repetition led to greater skipping in the full-preview condition, a result that extends those of Gordon et al. (in press) from proper names to content words. More importantly, target-word repetition also led to increased skipping in the TL preview condition, where the parafoveal string was a different word made by transposing two letters of the target word. This is an example of priming within a TL pair leading to facilitation in recognition. This pattern was not seen in Gordon et al. (in press) when the TL preview string was a nonword (e.g., *Herman* did not prime *Hreman* in a way that led to increased skipping). A crucial difference is that in the current experiment the TL preview string was an actual English word, so priming would assist in providing an affirmative answer in an implicit lexical decision.

Finally, the finding that downstream processing was disrupted after skipping of a TL- as compared to a full-word preview string supports two conclusions about the relationship between word recognition and eye-movement control mechanisms during reading. First, it indicates that the implicit lexical decision underlying language-based skipping is part of a process that leads to accurate recognition of the word in parafoveal preview. Mistaken recognition of the TL word as the target (e.g., misperceiving the TL preview word *clam* as the target word *calm*) would provide no basis for greater processing difficulty as compared to skipping a fully-previewed target word. Second, it indicates that the recognition process underlying this implicit lexical decision is at least partially insensitive to how the meaning of a word fits with the meaning of the sentence, a conclusion that is also supported by eye-tracking findings showing that target words whose meanings are implausible in sentence context do not affect first-pass measures of early word processing but do affect downstream measures that reflect later processing (Rayner, Warren, Juhasz, & Liversedge, 2004).

General Discussion

The principal results of this paper concern the manner in which ease of lexical access affects first-pass skipping rates, a measure that has been central in determining how lexical and oculomotor processes are coordinated during reading. Experiment 1 showed that with full parafoveal preview greater skipping occurred for high-frequency target words (e.g., *north*) than for low-frequency target words (e.g., *blink*), a finding that is consistent with earlier research (Rayner & Fisher, 1996; Rayner & Raney, 1996; White, 2008). However, the frequency of the target word had no effect on skipping when parafoveal preview contained a TL nonword generated by transposing the position of two word-internal letters in the target word (e.g., *nroth* for high-frequency targets and *bilnk* for low-frequency targets). This interaction between preview type and word frequency generalizes findings by Gordon et al. (in press), which showed an interaction between preview type and repetition priming, a factor that like frequency affects ease of lexical access. Additionally, Experiment 1 showed that this interaction occurs for content words as well as for the proper name targets studied by Gordon et al. Together, these results support the idea, presented in EZ Reader and related models (Reichle et al. 1998; Pollatsek et al. 2006), that language-based skipping during reading involves determination that full lexical identification of the letter string in parafoveal preview is imminent. Experiment 2 showed that repetition priming by within-sentence prime-target pairs increases skipping rates for target words presented with full parafoveal preview (e.g., the preview word *scared* was skipped more often when *scared* rather than *afraid* appeared earlier in the sentence) and also for target words presented as TL neighbor words in parafoveal preview (e.g., the preview word *sacred* was skipped more often when *scared* rather than *afraid* appeared earlier in the sentence). Again, this pattern is consistent with the idea that language-based skipping involves a determination that lexical identification of the parafoveal string is imminent by showing that within-sentence TL priming facilitates this process for TL word preview strings in contrast to the TL nonword preview strings studied by Gordon et al. Finally, Experiment 2 showed that processing was delayed following skips of TL word preview strings as compared to skips of full word preview strings, as would be expected given that the TL word preview string was semantically anomalous in the context of the sentence.

The results of Experiments 1 and 2, and of Gordon et al. (in press), support the idea that that implicit lexical decisions by word-recognition processes initiate motor processes that lead to the execution of saccades. This decision is characterized as implicit on the supposition that readers are unlikely to be aware of very-rapid, low-level processes that support reading comprehension. This decision is characterized as lexical because it is sensitive to the difference between words and highly-similar TL nonwords, but is insensitive to the fit of the meaning of the word within the overall meaning of the sentence, with the anomalous meaning of a TL word affecting processing only after that word was skipped.

With respect to current models of eye-movement control during reading, this implicit lexical decision maps best onto the first of two stages of lexical processing (L1 and L2) in the EZ Reader model (Pollatsek et al. 2006; Reichle et al. 1998). In this model, completion of L1 requires a familiarity check indicating that word recognition is imminent and it triggers motor programming for the upcoming saccade. Completion of L2 requires deeper lexical processing of the word and is followed by an attention shift to the letter string in the parafovea. In order for a parafoveal string to be skipped, L2 must be completed for the fixated string ($Word_n$) and L1 must be completed for the parafoveal string ($Word_{n+1}$) with sufficient time to cancel the saccade toward $Word_{n+1}$ that was initiated after completion of L1 for $Word_n$. The absence of an affirmative answer to an implicit lexical decision about the parafoveal letter string, created in this study and in Gordon et al. (in press) through the presentation of TL nonwords in the parafovea, would block completion of L1 on the parafoveal string and therefore preclude language-based, or recognition-based, skipping.

Conclusion

Patterns of skipping are particularly informative about the nature of reading because they are the only measure showing language effects on the targeting of first-pass saccades rather than on the duration of fixations. While skips occur for only a fraction of words, a range of theoretical perspectives attributes them to the same mechanisms that determine the characteristics of fixations directly on words (e.g., Brysbaert & Vitu, 1998; Engbert et al. 2005; Pollatsek et al. 2006), mechanisms that reflect the ease with which words are recognized, the abilities and limitations of the oculomotor system and the nature of the coordination between lexical and oculomotor processes. The current results and those of Gordon et al. (in press) support serial-attention shifting models of this coordination and further support the idea that the eyes are driven forward by word recognition processes that rapidly and accurately determine lexical status.

