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Word Skipping During Sentence Reading: Effects of Lexicality on Parafoveal Processing

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Abstract

Two experiments examined how lexical status affects the targeting of saccades during reading by using the boundary technique to vary independently the content of a letter string when seen in parafoveal preview and when directly fixated. Experiment 1 measured the skipping rate for a target word embedded in a sentence under three parafoveal preview conditions: full preview (e.g. brain-brain), pseudohomophone preview (e.g. brane-brain), and orthographic nonword control preview (e.g. brant-brain); in the first condition the preview string was always an English word while in the second and third conditions it was always a nonword. Experiment 2 investigated three conditions where the preview string was always a word: full preview (e.g. beach-beach), homophone preview (e.g. beech-beach), and orthographic control preview (e.g. bench-beach). None of the letter string manipulations used to create the preview conditions in the experiments disrupted sub-lexical orthographic or phonological patterns. In Experiment 1 higher skipping rates were observed for the full (lexical) preview condition, which consisted of a word, compared to the nonword preview conditions (pseudohomophone and orthographic-control). In contrast Experiment 2 showed no difference in skipping rates across the three types of lexical preview conditions (full, homophone and orthographic control), though preview type did influence reading times. This pattern indicates that skipping depends not only on the presence of disrupted sub-lexical patterns of orthography or phonology but is also critically dependent on processes that are sensitive to the lexical status of letter strings in the parafovea.

Computational models of eye-movement control during reading have attempted to advance understanding of the extent to which oculomotor and linguistic factors affect decisions about when and where to move the eyes (Engbert, Nuthmann, Richter, & Kliegl, 2005; Pollatsek, Reichle, & Rayner, 2006; Reilly & O'Regan, 1998; Yang & McConkie, 2001; for comparisons between models see Reichle, Rayner, & Pollatsek, 2003). The E-Z Reader model (Pollatsek et al., 2006; Reichle, Pollatsek, Fisher, & Rayner, 1998) is a prominent account which contends that word recognition, a process that is influenced by linguistic factors (e.g., word frequency, word predictability in a context), is the primary engine of eye-movement control including processes of attention shift and the timing of saccades during reading. Other models support the idea that the process of eye-movement control is mainly determined by visual factors such as word length and location of the preceding fixation (Reilly & O'Regan, 1998; Yang & McConkie, 2001).

The rate of word skipping, where a word is not fixated during first-pass reading, is strongly influenced by factors that influence oculomotor processing, most notably word length and the proximity of the preceding fixation to the start of the word. Short words are skipped more frequently than long words (Brysbaert, Drieghe, & Vitu, 2005; Brysbaert & Vitu, 1998; Rayner, Slattery, Drieghe & Liversedge, 2011), and words with close preceding

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fixations are skipped more frequently than words with distant preceding fixations (Drieghe, Rayner, & Pollatsek, 2005; White, 2008). Word skipping is also influenced by factors that influence linguistic processing, with frequent words more likely to be skipped than less frequent words (Brysbaert et al., 2005; Choi & Gordon, 2012; Rayner & Fisher, 1996; Rayner & Raney, 1996; White, 2008), predictable words more likely to be skipped than non-predictable words (Drieghe et al., 2005; Ehrlich & Rayner, 1981; Rayner & Well, 1996), and repeated words more likely to be skipped than words that have not been seen in the experiment (Choi & Gordon, 2012; Gordon, Plummer & Choi, 2012; Lowder, Choi & Gordon, in press). Word skipping has been important in the evaluation of models of how the eyes are controlled during reading because, while factors affecting oculomotor processes systematically influence various facets of the targeting of saccades, word skipping is the only measure of forward saccade targeting between words that is influenced by factors affecting linguistic processing (Brysbaert et al., 2005).

The influence of linguistic factors on word skipping suggests that the skipped-over word is in some way recognized using perceptual information obtained from the parafovea while the eyes are fixated somewhere to the left of the word. In recent research using the Rayner (1975) boundary paradigm, we have shown that lexical factors (word repetition and frequency) only influence skipping rates when the letter string in parafoveal preview is a valid word (Choi & Gordon, 2012; Gordon et al., 2012; see also Drieghe et al., 2005). Skipping rates were not influenced by the lexical characteristics of a base word that is seen in the parafovea as a transposed letter (TL) nonword (Choi & Gordon, 2012; Gordon et al., 2012) even though such TL nonwords effectively activate the orthographic representations of the base words from which they are derived (Johnson, Perea, & Rayner, 2007; Perea & Lupker, 2003). For example, skipping rates for high-frequency words (e.g., *north*) were greater than for low-frequency words (e.g., *blink*), but skipping rates did not differ when the letter string in parafoveal preview was the related TL nonword (e.g., *nroth* vs. *bilnk*). Choi and Gordon argued that language-based word skipping occurs based on an *implicit lexical decision* during reading. That is to say, the letter string in the parafovea must be processed to the point where it is recognized as being a word. Though TL nonwords are sufficiently similar to their base words that they can activate representations of those words, they are not words and are not seen as such. With respect to the E-Z Reader model (Pollatsek et al. 2006; Reichle et al. 1998), the implicit lexical decision is meant as a more detailed characterization of the familiarity check (or L1 stage of processing), which indicates that recognition of a word is imminent.

It should be noted that most research on word recognition that has used the boundary technique has focused on parafoveal preview benefit, where first-pass reading time on the target word is examined in relation to the preview string. Some boundary studies show no significant effects on skipping (e.g., Pollatsek, Lesch, Morris, & Rayner, 1992; Yang, Wang, Tong, & Rayner, 2012) or do not report skipping data at all (e.g., Inhoff, Starr, & Shindler, 2000; Johnson, et al, 2007). We believe that this is so because skipping is only a sensitive measure of lexical processing under very narrow circumstances. In particular, the target word must neither be too short (because it will be skipped too often) nor too long (because it will be skipped too rarely). Further, the word preceding the target word also must not be too short because in that case it will be skipped with the eyes landing on the target word (two words in a row are rarely skipped). Perhaps because of a focus on parafoveal preview benefit, many studies using the boundary technique (or other gaze-contingent techniques) appear not to have attempted to meet these constraints.

