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Previewing the Neighborhood: The Role of Orthographic Neighbors as Parafoveal Previews in Reading

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In 2 experiments, a boundary technique was used with parafoveal previews that were identical to a target (e.g., *sleet*), a word orthographic neighbor (*sweet*), or an orthographically matched nonword (*speet*). In Experiment 1, low-frequency words in orthographic pairs were targets, and high-frequency words were previews. In Experiment 2, the roles were reversed. In Experiment 1, neighbor words provided as much preview benefit as identical words and greater benefit than nonwords, whereas in Experiment 2, neighbor words provided no greater preview benefit than nonwords. These results indicate that the frequency of a preview influences the extraction of letter information without setting up appreciable competition between previews and targets. This is consistent with a model of word recognition in which early stages largely depend on excitation of letter information, and competition between lexical candidates becomes important only in later stages.

Keywords: eye movements, reading, orthographic neighborhood, parafoveal processing, word frequency

The size and composition of the orthographic neighborhood of a word (i.e., the number of words that can be created by changing a single letter in a target word; e.g., the neighborhood of *sleet* is *fleet, sheet, skeet, sweet, slept, sleek,* and *sleep*; Coltheart, Davelaar, Jonasson, & Besner, 1977) has been claimed to be a factor that can influence word recognition. Several studies (see Andrews, 1997 for a review) have found that the more neighbors that a word has, the easier it is to recognize. This facilitation effect has been interpreted as being due to the partial activation of the orthographic neighbors, which all have excitatory connections to the target word. The larger the neighborhood is, the more potential paths of activation for any one word there are, and a word possessing many neighbors receives more facilitation than one without a similar orthographic neighborhood.

Although neighborhood size appears to affect word processing, the composition of the orthographic neighborhood may also be a critical factor in word recognition. What is more important, several studies have found that the frequency of the orthographic neighbors has an impact on the ability to recognize a word. The finding that more neighbors leads to faster responses was specifically found for low-frequency words rather than high-frequency words (Andrews, 1989, 1992). The explanation for a facilitative effect is that the orthographic neighbors provide a support mechanism that permits the more rapid activation of the low-frequency word. According to Andrews (1992), this effect is due to the "lexical similarity" of the neighbors. Other studies (e.g., Carreiras, Perea, & Grainger, 1997; Grainger, O'Regan, Jacobs, & Segui, 1989), however, have demonstrated an inhibitory effect of the orthographic neighborhood of a word. They found that the presence of a higher-frequency neighbor led to slower responses to lower-frequency neighbors, presumably because the high-frequency neighbor is activated more easily than the other neighbors and is a strong competitor to the word actually presented. Grainger, O'Regan, Jacobs, & Segui (1989) referred to this as the *neighborhood frequency effect*.

There is ambiguity in most experiments about whether the locus of these neighborhood effects is orthographic or phonological. That is, as alphabetic systems are chiefly coding for phonology, orthographic neighbors are also likely to be phonological neighbors (i.e., words that differ from them by exactly one phoneme). In fact, Yates, Locker, and Simpson (2004) present a table indicating that in many of the studies demonstrating facilitative effects in lexical decision due to larger neighborhoods that the stimulus sets with larger orthographic neighborhoods also had larger phonological neighborhoods. Yates, Locker, and Simpson also demonstrated a phonological neighborhood size effect when orthographic neighborhood size was controlled. We prefer to remain agnostic on this issue, and we certainly would not be disappointed if the locus

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of these effects were in fact phonological, as we have made a case for early phonological coding in reading of text (e.g., Pollatsek, Lesch, Morris, & Rayner, 1992; Rayner, Sereno, Lesch, & Pollatsek, 1995). Because most of the studies have explicitly manipulated the orthographic characteristics of words (as do the present experiments), we will refer to the words as *orthographic neighbors*.