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Appendix 1

The stimuli from Experiment 1 are shown below with the alternate preview strings enclosed in brackets and separated by a slash.

After the disaster many people were still [ailve/alive] alive in the rubble of the building.

At the competition, the surfer was extremely [aigle/agile] agile on the waves.

The sizable fireplace released thick [balck/black] black smoke from the chimney.

The church door was adorned with a golden [cihme/chime] chime and hand-carved sculptures.

Last week the county's annual [bolod/blood] blood drive saw record donations.

For dessert, his wife made a tasty [btach/batch] batch of chocolate chip cookies.

Authorities agreed that there was justifiable [cuase/cause] cause for everyone's concern.

After the war, the soldier received an honorary [bdage/badge] badge of courage and valor.

Yesterday the businesswoman bought a comfortable [cahir/chair] chair for her desk.

The only sign of life was the momentary [bilnk/blink] blink of his left eye.

After the scandal, the board removed the decorated [cihef/chief] chief of surgery from the hospital.

The newspapers say that lobbyists discreetly [birbe/bribe] bribe politicians for special interests.

After the break, the test in the art history [calss/class] class was the following Friday.

The receipt called for green peppers and fresh [bsail/basil] basil to be a part of the sauce.

Leaving work, the woman picked up her youngest [cihld/child] child from the daycare center.

The fox swiftly attacks the vulnerable [cihck/chick] chick in the open field.

The temperature and ecosystem contribute to the iconic [celar/clear] clear seas of the tropics.

Because of the accident, firemen carefully [aevrt/avert] avert pedestrians to a detour.

The wife admitted she wasn't really [agnry/angry] angry about the dirty apartment.

No one knew the name of the spicy [cdier/cider] cider sold in stores last Spring.

Last month, technicians finished the newest [mdoel/model] model of the computer.

Even with all the city lights the bright [cmoet/comet] comet could be seen in the night sky.

Darren and Sam can never leave [eraly/early] early enough to catch the bus.

The government took actions to protect the endangered [croal/coral] coral reef in Australia.

Giant birds were the dominant predators in prehistoric [erath/earth] earth after dinosaur extinction.

As expected, the show opened with great [elcat/eclat] eclat, one of the most successful ever.

Lauren did not attend practice during [fnial/final] final exams so that she could study.

The fast growing and edible garden [cerss/cress] cress is beloved for its aroma.

Elaine had nothing in common with other popular [grils/girls] girls at the high school.

The cordless variety did not have the trademark [cruly/curly] curly wire of earlier phones.

After Chris saw the dirty [galss/glass] glass on the counter he knew he wasn't alone.

The soldier was very resourceful and a skilled [dvier/diver] diver making him perfect for the mission.

The recent voter survey casts serious [duobt/doubt] doubt about the upcoming election.

Staying close behind its prey, the determined [huond/hound] hound displayed speed and endurance.

The adventurous pair slipped away from the travel [gorup/group] group during the tour.

Debaters are encouraged to examine every [fcaet/facet] facet of an argument for weaknesses.

Long after the sacrifice the animal's [haert/heart] heart sat on the altar.

Found in wooded areas, the beautiful [fnich/finch] finch is a seed-eating songbird.

After cleaning out old files, there were fewer [haevy/heavy] heavy boxes in storage.

Visitors gathered around to hear the strange [cahnt/chant] chant of the temple monks.

The man lost his cell phone in the messy [huose/house] house late last night.

While sleeping, everyone was startled by the sudden [falre/flare] flare from the campfire.

The marketing executives had a meeting to review recent [iedas/ideas] ideas for new commercials.

Most pet owners use chemicals that target the adult [felas/fleas] fleas as well their eggs and larvae.

Almost everyone could hear the truck's [lrage/large] large speakers as it passed.

The armed guards protected the precious [crago/cargo] cargo aboard the plane.

Harold took a different flight and arrived [ltaer/later] later than everyone else.

The old painting was covered in silver [golss/gloss] gloss for artistic effect and protection.

The book claimed Islam was the country's [mjaor/major] major religion after the seventeenth century.

Surprisingly, Travis could not find a single [golve/glove] glove at the clothing store.

The foreman told the employees not to leave [epmty/empty] empty cases on the shelves.

Melissa eagerly ate the meager [falke/flake] flake of bread left from the pastry.

The deceitful accountant was caught taking [mnoey/money] money and hiding the evidence.

The father was always concerned about the metal [garte/grate] grate at the end of the driveway.

The striking photo of the predator's ferocious [muoth/mouth] mouth was a haunting image.

The hair follicle is an example of a tubular [galnd/gland] gland found in the skin.

The director captured the rare and amazing [msuic/music] music from an isolated culture.

The senator used her considerable political [colut/clout] clout to push the bill through congress.

Today the panel will discuss the unexpected [daeth/death] death of the well known actor.

The workers needed a machine to lift the bulky [carte/crate] crate off the ground.

The missionaries did not let the war spoil their [fiath/faith] faith in people's inherent goodness.

The horseback rider carried a ceremonial [lnace/lance] lance to display his status.

The soldiers were told that the base was slightly [nroth/north] north of their current location.

The veteran detective immediately noticed the broken [ltach/latch] latch on the back window.

At the supply store the man bought [paepr/paper,] paper, pencils and pens for the office.