The major goal of the current study is to test an alternative to the Choi and Gordon (2012) account that language-based skipping is based on an implicit assessment of whether the parafoveal string is a word. The TL nonwords used in Choi and Gordon and Gordon et al.

(2012) included sub-lexical letter clusters that are impossible (or very infrequent) in English (e.g., *nro* in *nroth* and *lnk* in *bilnk*). Eye-tracking studies have shown that letter cluster information affects saccade targeting and fixation durations during reading (Hyönä, 1995; Lima & Inhoff, 1985; Plummer & Rayner, 2012; Radach, Inhoff, & Heller, 2004; Vonk, Radach, & van Rijn, 2000; White, 2008; White & Liversedge, 2006a, 2006b). If readers detected the impossible letter clusters, word skipping might have been inhibited based on the detection of the letter cluster information, not based on the lexical status of the whole letter string in parafoveal preview. The current research investigates whether word skipping is modulated by the lexical status of letter strings in parafoveal preview even when the nonword preview string does not contain impossible letter clusters. This is done by examining the processing of pseudohomophone nonword previews (e.g., *brane* as a preview of *brain*) and of homophone word previews (e.g., *beech* as a preview of *beach*). As with TL nonwords, pseudohomophones and homophones cause activation of their base words in a variety of tasks (Lukatela, Frost, Turvey, 1998; Lukatela & Turvey, 1994; Rastle & Brysbaert, 2006). Examination of how target-word processing is influenced by pseudohomophone and homophone previews allows dissociation of the lexical status of the preview from its phonological match to the target word. However, the effects of these two types of previews cannot be measured on the same target word because very few words have both pseudohomophones and homophones (e.g., *brain* does not have a homophone and *beach* does not have a pseudohomophone). Accordingly, different sets of target words were used to examine the effects of these two types of previews. These different target words appeared in a large set of sentences that were read by the same group of participants in a single session. Because these two types of stimuli involve different preview-target relations and different target words, we present them as separate experiments so that the logic and results of the comparisons among conditions is clear. Of particular importance to the primary goal of this study, the pseudohomophones used here do not include impossible letter clusters such as those found in the TL nonwords that we used previously. If the skipping difference between the word preview condition and the nonword preview condition observed in previous work (Choi & Gordon, 2012; Gordon et al., 2012) occurred due to the effect of sub-lexical letter clusters in parafoveal preview, we would not expect a difference in skipping rates between the valid word preview versus pseudohomophone nonword preview because there are no illegal sub-lexical letter clusters in pseudohomophones. Alternatively, if the previous results were driven by the lexicality of the whole letter string, the skipping difference would be observed again when pseudohomophones serve as the nonword preview.

A secondary goal is to examine how phonological information in parafoveal preview affects skipping during reading. A number of studies have shown that parafoveal preview of phonological and/or orthographic information in a word produces reduced first-pass times (i.e., parafoveal preview benefit) when that word is fixated (Ashby, Treiman, Kessler, & Rayner, 2006; Chace, Rayner, & Well, 2005; Henderson, Dixon, Petersen, Twilley, & Ferreira, 1995; Lesch & Pollatsek, 1998; Miellet & Sparrow, 2004; Pollatsek, Lesch, Morris, & Rayner, 1992). However, other studies (e.g., Pollatsek et al., 1992) have shown that hardly any additional preview benefit is found when preview and target are phonologically similar (e.g., beech-beach) as compared to when their orthographic similarity is equivalent but they differ phonologically (e.g., bench-beach). The high correlation between orthographic and phonological similarity makes it difficult to dissociate whether there are distinct orthographic and phonological components of parafoveal preview. A focus on skipping (e.g., Fitzsimmons & Drieghe, 2011) sidesteps this problem to some extent because different types of overlap between the preview string and target word are not relevant during skips because the target word is not seen before the skip.

Experiment 1

This experiment tests the hypothesis that language-based word skipping is modulated by the lexical status of the letter string in parafoveal preview (Choi & Gordon, 2012). As discussed above, the TL nonword previews that were used by Choi and Gordon and by Gordon et al. (2012) contained letter clusters that were illegal in English; detection of these clusters may have inhibited lexical processing of the TL nonwords in the parafovea. In contrast, this experiment examines whether the lexicality of the preview string affects skipping rates in the case of pseudohomophone previews that contain no illegal letter clusters and which are phonologically matched to words. The three conditions are illustrated in 1a–1c below, where the parafoveal preview string and target word are shown in brackets and are separated by a colon. In the full preview condition, the preview and the target are identical. In the pseudohomophone preview condition, the preview and the target have an identical phonological representation and similar orthographic representations. In the orthographic control preview condition, the preview and the target have similar orthographic and phonological representations. Preview condition was manipulated using the boundary technique (Rayner, 1975), in which the preview string is displayed at the target word position until the eyes cross an invisible boundary in the space before the target word position. When the eyes cross the boundary, the preview string is replaced by the target word.

1a Wendy had always wanted to study the complex [brain:brain] activity involved in problem solving. [Full preview condition]

1b Wendy had always wanted to study the complex [brane:brain] activity involved in problem solving. [Pseudohomophone preview condition]

1c Wendy had always wanted to study the complex [brant:brain] activity involved in problem solving. [Orthographic control preview condition]

In addition to providing information about the mechanisms governing language-based skipping, the conditions in this experiment also provide information about how overlap between the preview string and target modulate processing of the target word as measured by first-pass reading times on the target. If the degree of orthographic overlap between the preview and target affects target word processing, we would expect shorter first-pass reading times in the full preview condition than in the other two conditions. Further, if phonological overlap between the preview and target affects target word processing, then we would expect shorter first-pass reading times in the pseudohomophone condition than in the orthographic control condition. Finally, if parafoveal processing is mainly based on coarse analyses of the letter string (Slattery, 2009), which might elicit misidentification of the preview as a target word, there should be no difference in the first-pass fixation durations across the three preview types.