Most studies exploring the effects of neighborhoods have presented words in isolation (either through masked priming, lexical decision, or word naming). A majority of these studies have used the lexical-decision task to test the effects of neighborhood size on word recognition (Andrews, 1997). This task requires participants to make a judgment about the lexicality of a letter string presented on a computer screen and is presumed to tap into the lexical processing that occurs when people read words normally. It is rarely the case, however, that when a person reads a word (even one in isolation), he or she is required to judge whether the string of letters is a word or not. In other words, the decision that is required in this task is somewhat artificial and may not require the same processing that words encountered during reading normally receive. Schilling, Rayner, and Chumbley (1998) found a reasonably good correlation between eye fixation times and lexical decision times, but if the goal of this research is to understand the orthographic neighborhood effects in reading, we must take the next step and examine how these orthographic effects apply when they are manipulated in the context of reading a sentence.

Few studies have examined neighborhood effects in reading. Two relevant eye movement studies (in English) were reported by Pollatsek, Perea, and Binder (1999) and Perea and Pollatsek (1998). Pollatsek, Perea, and Binder (1999) explored the effects of neighborhood size on the reading of a target word that was embedded in a sentence. In contrast to the facilitative effect that orthographic neighborhood size had in a lexical-decision task using the same target words, they found that words with large orthographic neighborhoods were read more slowly than words with smaller neighborhoods. One factor that appeared to influence the reading of the word was whether the word had a higher-frequency neighbor; the existence of higher-frequency neighbors appeared to increase the difficulty in reading a target word. Perea and Pollatsek (1998) also found that the presence of at least one higher-frequency neighbor slowed reading. This effect appeared to be limited to later stages of reading, however, as the effects were primarily on "spillover" measures (i.e., processing time on the text immediately following the target word) and on measures of the total reading time on the target word (which includes time spent rereading the target word after regressions back to it). Both of these studies indicate that the presence of higher-frequency neighbors has an inhibitory effect on the reading of a word, although it mainly appears later in processing.

The current study used an eye movement contingent boundary technique (Rayner, 1975) in order to explore frequency effects within an orthographic neighborhood more fully. The boundary technique permits the alteration of the information that is available to the reader before the foveal processing of a target word. Although the text may be altered, readers are typically unaware of any but the most extreme changes. By manipulating the type of preview information that is available in the parafovea, we can explore the role of that type of information in reading and whether processing of that information before the reader views the word has an impact on reading. Specifically, we examined the effect of a high-frequency orthographic preview on the reading of a low-frequency target word (Experiment 1) and the effect of a low-frequency orthographic preview on the reading of a high-frequency target word (Experiment 2). If, as in previous studies, words that have a higher-frequency neighbor were processed more slowly than words without high-frequency neighbors, one would expect a higher-frequency neighbor preview to have an inhibitory effect on the later reading of a lower-frequency target word. That is, the preview of the high-frequency neighbor would presumably activate a lexical representation that would compete with the lexical representation of the low-frequency target word. In contrast, one might expect the preview of a low-frequency neighbor to have a facilitative effect on a high-frequency target word, because it would facilitate letter processing and excite the word node of the target, but offer little in the way of lexical competition to the word node.

Experiment 1

Perea and Pollatsek (1998) found that the effects of the orthographic neighborhood were primarily in measures associated with later stages of word processing (e.g., total time spent reading the target word and "spillover" in the reading of the next section of text). In the current experiment, we were interested in whether providing high-frequency orthographic neighbor information could affect earlier reading processes of a lower-frequency neighbor. If the inhibitory effect that has been found previously is the result of the high-frequency word information becoming active while participants read the target word, providing a preview of the high-frequency information should both increase its activation to compete with the low-frequency word and start the competition process earlier.

Method

Participants. Eighteen members of the University of Massachusetts community were recruited for this experiment (either for pay or course credit). All had normal vision or wore contact lenses. Before analyzing the data, we eliminated any trial in which there was an error in the display change either due to a blink or from a change that did not occur on the saccade into the target region. Furthermore, for reasons discussed later, we restricted the data to cases in which the eyes were fixated less than six character spaces from the beginning of the target word. We only analyzed participants[1] who retained more than 75% of the trials from the experiment once these trials were removed and who did not have any missing cells in their data.