The ship's captain was annoyed to see the [laeky/leaky] leaky containers spilling their contents.

The battery did not have sufficient [pwoer/power] power for the advanced computer.

Even alone on display the wingless [luose/louse] louse could only be seen under a microscope.

The greedy girl took an enormous [peice/piece] piece of cake at the party.

It was easy to picture the rustic and sturdy [mnier/miner] miner working in a cave.

Lisa's first car would forever hold a special [palce/place] place in her memory.

Looking at the color of the distinctive [pnada/panda] panda it is easy to see why they are so adored.

Julie and Victor took pictures at the highest [piont/point] point of elevation on the mountain.

The explorer loved traveling through the perpetually [msity/misty] misty forests of the island.

Some of the children played songs at the surprise [praty/party] party for their teacher.

The lone traveling hero is a familiar [mtoif/motif] motif in western and eastern cultures.

The volunteers spent all day cleaning the polluted [rvier/river] river after a modest breakfast.

Native to trees in China, the delicious [paech/peach] peach is now available all over.

It is very difficult to draw a perfectly [ruond/round] round circle even using tools.

The girl braided her hair in an intricate [palit/plait] plait before going to the dance.

They had fun during the relatively [sohrt/short] short vacation at the beach last weekend.

The company had the cheapest basic model [sdean/sedan] sedan currently on the market.

Two common indicators of drug use are disrupted [selep/sleep] sleep schedules and changes in mood.

The professor was pleased with the student's insightful [qeury/query] query about the complex topic.

Even outside the room she could hear the muffled [suond/sound] sound of the television.

When not in school the children loved eating [slaty/salty] salty junk food and drinking soda.

The talented artist wanted to fill the empty [sapce/space] space on the canvas with colors.

The scientist had trouble finding his oldest [neice/niece] niece in the crowd of teenagers.

At a crime scene, policemen immediately [sepak/speak] speak to witnesses in the area.

When Susan saw the size of the little [palnk/plank] plank she knew it was insufficient.

While in the city, Jerry buys produce at the fruit [satnd/stand] stand near the train station.

When tired his handwriting would often [salnt/slant] slant drastically to the right.

The traveler was in a different [satte/state] state everyday during her trip.

Many historical explorers were searching for exotic [sipce/spice] spice and rare treasure.

It was hard for anyone to remember the intricate [sotry/story] story with all of its details.

The hikers took cover as the powerful [soput/spout] spout erupted suddenly nearby.

After dinner, the entire family went to the spacious [sutdy/study] study for reading time.

The thoughtless kids left the ball at the bottom [satir/stair] stair of the walkway.

The famous poet definitely had an unconventional [sytle/style] style for his time.

The smallest lizard was abnormally [sotut/stout] stout compared to the others.

The secretary walked across the room to the storage [tbale/table] table for stamps and envelopes.

Most American doctors have never given [ehter/ether] ether anesthesia to a patient.

The villagers come for the mutually beneficial [tarde/trade] trade of necessary commodities.

The tailor came to work early to quickly [tpaer/taper] taper the prom dress.

The sign directed clients to the company's [fornt/front] front office on the first floor.

Alex ran slowly to avoid the [sahrp/sharp] sharp thorn bush and thick vines.

Proficient skill with computers is of great [vlaue/value] value to people in modern society.

At the banquet the church recognized the oldest [uhser/usher] usher for his dedicated service.

The crowd was captivated by the stunning [vioce/voice] voice of the lead singer.

Too many acidic foods can lead to a stomach [ucler/ulcer] ulcer or even cancer.

Tonya and Abi took time to admire the peaceful [wtaer/water] water before going inside.

David thought the tuxedo was a comically [wierd/weird] weird outfit for the occasion.

The answers to the math questions were always [wohle/whole] whole numbers or negative integers.

The hungry orphans caught an appetizing [wihff/whiff] whiff of the food from the kitchen.

The article was part of an examination of working [wmoen/women] women in the southeast.

The couple prepared the dough without [yaest/yeast] yeast and no one noticed.

A popular science fiction setting is the future [wrold/world] world without crime or violence.

The petite woman held on to the strong [laesh/leash] leash as the dog chased squirrels.

The lazy student's answers were mostly [worng/wrong] wrong because he was never prepared.

The evil general's plan aimed to secretly [tiant/taint] taint the enemy's drinking water.

Appendix 2

The stimuli from Experiment 2 are shown below with the alternate prime words separated by a slash and the alternate preview strings enclosed in brackets and separated by a slash.

Bob escaped a barn/brush fire when he was six, so seeing the burning [bran/barn] barn scared him a lot.

In this town, coal/fuel is important because mining [cola/coal] coal is central to their economy.

Last year my crops/tomatoes were devastated, so I protect my [corps/crops] crops from pests and disease now.

There were many boats/ships, but now only two interesting [boast/boats] boats remained in the harbor.

I lost the small bolt/screw and I can’t find the large [blot/bolt] bolt that I need either.

The security guard thought the bulge/lump was a weapon, but the unknown [bugle/bulge] bulge was only a camera.

Usually I don’t mind burnt/charred toast, but today it was so utterly [brunt/burnt] burnt that it was inedible.

The director wanted a different angle/portion, so he had the camera [angel/angle] angle shifted to the right.

Jane hates busy/full stores, so she avoids shopping at the extremely [buys/busy] busy mall during the holiday season.

The room is calm/quiet during lunch, but afterwards this gentle [clam/calm] calm will become a clamorous uproar.