Method

Participants—Forty-eight undergraduates at the University of North Carolina at Chapel Hill participated in a single session that included stimuli for Experiments 1 and 2. All participants were native English speakers with normal or corrected-to-normal vision, were naïve about the goals of the research and received course credit for their participation.

Materials and Design—Thirty-six words were used as targets, and each word was embedded in a sentence. A long word (6 to 12 letters) appeared immediately before the target word in order to increase the likelihood that the pretarget word would be fixated rather than skipped. Target words were selected from Y. Lee, Binder, Kim, Pollatsek, and Rayner (1999) and Pollatsek et al. (1992). The average length of target words was 4.61 letters (ranging from 4 to 6 letters), and the average frequency was 18.68 counts per million (CELEX; Baayen, Piepenbrock, & Gulikers, 1995). For each target word, there were three parafoveal preview conditions: (a) full preview (e.g. *brain* as the preview of *brain*), (b) pseudohomophone preview (e.g. *brane* as the preview of *brain*), and (c) orthographic control preview (e.g. *brant* as the preview of *brain*). Note that the letter strings in the pseudohomophone and the orthographic control previews are nonwords. As in Pollatsek et al., visual similarity of letter strings in the three preview conditions was matched in terms of the proportion of letters in the preview string that matched those in the target string both in terms of identity and position (e.g., a value of .60 for the pair *brane-brain*). The average match in the pseudohomophone and full-orthographic conditions did not differ significantly (.67 vs. .71, $t(70) = 1.4$, $p > .16$), and the first letter of the preview and the target was always same. Additionally, the bigram token and type frequency of the preview strings, computed using N-Watch (Davis, 2005), were not significantly different across the three preview conditions. For bigram tokens, average frequencies were: 1530 (full preview), 1388 (pseudohomophone preview), and 1457 (orthographic control preview), $F < 1$, ns. For bigram types, average frequencies were: 29 (full preview), 30 (pseudohomophone preview), and 27 (orthographic control preview), $F < 1$, ns.

Three counterbalanced lists were constructed such that each list included 12 critical words per condition. The same numbers of participants were tested in each counterbalanced list. In addition, there were 36 experimental sentences from Experiment 2 and 36 filler sentences. The presentation order of the sentences was randomized for each participant.

Procedure—Eye movements were monitored with an Eyelink 1000 model (SR Research, Ontario, Canada), with sentences presented on a 21 inch ViewSonic G225f monitor at a display resolution of 1024 × 768 with the 120 Hz refresh rate. A headrest was used to minimize head movement. Eye movements were recorded from the reader's dominant eye at a sampling rate of 1000 Hz. Sentences were presented in black color on a white background, with characters presented in Courier font (a mono-spaced font). The distance between the participant and the display monitor was 61cm; 3.8 characters subtended 1° of visual angle. After the initial calibration and validation were completed, participants were asked to read sentences on the monitor naturally and respond to a yes-no question following each sentence. Sentences were presented at the center of the screen in a random order. Eye movements were measured when participants started to fixate the first letter of the sentences. An invisible boundary (Rayner, 1975) in the space before the target word was used to manipulate preview. Display changes occurred an average of 6.3 ms after the boundary was crossed. Participants did not report any screen changes as they were reading the sentences.

Results

Analysis of eye movements—All trials in which there was a blink or track loss during first-pass reading of the pre-target word, the target word, or the word after the target were excluded from the analysis, as were all trials in which the display change occurred prior to or after the first saccade that crossed the invisible boundary. For the final analysis 6% of trials were excluded by these criteria. 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 replacing fixation durations that exceeded lower and upper cutoffs of 80ms and 700ms with values set to the relevant cutoffs. This procedure affected 1.1% of durations. Five reading-time measures were calculated from the resulting fixation durations: S*ingle-fixation duration* (SFD) is 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) is 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) is the average of the sum of all first-pass fixation durations on a word. *Regression-path duration* (RPD, sometimes called *go-past time*) is the sum of all fixations beginning with the initial fixation on a region and ending when the gaze is directed away from the region to the right. *Total time* (TTime) is the sum of all fixations on a word. Three preview conditions were analyzed by a one-way analysis of variance (ANOVA). Error variance was calculated by participants (F_1) and by items (F_2).

Target-word skipping—Table 1 shows the mean first-pass skipping rates for the target word as a function of the experimental conditions. The effect of preview on the skipping rate for the target word during first-pass reading was significantly different across the three preview conditions, $F_1(2,94) = 7.09$, $p < .005$; $F_2(2,70) = 4.14$, $p < .05$. Contrast analyses showed higher skipping rates in the full preview condition as compared to the average of the pseudohomophone and the orthographic control conditions, $F_1(1,47) = 13.26$, $p < .005$; $F_2(1,35) = 7.60$, $p < .01$. The contrast between the pseudohomophone and the orthographic control preview did not show a difference in skipping rates, *F*s < 1, *p*s > .05.

An additional set of analyses was conducted only on trials where the launch site of the forward saccade was five or fewer characters from the left edge of the target word because that vantage point clearly allows parafoveal processing of the target. For these restricted analyses, the effect of preview on skipping rate was significant in the subject analysis and marginally significant in the item analysis, $F_1(2,92) = 4.41$, $p < .05$; $F_2(2,70) = 2.34$, $p < .11$. Contrast analyses showed that skipping rates in the full preview condition were higher than the average of the pseudohomophone and the orthographic control conditions, $F_1(1,47) = 7.18$, $p < .01$; $F_2(1,35) = 4.27$, $p < .05$, and that they did not differ between the pseudohomophone and the orthographic control conditions, *F*s < 1, *p*s > .05. Analysis of trials where the launch site was beyond five characters to the left of the target showed no significant differences across preview conditions.