When people carve/etch graffiti in stalls, did they spontaneously [crave/carve] carve it or is it planned?

Mary got the cold/flu in the summer even though the usual [clod/cold] cold occurs in the winter.

Why would you go to Florida’s coast/shores when the North Carolina’s [coats/coast] coast is as nice and much closer?

James has friend who owns a bar/pub, but today his friend’s [bra/bar] bar would be closed.

Greg has an ability to unite/ally people, so if he can’t [untie/unite] unite these families, I don’t think anyone will.

Bill wants to go forth/onward with moving, but he can't bring [froth/forth] forth the plan because of his family.

There was a beast/brute that could fly, but Susan doubts a large [beats/beast] beast could do so.

Anne doesn't buy dairy/milk because she doesn't like [diary/dairy] dairy, not because she's vegan.

Acoustically, a dog’s ears/hearing are much better than any human [eras/ears] ears when it comes to detecting very high frequency sounds.

I met a farmer/rancher who has been an organic [framer/farmer] farmer for twenty years.

They knew that Tim would be fired/gone soon, so when he was [fried/fired] fired, nobody was surprised.

Because my key was in John's fist/palm, I tried to pry his [fits/fist] fist open with my hands.

I wanted a new grater/shredder, but not a single [garter/grater] grater was left in the whole store.

Everyone is a liar/fibber, so even a confirmed [lair/liar] liar should get a second chance.

Ted hasn't seen a lion/feline, so he wants to see the African [loin/lion] lion exhibit at the zoo.

Last night David lost/left his key and Patrick [lots/lost] lost the other, so now we’re locked out of the house.

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The bird spent weeks building his nest/aerie and now, the completed [nets/nest] nest is ready to be used.

Jill thinks that Kyle is the perfect/ideal man, but a really [prefect/perfect] perfect man would respect her more.

The idea was quite/wholly plausible, but the test proved [quiet/quite] quite the opposite was true.

George wanted to keep his bike from rust/damage, but preventing [ruts/rust] rust was more difficult than he anticipated.

I have only seen a white swan/bird but I think a black [sawn/swan] swan can exist in nature too.

My brother adds salt/spice to his food, but even a little [slat/salt] salt is too much for my sister.

We saw a post/stilt that was rotting, but replacing a damaged [pots/post] post can be very expensive.

Zach isn’t scared/afraid of bugs, but he is definitely [sacred/scared] scared of the snakes in the forest.

Their fevers seemed to be signs/proof of mono, but they were really [sings/signs] signs of a rare disease.

The defiance of one slave/serf led to an enormous [salve/slave] slave revolt in France.

Maggie wore a silver/pearl necklace and her grandmother’s [sliver/silver] silver ring to the wedding.

The reward was split/divided, but I was upset that it was an uneven [spilt/split] split for all I had done.

Mel tried to get the stain/juice out, but a grape juice [satin/stain] stain is very difficult to remove.

If you follow this trail/path and turn onto the second [trial/trail] trail on the right, the restrooms will be on the left.

References

Acha J, Perea M. The effect of neighborhood frequency in reading: Evidence with transposed-letter neighbors. Cognition. 2008; 108:290–300. [PubMed: 18374323]

Andrews S. Lexical retrieval and selection processes: Effects of transposed-letter confusability. Journal of Memory and Language. 1996; 35:775–800.

Baayen RH, Davidson DH, Bates DM. Mixed-effects modeling with crossed random effects for subjects and items. Journal of Memory and Language. 2008; 59:390–412.

Baayen, RH.; Piepenbrock, R.; Gulikers, L. The CELEX lexical database [CD-ROM]. Philadelphia: University of Pennsylvania Linguistic Data Consortium; 1995.

Barr DJ, Levy R, Scheepers C, Tily HJ. Random effects structure in mixed>effects models: Keep it maximal. (under review).

Brysbaert, M.; Drieghe, D.; Vitu, F. Word skipping: Implications for theories of eye movement control in reading. In: Underwood, G., editor. Cognitive processes in eye guidance. Oxford: Oxford University Press; 2005. p. 53-77.

Brysbaert, M.; Vitu, F. Word skipping: Implications for theories of eye movement control in reading. In: Underwood, G., editor. Eye guidance in reading and scene perception. Oxford: Elsevier; 1998. p. 125-148.

Calvo MG, Meseguer E. Eye movements and processing stages in reading: Relative contributions of visual, lexical, and contextual factors. The Spanish Journal of Psychology. 2002; 5:66–77. [PubMed: 12025367]

Chambers SM. Letter and order information in lexical access. Journal of Verbal Learning and Verbal Behavior. 1979; 18:225–241.

Davies M. The Corpus of Contemporary American English: 425 million words, 1990-present. 2008 Available online at http://corpus.byu.edu/coca/.

Davis CJ. N-Watch: A program for deriving neighborhood size and other psycholinguistic statistics. Behavioral Research Methods. 2005; 37:65–70.

Drieghe D. Foveal processing and word skipping during reading. Psychonomic Bulletin & Review. 2008; 15:856–860. [PubMed: 18792516]

Drieghe D, Rayner K, Pollatsek A. Eye movements and word skipping during reading revisited. Journal of Experimental Psychology: Human Perception & Performance. 2005; 31:954–969. [PubMed: 16262491]

Duñabeitia JA, Molinaro N, Laka I, Estévez A, Carreiras M. N250 effects for letter transpositions depend on lexicality: Casual or causal? NeuroReport. 2009; 20(4):381–387. [PubMed: 19248245]

Ehrlich SF, Rayner K. Contextual effects on word recognition and eye movements during reading. Journal of Verbal Learning and Verbal Behavior. 1981; 20:641–655.