Fixation times—Table 1 also shows reading times for Experiment 1. All three first-pass measures of reading time on the target word (first fixation duration, single fixation duration and gaze duration) varied significantly as a function of preview condition, [FFD, $F_1(2,94) = 3.80$, $p < .05$; $F_2(2,70) = 4.95$, $p < .05$; SFD, $F_1(2,92) = 6.80$, $p < .005$; $F_2(2,70) = 4.80$, $p < .05$; GZD, $F_1(2,94) = 5.61$, $p < .01$; $F_2(2,70) = 3.38$, $p < .05$]. Contrast analyses showed that times were shorter for the identical preview condition as compared to the average of the pseudohomophone and the orthographic control conditions [FFD, $F_1(1,47) = 6.17$, $p < .05$; $F_2(1,35) = 10.03$, $p < .005$; SFD, $F_1(1,47) = 12.18$, $p < .005$; $F_2(1,35) = 11.42$, $p < .005$; GZD, $F_1(1,47) = 11.43$, $p < .005$; $F_2(1,35) = 5.83$, $p < .05$]. Times did not differ significantly between the pseudohomophone and orthographic control conditions, [FFD, $F_1(1,47) = 1.55$, $p > .05$; $F_2(1,35) = 1.60$, $p > .05$; SFD, $F_1(1,47) = 1.81$, $p > .05$; $F_2(1,35) = 1.95$, $p > .05$; GZD, $F_1(1,47) < 1$, $p > .05$; F_2 $(1,35) = 1.10$, $p > .05$].

Analyses restricted to trials where the launch site was five or fewer characters from the target word showed a similar pattern for the three first-pass reading time measures: [FFD, $F_1(2,78) = 3.19$, $p < .05$; $F_2(2,70) = 4.22$, $p < .05$; SFD, $F_1(2,70) = 5.11$, $p < .01$; $F_2(2,70) = 7.48$, $p < .005$; GZD, $F_1(2,78) = 3.44$, $p < .05$; $F_2(2,70) = 2.23$, $p < .12$]. Contrast analyses showed that the first-pass fixation durations were shorter with identical previews than with the average of the pseudohomophone and orthographic-control previews [FFD, $F_1(1,39) = 3.00$, $p < .092$; $F_2(1,35) = 12.51$, $p < .005$; SFD, $F_1(1,35) = 9.25$, $p < .005$; $F_2(1,35) = 25.57$, $p < .001$; GZD, $F_1(1,47) = 4.2$, $p < .05$; $F_2(1,35) = 4.81$, $p < .05$]. The pseudohomophone and orthographic-control conditions did not differ.

Regression-path duration on the target word also showed a significant difference in the subject analysis and a marginal effect in the item analysis across the three types of previews, $F_1(2,94) = 4.70$, $p < .05$; $F_2(2,70) = 2.26$, $p < .12$. Contrasts showed that times were shorter in the full preview condition compared to the average of the pseudohomophone and the orthographic control conditions, $F_1(1,47) = 7.53$, $p < .01$; $F_2(1,35) = 5.67$, $p < .05$, but that there was no difference between the pseudohomophone and orthographic control conditions, *F*s < 1, *p*s > .05. Restricting the analyses to trials with nearby launch sites yielded a similar pattern of results, $F_1(2,88) = 2.55$, $p < .09$; $F_2(2,70) = 1.83$, $p < .17$. The contrast between the full preview and the average of the pseudohomophone and the orthographic-control conditions was significant in the subject analysis but not in the item analysis, $F_1(1,44) = 4.09$, $p < .01$; $F_2(1,35) = 2.49$, $p < .13$; the contrast between the pseudohomophone and the orthographic-control conditions was not significant, *F*s < 1, *p*s > .05. Total time on the target word also varied as a function of condition, $F_1(2,94) = 5.82$, $p < .005$; $F_2(2,70) = 4.76$, $p < .05$, with shorter times in the full preview condition as compared to the average of the other two conditions, $F_1(1,47) = 8.78$, $p < .01$; $F_2(1,35) = 7.90$, $p < .01$, and no difference between the pseudohomophone and orthographic control conditions, $F_1(1,47) = 1.65$, $p > .05$; $F_2(1,35) = 1.76$, $p > .05$. For the launch- site restricted analysis, total time on the target word varied as a function of condition, $F_1(2,88) = 3.35$, $p < .05$; $F_2(2,70) = 3.52$, $p < .05$, with no difference between the full preview and the average of the pseudohomophone and the orthographic control previews. Overall, the patterns for regression-path duration and total time were similar to those found for first-pass reading time measures.

Discussion

The main finding of Experiment 1 was that skipping rates were higher for target words in the full preview condition than in the pseudohomophone and orthographic-control preview conditions. This pattern is consistent with the idea that skipping rates are affected by the ease of processing the letter string in parafoveal preview only when that letter string is actually a word (Choi & Gordon, 2012; Gordon et al., 2012; see also Yen, Tsai, Tzeng, & Hung, 2008 for a similar result using Chinese). The greater skipping rates for the full preview condition as compared to the nonword preview conditions cannot be attributed to the presence of illegal letter clusters in the nonword conditions because the pseudohomophone and orthographic-control preview conditions did not contain illegal clusters, a pattern that suggests that language-based skipping involves an implicit decision of lexicality of the entire letter string in the parafovea (Choi & Gordon, 2012; see also Miellet & Sparrow, 2004).

First-pass reading times showed that target words in the full preview condition were fixated for less time than those in the pseudohomophone or orthographic control preview conditions, with no difference between the pseudohomophone and the orthographic control preview conditions. This pattern indicates that parafoveal preview benefit is very sensitive to the degree of overlap between the preview string and the fixated word. This pattern also provides no evidence that the phonological match of the preview string to the target word in the pseudohomophone condition provided any additional parafoveal preview benefit compared to the orthographic control condition which provided an equivalent orthographic match to the target. Substantial evidence shows that pseudohomophones effectively activate phonological and/or orthographic representations of base words during recognition of isolated words (for a review, see Rastle & Brysbaert, 2006). The current results fit with previous studies of eye movements during silent reading of English sentences where it has been difficult to tie effects specifically to pseudohomophones (H. W. Lee, Kambe, Pollatsek, & Rayner, 2005; Lee et al., 1999; cf. Miellet & Sparrow, 2004).