Engbert R, Nuthmann A, Richter EM, Kliegl R. SWIFT: A dynamical model of saccade generation during reading. Psychological Review. 2005; 112:777–813. [PubMed: 16262468]

Fitzsimmons G, Drieghe D. The influence of number of syllables on word skipping during reading. Psychonomic Bulletin & Review. 2011; 18:736–741. [PubMed: 21557026]

Gordon PC, Hendrick R, Johnson M, Lee Y. Similarity-based interference during language comprehension: Evidence from eye tracking during reading. Journal of Experimental Psychology: Learning, Memory and Cognition. 2006; 32:1304–1321.

Gordon PC, Plummer P, Choi W. See before you jump: Full recognition of parafoveal words precedes skips during reading. Journal of Experimental Psychology: Learning, Memory, and Cognition. (in press).

Henderson JM, Ferreira F. 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. 1990; 16:417–429.

Johnson RL. The quiet clam is quite calm: Transposed-letter neighborhood effects in reading. Journal of Experimental Psychology: Learning, Memory, and Cognition. 2009; 35:943–969.

Johnson R, Dunne MD. Parafoveal processing of transposed-letter words and nonwords: Evidence against parafoveal lexical activation. Journal of Experimental Psychology: Human Perception and Performance. 2012; 38:191–212. [PubMed: 22060141]

Johnson RL, Perea M, Rayner K. Transposed-letter effects in reading: Evidence from eye movements and parafoveal preview. Journal of Experimental Psychology: Human Perception and Performance. 2007; 33:209–229. [PubMed: 17311489]

Kennedy A, Pynte J. Parafoveal-on-foveal effects in normal reading. Vision Research. 2005; 45:153–168. [PubMed: 15581917]

Kennison SM, Clifton C. 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. 1995; 21:68–81.

Kerr, PW. Doctoral dissertation. Urbana, IL: University of Illinois at Urbana-Champaign; 1992. Eye movement control during reading: The selection of where to send the eyes.

Kliegl R, Engbert R. Fixation durations before word skipping in reading. Psychonomic Bulletin & Review. 2005; 12:132–138. [PubMed: 15945206]

Kwon N, Lee Y, Gordon PC, Kluender R, Polinsky M. Cognitive and linguistic factors affecting subject/object asymmetry: An eye-tracking study of pre-nominal relative clauses in Korean. Language. 2010; 89:546–582.

Lee Y, Lee H, Gordon PC. Linguistic complexity and information structure in Korean: Evidence from eye-tracking during reading. Cognition. 2007; 104:495–534. [PubMed: 16970936]

Lima SD, Inhoff AW. Lexical access during eye fixations in reading: Effects of word initial letter sequence. Journal of Experimental Psychology: Human Perception & Performance. 1985; 11:272–285. [PubMed: 3159838]

McConkie, GW.; Kerr, PW.; Dyre, BP. What are ‘normal’eye movements during reading: Toward a mathematical description. In: Yegge, J.; Lennerstrand, G., editors. Eye movements in Reading. Oxford: Elsevier; 1994. p. 315-327.

McConkie GW, Kerr PW, Reddix MD, Zola D. Eye movement control during reading: I. The location of initial eye fixations on words. Vision Research. 1988; 28:1107–1118. [PubMed: 3257013]

McDonald SA, Shillcock RC. Eye movements reveal the online computation of lexical probabilities during reading. Psychological Science. 2003a; 14(6):648–652. [PubMed: 14629701]

McDonald SA, Shillcock RC. Low-level predictive inference in reading: The influence of transitional probabilities on eye movements. Vision Research. 2003b; 43:1735–1751. [PubMed: 12818344]

Morrison RE. Manipulation of stimulus onset delay in reading: Evidence for parallel programming of saccades. Journal of Experimental Psychology: Human Perception and Performance. 1984; 10:667–682. [PubMed: 6238126]

Moxey LM, Sanford AJ, Sturt P, Morrow LI. Constraints on the formation of plural reference objects: The influence of role, conjunction, and type of description. Journal of Memory and Language. 2004; 51:346–364.

O’Connor RE, Forster KI. Criterion bias and search sequence bias in word recognition. Memory & Cognition. 1981; 9:78–92. [PubMed: 7231172]

O’Regan, JK. Eye movements and reading. In: Kowler, E., editor. Eye movements and their role in visual and cognitive processes. Elsevier; 1990. p. 395-453.

Perea M, Lupker SJ. Does jugde activate COURT? Transposed-letter similarity effects in masked associative priming. Memory & Cognition. 2003a; 31:829–841. [PubMed: 14651292]

Perea, M.; Lupker, SJ. Transposed-letter confusability effects in masked form priming. In: Kinoshita, S.; Lupker, SJ., editors. Masked priming: The state of the art. New York: Psychology Press; 2003b. p. 97-120.

Hollis J, Valentine T. Proper-name processing: Are proper names pure referencing expressions? Journal of Experimental Psychology: Learning, Memory, and Cognition. 2001; 27:99–116.

Plummer P, Rayner K. Effects of parafoveal word length and orthographic features on initial fixation landing positions in reading. Attention, Perception & Psychophysics. 2012; 74:950–963.

Pollatsek A, Reichle ED, Rayner K. Tests of the E-Z Reader model: Exploring the interface between cognition and eyemovement control. Cognitive Psychology. 2006; 52:1–56. [PubMed: 16289074]

R Development Core Team. R: A Language and Environment for Statistical Computing. Austria: R Foundation for Statistical Computing Vienna; 2011.

Rayner K. The perceptual span and peripheral cues in reading. Cognitive Psychology. 1975; 7:65–81.

Rayner K. Eye movements in reading and information processing: 20 years of research. Psychological Bulletin. 1998; 124:372–422. [PubMed: 9849112]

Rayner K, Ashby J, Pollatsek A, Reichle ED. 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. 2004; 30:720–732. [PubMed: 15301620]

Rayner K, Fischer MH. Mindless reading revisited: Eye movements during reading and scanning are different. Perception and Psychophysics. 1996; 58:734–747. [PubMed: 8710452]

Rayner K, Raney GE. Eye movement control in reading and visual search: Effects of word frequency. Psychonomic Bulletin and Review. 1996; 3:245–248.

Rayner K, Slattery TJ, Drieghe D, Liversedge SP. Eye movements and word skipping during reading: Effects of word length and predictability. Journal of Experimental Psychology: Human Perception and Performance. 2011; 37:514–528. [PubMed: 21463086]

Rayner K, Warren T, Juhasz BJ, Liversedge SP. The effect of plausibility on eye movements in reading. Journal of Experimental Psychology: Learning, Memory and Cognition. 2004; 30:1290–1301.

Rayner K, Well AD. Effects of contextual constraint on eye movements in reading: A further examination. Psychonomic Bulletin & Review. 1996; 3:504–509.

Rayner K, White SJ, Johnson RL, Liversedge SP. Raeding wrods with jubmled lettres: There is a cost. Psychological Science. 2006; 17:192–193. [PubMed: 16507057]

Rayner, K.; White, SJ.; Kambe, G.; Miller, B.; Liversedge, SP. On the processing of meaning from parafoveal vision during eye fixations in reading. In: Hyönä, J.; Radach, R.; Deubel, H., editors. The Mind's Eye: Cognitive and Applied Aspects of Eye Movement Research. Amsterdam: Elsevier; 2003. p. 213-234.

Reichle ED, Pollatsek A, Fisher DL, Rayner K. Toward a model of eye movement control in reading. Psychological Review. 1998; 105:125–157. [PubMed: 9450374]

Reichle ED, Rayner K, Pollatsek A. The E-Z Reader model of eyemovement control in reading: Comparisons to other models. Behavioral & Brain Sciences. 2003; 26:445–526. [PubMed: 15067951]

Schilling HEH, Rayner K, Chumbley JI. Comparing naming, lexical decision, and eye fixation times: word frequency effects and individual differences. Memory & Cognition. 1998; 26:1270–1281. [PubMed: 9847550]

Slattery TJ. Word misperception, the neighbor frequency effect, and the role of sentence context: Evidence from eye movements. Journal of Experimental Psychology: Human Perception and Performance. 2009; 35:1969–1975. [PubMed: 19968447]

Taylor WL. Cloze procedure: A new tool for measuring readability. Journalism Quarterly. 1953; 30:415–433.

Van Petten C, Kutas M, Kluender R, Mitchiner M, McIsaac H. Fractionating the word repetition effect with event-related potentials. Journal of Cognitive Neuroscience. 1991; 3(2):131–150.

Vitu F, O'Regan JK, Inhoff AW, Topolski R. Mindless reading: Eye-movement characteristics are similar in scanning letter strings and reading texts. Perception and Psychophysics. 1995; 57:352–364. [PubMed: 7770326]

White SJ. Eye movement control during reading: Effects of word frequency and orthographic familiarity. Journal of Experimental Psychology: Human Perception and Performance. 2008; 34:205–223. [PubMed: 18248149]

White SJ, Johnson RL, Liversedge SP, Rayner K. Eye movements when reading transposed text: The importance of word beginning letters. Journal of Experimental Psychology: Human Perception and Performance. 2008; 34:1261–1276. [PubMed: 18823209]

White SJ, Liversedge SP. Orthographic familiarity influences initial eye fixation positions in reading. European Journal of Cognitive Psychology. 2004; 16:52–78.

White SJ, Liversedge SP. Foveal processing difficulty does not modulate nonfoveal orthographic influences on fixation positions. Vision Research. 2006a; 46:426–437. [PubMed: 16111733]

White SJ, Liversedge SP. Linguistic and non-linguistic influences on the eyes' landing positions during reading. Quarterly Journal of Experimental Psychology. 2006b; 59:760–782.

White SJ, Rayner K, Liversedge SP. Eye movements and the modulation of parafoveal processing by foveal processing difficulty: A reexamination. Psychonomic Bulletin & Review. 2005; 12:891–896. [PubMed: 16524007]

Williams CC, Perea M, Pollatsek A, Rayner K. Previewing the neighborhood: The role of orthographic neighbors as parafoveal previews in reading. Journal of Experimental Psychology: Human Perception and Performance. 2006; 32:1072–1082. [PubMed: 16846298]

Yang SN, McConkie GW. Eye movements during reading: a theory of saccade initiation times. Vision Research. 2001; 41:3567–3585. [PubMed: 11718796]