Experiment 2

This experiment further tests the hypothesis that language-based skipping is affected by the lexical status of the letter string in parafoveal preview. The three conditions are illustrated in 2a–2c below, with the parafoveal preview string and target word shown in brackets and separated by a colon. As in Experiment 1, the overlap between the preview string and target word was manipulated to vary the orthographic and phonological relationships between parafoveal and foveal information, but phonological identity between the preview and target was achieved using homophones rather than pseudohomophones, and the orthographic control strings were words. Thus, the invalid preview conditions used words in this experiment while in Experiment 1 they used nonwords. If language-based skipping is based on determination of the lexical status of the string in parafoveal preview, then skipping rates should not differ across the three conditions since the preview string in each case is a word, which is matched in length and frequency across conditions.

2a Jane found the novel to be surprisingly [plain:plain] in its style and plot, so she wondered why it got such great reviews. [Full preview condition]

2b Jane found the novel to be surprisingly [plane:plain] in its style and plot, so she wondered why it got such great reviews. [Homophone preview condition]

2c Jane found the novel to be surprisingly [plate:plain] in its style and plot, so she wondered why it got such great reviews. [Orthographic control preview condition]

While the invalid preview strings in this experiment are always words, it should be noted that their meanings do not fit plausibly with the preceding context. As in Experiment 2 of Choi and Gordon (2012), this provides the opportunity to examine whether skipping of the invalid word previews is based on accurate identification (e.g., recognizing *plane* as *plane*) or on misidentification of the preview word as the contextually appropriate target word (e.g., recognizing *plane* as *plain*). Accurate recognition of the invalid preview string should lead to a downstream processing cost as was found by Choi and Gordon with invalid preview words that did not fit the meaning of the sentence context. Alternatively, if skipping of invalid word previews occurs because of misidentification of the preview string as the target word, then there should be no downstream processing cost.

When the target word is not skipped the amount of parafoveal preview benefit should depend on the orthographic overlap between the preview and target words as was found in Experiment 1. That is, first-pass reading times should be shorter with valid (full) preview than with invalid preview and there should be no difference in first-pass times between the homophone and orthographic control conditions. However, the use of words in this experiment rather than nonwords as the invalid preview strings might change this pattern, perhaps making it more likely that phonological priming might be observed due to better activation of phonological representations by homophones than by pseudohomophones. In an earlier study of this issue, Pollatsek et al. (1992) found that first-pass fixation durations on the target word were shortest with full preview (e.g., *chute-chute*), followed by homophone preview (e.g., *shoot-chute*), and then followed by orthographic controls for the homophone (e.g., *shout-chute*). However, a breakdown of the stimuli found no difference in first-pass fixation durations when the preview and the target strings were highly similar in the sense that they shared two initial letters (*plain-plain* vs. *plane-plain* vs. *plate-plain*). The invalid preview conditions in this experiment involve preview words that are highly similar to the targets with approximately 80% of them sharing the first two letters.

Method

Materials and Design—Thirty-six words were used as targets, with each word embedded in a sentence with a long pre-target word as in the previous experiment. Target words were selected from Y. Lee et al. (1999) and from Pollatsek et al. (1992). The average length of target words was 4.56 letters (ranging from 4 to 6 letters), and the average frequency was 23.17 counts per million (CELEX; Baayen, et al., 1995). For each target word, there were three parafoveal preview conditions: (a) full preview (e.g. *plain* as the preview of *plain*), (b) homophone preview (e.g. *plane* as the preview of *plain*), and (c) orthographic control preview (e.g. *plate* as the preview of *plain*). Visual similarity of letter strings of the two invalid preview conditions was balanced using the letter-overlap measure employed in Experiment 1. The proportion of letters that matched both in identity and in position did not differ for homophone and orthographic control pairs (.67 vs. .69, $t(70) < 1$), and the first letter of the preview and target words was always shared as in Experiment 1.

Orthographic characteristics of the preview words were matched using the default vocabulary (CELEX) in the N-Watch program (Davis, 2005). There was no difference in word frequency between valid (23 counts per million), homophone (18 counts per million), and orthographic-control (24 counts per million) conditions, $F < 1$, ns. The number of orthographic neighbors for preview words was also matched across the three preview conditions ($F < 1$, ns). The bigram token and type frequency of the preview strings, computed using N-Watch (Davis, 2005), showed no statistical difference in token or type frequency across the three preview conditions: Bigram token frequency: 1749 (full preview), 1792 (pseudohomophone preview), and 1642 (orthographic control preview), $F < 1$, ns; Bigram type frequency: 35 (full preview), 36 (pseudohomophone preview), and 35 (orthographic control preview), $F < 1$, ns.

Results

Analysis of eye movements—Analysis of the eye tracks was performed in the same way as in Experiment 1; 7.2% of trials were excluded using the same criteria as in Experiment 1. Reading time measures were calculated after substituting outlier fixations in the same manner as Experiment 1; this procedure affected 2% of the data.

Target-word skipping—Table 2 shows the mean first-pass skipping rates for the target word as a function of the experimental conditions. The effect of preview on the skipping rates of the target word during first-pass reading was not significant across the three preview conditions, Fs < 1[1]. This effect remained non-significant ($Fs < 1$) when the analysis was restricted to trials where the forward saccade was launched within five characters of the target word.

Consequences of skipping different previews—Regression-path duration on the word after the target was analyzed to examine whether skipping the target word based on the homophone preview and the orthographic control preview caused some disruption in comprehension as compared to skipping the target based on the full preview. Such an effect was found by Choi and Gordon (2012) and would be expected if the invalid preview words were accurately identified prior to the skip since the meaning of those words does not fit

[1]In Experiment 1 skipping rates were greater with word preview (e.g., brain-brain) than with nonword preview (e.g., brane-brain). Because the same subjects participated in both Experiment 1 and 2, a within-subjects, cross-experiment ANOVA was conducted to test whether lexical status had a significant effect on skipping rates for the full set of stimuli. A contrast analysis showed significantly greater skipping for word previews as compared to nonword previews, $t(47) = 4.2$, $p < .001$, a pattern that is consistent with the idea that skipping rates were strongly modulated by lexical status of the letter string in parafoveal preview. Note that analyses cannot be done with fully crossed factorial model of lexicality (word versus nonword) and preview type (full, phonologically related, and orthographically related) because there was no instance of a full preview without lexicality in this design.

with the sentence. Alternatively, increased fixation durations would not be expected if the invalid preview words were misperceived as the semantically congruous target word. RPD on the word after the target was computed only for cases where the target word was skipped. RPD on the word after the target following a skip was 308ms for full preview, 375ms for homophone preview, and 385ms for orthographic-control preview, $F_1(2,56)$ =3.28, $p < .05$; $F_2(2,60) = 5.21$, $p < .01$. Contrast analyses showed that this effect was driven by shorter times in the full preview condition versus the average of the homophone and the orthographic-control previews conditions, $F_1(1,28) = 6.97$, $p < .05$; $F_2(1,30)$ =11.23, $p < .005$.