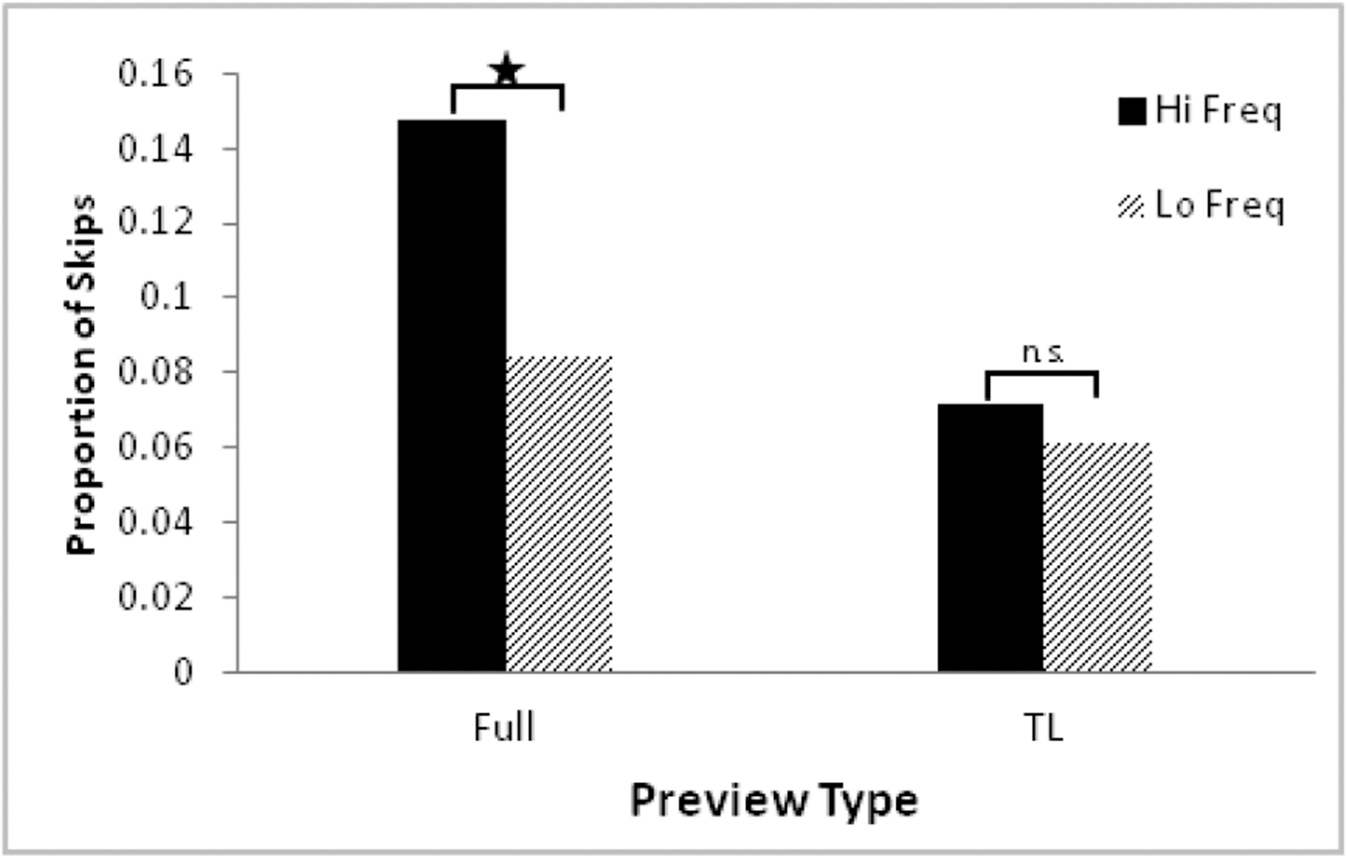

Figure 1.
Proportion of trials on which the target word was skipped during first-pass reading, as a function of preview type and word frequency.

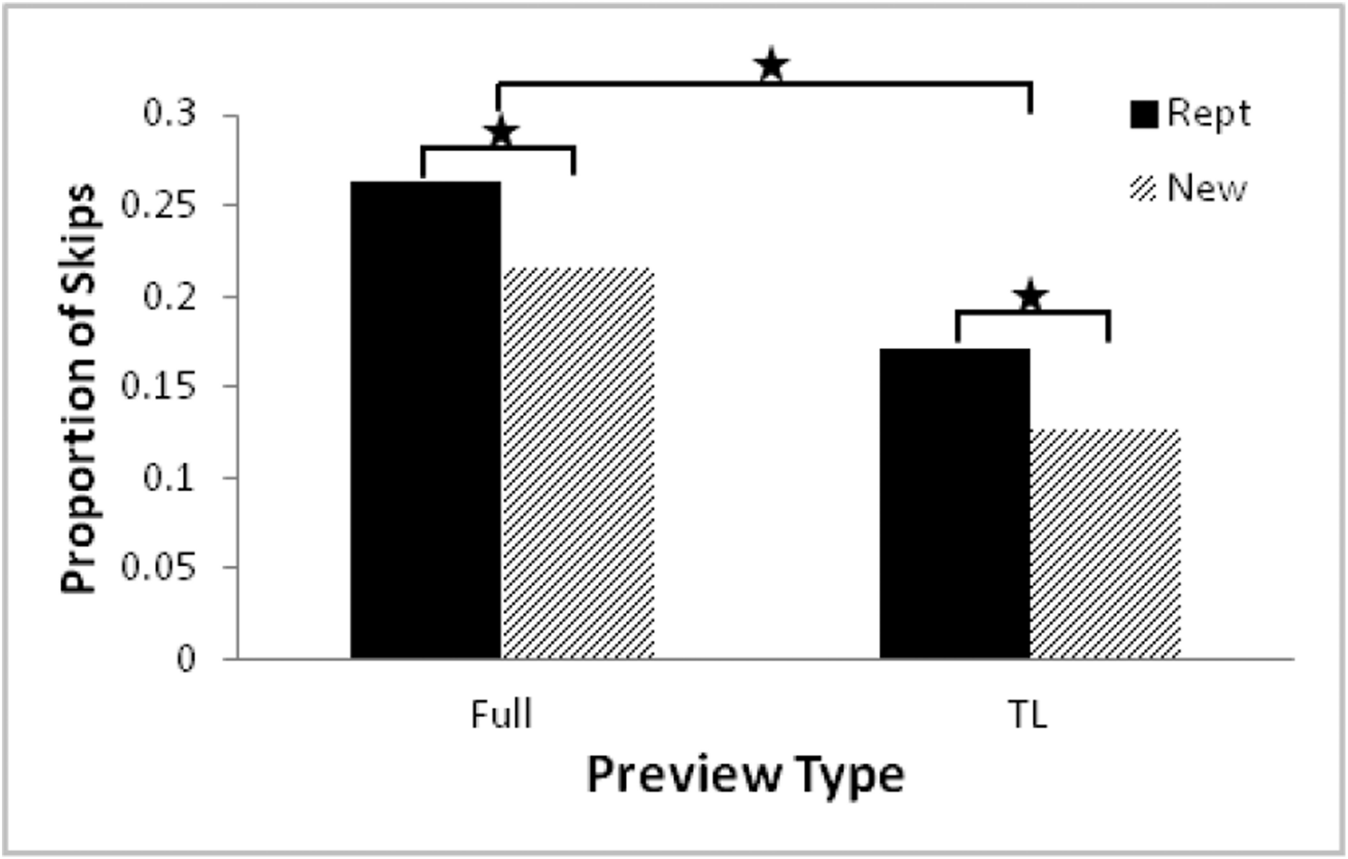

Figure 2.
Proportion of trials on which the target word was skipped during first-pass reading, broken down by preview type and word repetition.

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Table 1

Orthographic Characteristics for the Target Words used in Experiment 1.

	FREQ	BF_TK	BF_TP	TF_TK	TF_TP	NofN
High Freq	226	1645	35.7	425	6.1	3.0
Low Freq	3.87	1569	36.5	333	6.9	3.3

Note. FREQ = word frequency, BF_TK = Bigram Token Frequency calculated as the mean of the token frequencies of the bigrams in the stimulus, BF_TP = Bigram Type Frequency calculated as the mean of the type frequencies of the bigrams in the stimulus, TF_TK = Trigram Token Frequency, TF_TP = Trigram Type Frequency, NofN = Number of Orthographic Neighbors.

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Table 2

Mean Transitional Probabilities by Frequency Condition in Experiment 1 Shown Individually for the Genres in The Corpus of Contemporary English.

	Spoken	Fiction	Magazine	Newspaper	Academic
High Freq	0.0043 (.01)	0.0065 (.013)	0.0044 (.009)	0.0039 (.009)	0.0032 (.0096)
Low Freq	0.0042 (.02)	0.0026 (.016)	0.0070 (.047)	0.0118 (.086)	0.0088 (.065)

Note. Standard deviations are shown in parentheses.

Table 3

Reading Times (ms) on the Word Preceding the Target in Experiment 1 as a Function of Experimental Condition.

	HF Full	LF Full	HF TL	LF TL
SFD	222 (42)	222 (51)	216 (40)	227 (56)
FFD	219 (38)	222 (50)	215 (36)	224 (53)
GZD	267 (57)	272 (67)	261 (59)	273 (63)

Note. SFD = Single Fixation Duration, FFD = First Fixation Duration, GZD = Gaze Duration, HF = High Frequency, LF = Low Frequency, TL = Transposed-Letter string. Standard deviations (ms) are shown in parentheses.

Table 4

Reading Times (ms) on the Target Word in Experiment 1 as a Function of Experimental Condition.

	High Full	**Low Full**	**High TL**	**Low TL**
SFD	211 (33)	233 (54)	224 (44)	259 (55)
FFD	210 (35)	231 (52)	221 (35)	246 (46)
GZD	228 (39)	260 (57)	240 (43)	284 (51)

Note. Standard deviations (ms) are shown in parentheses.

Table 5

Reading Times (ms) on the Word After the Target in Experiment 1 as a Function of Experimental Condition.

	High Full	Low Full	High TL	Low TL
SFD	197 (54)	215 (47)	195 (61)	210 (48)
FFD	199 (45)	214 (43)	198 (59)	214 (51)
GZD	214 (62)	238 (49)	217 (83)	254 (62)

Note. Standard deviations (ms) are shown in parentheses.

Table 6

Reading Times (ms) on the Word Preceding the Target in Experiment 2 as a Function of Experimental Condition.

	Rept Full	New Full	Rept TL	New TL
SFD	210 (39)	203 (29)	216 (33)	213 (33)
FFD	212 (38)	215 (30)	206 (31)	213 (31)
GZD	251 (58)	251 (64)	247 (60)	246 (44)

Note. Standard deviations (ms) are shown in parentheses.

Table 7

Reading Times (ms) of the Target Word in Experiment 2 as a Function of Experimental Condition.

	Rept Full	New Full	Rept TL	New TL
SFD	211 (44)	224 (34)	221 (40)	225 (37)
FFD	209 (33)	221 (32)	216 (35)	226 (28)
GZD	226 (58)	239 (38)	240 (48)	251 (44)

Note. Standard deviations (ms) are shown in parentheses.