Fixation times—Table 2 shows reading times as a function of condition. Overall ANOVAs on the three first-pass measures did not show significant differences as a function of preview condition [FFD, $F_1(2,94) = 1.20$, $p > .05$; $F_2(2,70) < 1$, $p > .05$; SFD, $F_1(2,92) = 2.25$, $p > .05$; $F_2(2,70) < 1$, $p > .05$; GZD, $F_1(2,94) = 2.79$, $p = .067$; $F_2(2,70) = 1.60$, $p > .05$]. Given the results of Experiment 1, contrast analyses were performed testing the difference between the full preview condition and the average of the homophone and orthographic-control conditions. For gaze duration, times were shorter in the full preview condition, an effect that was significant by subjects and marginal by items, $F_1(1,47) = 4.11$, $p < .05$; $F_2(1,35) = 2.81$, $p = .10$. For single fixation duration this difference was marginal, $F_1(1,46) = 3.25$, $p = .078$; $F_2(1,35) < 1$, $p > .05$. Restricting the analysis to trials that met the nearby launch-site criterion strengthened the benefit of full preview, [FFD, $F_1(2,74) = 1.33$, $p > .05$; $F_2(2,64) = 1.47$, $p > .05$; SFD, $F_1(2,70) = 3.33$, $p < .05$; $F_2(2,64) = 5.52$, $p < .01$; GZD, $F_1(2,74) = 2.92$, $p < .06$; $F_2(2,64) = 4.03$, $p < .05$]. Contrast analyses showed that the first-pass reading times were shorter in the full preview condition as compared to the average of the homophone and orthographic control conditions [FFD, $F_1(1,37) = 2.03$, $p < .163$; $F_2(1,32) = 2.64$, $p < .114$; SFD, $F_1(1,35) = 7.33$, $p < .05$; $F_2(1,32) = 12.13$, $p < .001$; GZD, $F_1(1,37) = 5.71$, $p < .05$; $F_2(1,32) = 9.07$, $p < .01$]. However, the homophone and orthographic-control conditions did not differ significantly [FFD, $F_1(1,37) < 1$, ns; $F_2(1,32) < 1$, ns; SFD, $F_1(1,35) < 1$, ns; $F_2(1,32) < 1$, ns; GZD, $F_1(1,37) < 1$, ns; F_2 $(1,32) < 1$, ns].

Regression-path duration yielded a significant difference between conditions in the subject analysis, but not in the item analysis, $F_1(2,94) = 5.09$, $p < .01$; $F_2(2,70) = 1.36$, $p > .05$. Contrast analyses showed that the significant results were based on the difference between the full preview versus the average of the homophone and the orthographic control previews, $F_1(1,47) = 11.74$, $p < .001$; $F_2(1,35) = 3.23$, $p = .081$, but there was no difference between the homophone and the orthographic control previews, Fs < 1. Total reading time, which includes some regressive fixations that also contributed to regression-path duration, also showed a significant difference on this region as a function of preview, $F_1(2,94) = 6.97$, $p < .005$; $F_2(2,70) = 7.33$, $p < .001$. The contrast analyses of the total time between the full preview and the average of the homophone and the orthographic control previews showed a similar pattern to that obtained in RPD, $F_1(1,47) = 13.99$, $p < .001$; $F_2(1,35) = 12.91$, $p < .001$. Restricting analysis to trials with a nearby launch site did not change the general pattern of results, [RPD, $F_1(2,90) = 3.21$, $p < .05$; $F_2(2,70) = 1.72$, $p > .05$; TTime, $F_1(2,86) = 4.4$, $p < .05$; $F_2(2,70) = 3.49$, $p < .05$]. Contrast analyses showed that the full preview condition was shorter than the average of two invalid preview conditions, [RPD, $F_1(1,45) = 9.34$, $p < .01$; $F_2(1,35) = 3.15$, $p < .086$, TTime, $F_1(1,43) = 11.28$, $p < .005$; $F_2(1,35) = 5.68$, $p < .05$]. There was no difference between the homophone preview and the orthographic control preview, [RPD, Fs < 1, ns; TTime, Fs < 1, ns].

Discussion

The main findings of Experiment 2 pertain to the effects of preview condition on skipping rates and on the downstream consequences of skipping as a function of preview condition.

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Skipping rates did not differ between the valid (full) preview and invalid (homophone and orthographic control) preview conditions. This absence of an effect of validity on skipping rates when the invalid preview strings were words contrasts with the strong effect seen in Experiment 1 when the invalid preview strings were nonwords. This absence of an effect of validity on skipping rates is consistent with previous findings that there is no difference in skipping rates across different types of lexically valid preview strings (Choi & Gordon, 2012; Pollatsek et al., 1992). While skipping rates did not vary as a function of the validity of the preview, reading time downstream of the skip did vary as a function of condition. Regression-path duration was longer following skips of invalid preview words than following skips of valid preview words. This pattern suggests that the skipped-over words in the invalid preview conditions were accurately recognized prior to the skip, and that the meaning of the skipped word extracted after processes that initiated the skipping saccade and before the eyes landed on the post-target word, causing disruption in later processing because their meanings did not fit with the sentence context, a pattern that was observed by Choi and Gordon (2012) for transposed letter word pairs (e.g., *clam:calm*). A similar result was also reported by Angele and Rayner (in press) who found high skipping rates for the word “the” even when it was syntactically not allowed but that such skipping was followed by downstream disruption.

Gaze durations and single fixation durations on the target word were shorter in the valid (full) preview condition relative to the two invalid preview conditions in the subject analysis, but not in the item analysis. However, in the launch-site restricted analyses, these measures of first-pass reading were significantly shorter with full preview than with invalid preview, indicating that preview benefit increased when the previewed word was closer to fixation. This marginal advantage in preview benefit for identical as compared to homophone previews was not observed between the valid and invalid conditions of Pollatsek et al. (1992) in a post hoc partition that examined homophone preview strings that were orthographically similar to the target string. A greater benefit was observed in comparisons between identical and homophone preview when the homophones were orthographically different from the target (e.g., chute-shoot, Pollatsek et al.). Other studies have also shown that there is greater benefit for identical than different word (or constituent) previews, a pattern found in eye-movement measures of both early and late reading processes (Inhoff et al., 2000) or just on late measures (White, Bertram, & Hyönä, 2008). The absence of a difference in the current experiment in preview benefit for homophones and orthographic controls supports the conclusion that orthographic match is a major determinant of parafoveal preview benefit.

General Discussion

The current study produced two main findings about how properties of letter strings in the parafovea influence the control of eye movements during reading. First, it showed that words seen only in the parafovea are skipped more frequently than nonwords seen only in the parafovea even when the two types of letter strings are equivalent in terms of their orthographic and phonological relations to the target word which they replace. This result goes beyond earlier demonstrations of this effect (Choi & Gordon, 2012; Gordon et al. 2012) by showing that it occurs when the nonwords seen in the parafovea do not contain sub-lexical letter clusters that are orthographically or phonologically illegal. Second, it showed that there is a processing cost after skipping words whose meanings are anomalous in the sentence context. These effects show that language-based skipping during reading is influenced by the lexical status of the word in the parafovea. In addition, the results of the two studies provide information about the nature of parafoveal preview benefit when the target word was not skipped: 1) first-pass fixation durations on the target word were shorter with valid preview (e.g., *plain* as a preview of *plain*) than with invalid preview (e.g., *plane* or *plate* as a preview of *plain*); 2) there was no advantage of pseudohomophone or homophone preview over orthographically similar control preview.

The results on skipping show a tight relationship between word recognition processes and eye-movement control during reading that is consistent with serial-attention-shifting models such as E-Z Reader (Pollatsek et al. 2006; Reichle et al. 1998). According to these models, the timing and targeting of saccades are influenced by word recognition processes in the following way: Lexical processing proceeds on the fixated letter string until a familiarity check (the L1 stage) is completed indicating that recognition of that string as a word is imminent. Completion of L1 initiates motor programming of a saccade to the next word while lexical processing of the fixated string continues until it is fully recognized (the L2 stage). Completion of L2 causes an attentional shift to lexical processing of the next word. In most instances this lexical processing is still ongoing when the eyes move to the next word, and the processing during that shift provides parafoveal preview benefit for the next word. In a minority of cases, the familiarity check (L1) on the parafoveal string is completed with sufficient time to cancel the planned saccade to that string and to reprogram a longer saccade that skips the parafoveal string.

Choi and Gordon (2012) characterized the L1 stage as an implicit lexical decision because the rate of language-based skipping for previewed TL nonword strings did not depend on the ease of recognizing the base word from which the TL nonword was derived. TL nonwords are perceptually very similar to their base words and cause high levels of priming for those base words in studies of isolated word recognition (Perea & Lupker, 2003) and of reading where it takes the form of parafoveal preview benefit (Johnson et al., 2007). The finding that preview of TL nonwords causes parafoveal preview benefit but does not affect skipping shows skipping depends on the lexical status of the preview string and not on its similarity to the target word. Further, the finding that skipping rates did not depend on the frequency of the base word from which the TL nonword was derived (Choi & Gordon) suggests that the process of skipping is not directly triggered by the familiarity of the letter string in parafoveal preview because a TL nonword derived from a high-frequency base word should seem more familiar than a TL nonword derived from a low-frequency base word. The pattern of results in the current experiments provide additional support for this conclusion: Experiment 1 showed that skipping rates were higher with valid preview of a word than for preview of pseudohomophone and orthographic control nonword strings while Experiment 2 showed that skipping rates did not differ significantly between preview strings that were words (full preview, homophone preview, and orthographic control preview).

Reading models (e.g., SWIFT, Engbert et al., 2005) that regard lexical attention as a parallel gradient rather than a serial process regard word skipping as the result of a competition for target selection that does not require word identification for skipping to occur. The ability of such models to accommodate the current skipping results depends on the degree to which a lexical decision constitutes word identification as defined by those models. Reading models that minimize the role of word recognition in favor of oculomotor processes (e.g., Reilly & O'Regan, 1998; McConkie et al., 1988) do not naturally account for these findings because factors that influence oculomotor processes (e.g., preview length, word length and surrounding context) were identical across conditions in our experiments. The characterization of language-based skipping as due to a lexical decision that is insensitive to meaning is further bolstered by the finding that skipping of invalid lexical preview strings, whose meaning is anomalous in the prior sentence context, led to a disruption of processing downstream of the skip.

The results on parafoveal preview benefit support the straightforward conclusion that facilitation in foveal processing of a word is greatest when the preview letter string in the parafovea is identical but the results also raise questions with respect to the roles of orthographic and phonological overlap between parafoveal and foveal processing. Williams, Perea, Pollatsek, and Rayner (2006) reported that the effect of overlap was a function of the word frequency of previews, demonstrating that there was no difference in fixation durations between full preview and high-frequency neighbor word preview, whereas a significant difference was observed when full preview and low-frequency neighbor word preview conditions were compared. Note that the neighbor words that were used in Williams et al. differed by only one letter from the target words. The current results show that lexical status of the letter string in parafoveal preview modulates the effect of orthographic overlap on first-fixation duration and single-fixation duration, though not on gaze duration. Even if previewed nonwords have similar orthographic information to target words, it seems unlikely that they would influence the extent to which valid word previews activate linguistic representations (Angele, Tran, & Rayner, in press; Drieghe et al., 2005; Johnson et al., 2007; Williams et al., 2006). The absence in our experiments of additional benefit of pseudohomophones or homophones over orthographic controls is likely due to the high degree of orthographic overlap between preview and target strings, with 80% of the preview and target pairs sharing initial bigrams in our study.

Conclusion

The results of this study bolster recent evidence (Choi & Gordon, 2012; Gordon et al. 2012) that the coordination of lexical and eye-movement control processes is sensitive to whether the letter string in the parafovea is a word, a view that is consistent with robust findings showing elevated skipping rates for words that are easy to recognize because they are frequent or predicted in the context (Brysbaert et al., 2005). Processing of parafoveal letter strings that are not words benefits the recognition of orthographically similar words when they are subsequently fixated but they themselves do not lead to an affirmative lexical decision and hence do not lead to increased skipping. Of course, the mechanisms underlying this implicit lexical decision during reading are not necessarily identical to those examined in the many studies that have employed the explicit word-nonword task developed by Landauer and Freedman (1968) and named the lexical-decision task by Meyer and Schvanaveldt (1971).

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Appendix A. Stimuli used in Experiment 1

Previews			Target Word
Valid	Pseudo-Homophone	Orthographic Control	
blaze	blaiz	blate	blaze
facet	facit	facar	facet
braid	brade	brait	braid
frail	frale	frazl	frail
glaze	glaiz	glanz	glaze
cheat	cheet	cheot	cheat
glide	glied	glibe	glide
cloud	clowd	clowt	cloud
wheat	wheet	whert	wheat
pillow	pilloh	piltow	pillow
grade	graid	grale	grade
plea	plee	pleu	plea
brain	brane	brant	brain
weed	wead	wend	weed
nail	nale	naul	nail
teeth	teath	terth	teeth
focal	fokal	fosal	focal
toad	tode	tond	toad
kale	kail	kafe	kale
bone	boan	bome	bone
loops	lupes	lirps	loops
hound	hownd	hornd	hound
ferns	furns	forns	ferns
loaf	lofe	louf	loaf
rake	raik	rale	rake
fate	fait	fale	fate
lake	laik	lafe	lake
focus	focus	fonos	focus
fall	foll	frll	fall
bowl	boal	boul	bowl
tomb	tume	tumt	tomb
jerk	jurk	jork	jerk
hall	holl	hrll	hall

Previews			Target Word
Valid	Pseudo-Homophone	Orthographic Control	
purse	perse	porse	purse
pause	peuse	pouse	pause
screw	skrew	sorew	screw

Appendix B. Stimuli used in Experiment 2

Previews			Target Word
Valid	Homophone	Orthographic Control	
stair	stare	stain	stair
flea	flee	flex	flea
plain	plane	plate	plain
steal	steel	steak	steal
beach	beech	bench	beach
miner	minor	mince	miner
pole	poll	polo	pole
creak	creek	crest	creak
throne	thrown	throat	throne
flair	flare	flame	flair
fowl	foul	foil	fowl
pane	pain	pace	pane
pier	peer	pair	pier
male	mail	mate	male
mall	maul	mail	mall
main	mane	mare	main
foul	fowl	foil	foul
bail	bale	ball	bail
beech	beach	bench	beech
maul	mall	mail	maul
heel	heal	hell	heel
lute	loot	late	lute
reins	rains	ruins	reins
stare	stair	stars	stare
plane	plain	plate	plane
steel	steal	steed	steel
minor	miner	mince	minor
poll	pole	polo	poll
creek	creak	crest	creek
pain	pane	pawn	pain
flare	flair	flame	flare
mail	male	maul	mail

Previews			**Target Word**
Valid	**Homophone**	**Orthographic Control**	
pears	pairs	pores	pears
vain	vein	vine	vain
rains	reins	ruins	rains
pairs	pears	piers	pairs

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Table 1

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

	Parafoveal Preview					
	All cases			Cases where launched from within 5 letters		
	Full	**Pseudohomophone**	**Orthographic control**	**Full**	**Pseudohomophone**	**Orthographic control**
PofSkips	.27 (.23)	.19 (.20)	.19 (.21)	.37 (.29)	.27 (.31)	.27 (.32)
SFD	219 (35)	229 (41)	224 (40)	219 (46)	253 (65)	241(46)
FFD	220 (36)	235 (31)	228 (43)	221(57)	241 (50)	228 (45)
GZD	242 (43)	263 (60)	257 (48)	241 (67)	271 (75)	259 (62)
RPD	286 (74)	323 (91)	324 (112)	277 (107)	323 (144)	312 (115)
TTime	300 (101)	337 (118)	324 (109)	278 (107)	311 (127)	285 (119)

Note. Standard deviations are in parentheses. PofSkips = Proportion of Skipping, SFD = Single Fixation Duration, FFD = First Fixation Duration, GZD = Gaze Duration, RPD = Regression-Path Duration, TTime = Total Time

Table 2

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

	Parafoveal Preview					
	All cases			Cases where launched from within 5 letters		
	Full	Homophone	Orthographic control	Full	Homophone	Orthographic control
PofSkips	.25 (.18)	.22 (.21)	.24 (.22)	.34 (.25)	.34 (.34)	.33 (.31)
SFD	217 (42)	220 (48)	229 (45)	212 (37)	241 (56)	234(56)
FFD	220 (40)	225 (40)	231 (44)	220(43)	228 (62)	237 (54)
GZD	240 (48)	255 (49)	256 (56)	234 (50)	261 (66)	259 (65)
RPD	291 (79)	340 (121)	338 (112)	280 (104)	337 (174)	350 (174)
TTime	316 (137)	403 (298)	380 (211)	309 (143)	378 (288)	376 (203)

Note. Standard deviations are in parentheses. PofSkips = Proportion of Skipping, SFD = Single Fixation Duration, FFD = First Fixation Duration, GZD = Gaze Duration, RPD = Regression-Path Duration, TTime = Total Time