Materials and design. Forty-eight sentences were constructed with a target word that was the lower-frequency member of an orthographic neighbor pair that differed in either their second letter (e.g., *sleet* and *sweet*) or third letter (e.g., *paper* and *pacer*). The higher-frequency orthographic neighbors in the pairs (employed in one of the preview conditions) had a mean frequency of 142 per million words, whereas the lower-frequency orthographic neighbor target words had a mean frequency of 8 per million words (Francis & Kučera, 1982). For one orthographic pair, the high-frequency word was mistakenly listed as the low-frequency word and vice

[1] In both Experiment 1 and Experiment 2, an additional six participants were run but excluded because of the very strict requirements adopted for the data analysis. The 75% data threshold criterion is standard practice in display change experiments in which there are multiple reasons for data loss (Sereno & Rayner, 1992).

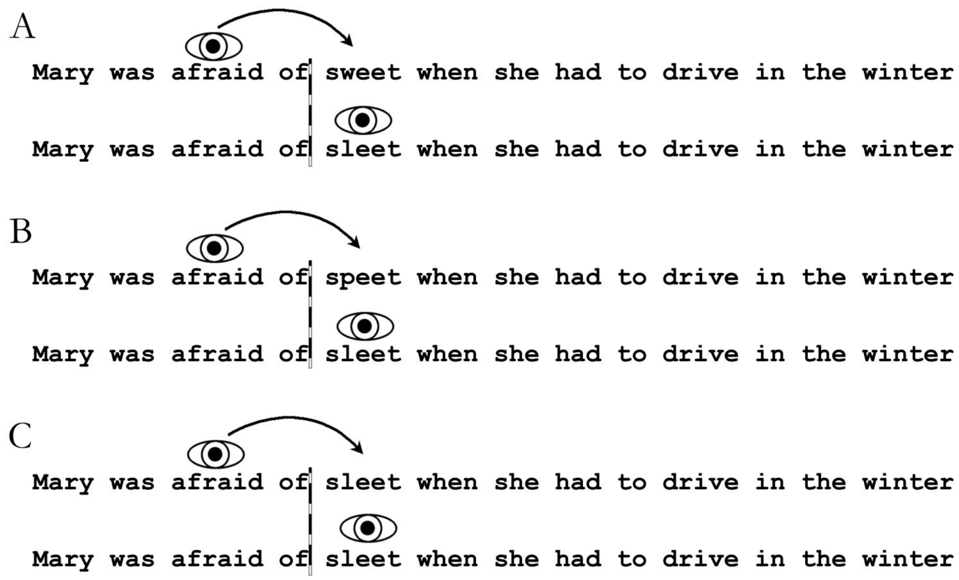

Figure 1. A representation of an eye movement contingent display change trial and the conditions in Experiment 1. A change from a high-frequency neighbor (*sweet*) to the low-frequency target (*sleet*) (A). The eye symbol represents the fixation point of a participant in the sentence, and the arrows represent the saccade taking the eye across the invisible boundary (the dashed vertical line). Before the eyes cross the boundary, the sentence is presented with the high-frequency neighbor (top line). Once the eyes cross the boundary, the text is changed to the target word (bottom line) and remains that way to the end of the trial. A change from a nonword orthographic neighbor (*speet*) to the target (B) and an identical preview condition in which the preview and target word are identical (a change does occur in the display, but it is impossible to see) (C).

versa, and for all analyses in both experiments reported here, this item was removed.

Using an eye movement contingent boundary technique (Rayner, 1975), we presented a preview of a word or a nonword that changed to the target low-frequency word as the participant moved his or her eyes across an invisible boundary to fixate on the target word (see Figure 1). Three different previews were used in this experiment: (a) identical preview (the low-frequency target word), (b) high-frequency (the higher-frequency word neighbor), and (c) orthographic nonword (an orthographically similar nonword that matched the target word on the same letters that the word neighbor did, such as *speet* for *sleet*). A change in the display occurred as each sentence was read, but because the target word was replaced by itself in the identical condition, no visible change occurred in that condition. The change from the preview to the target word occurred during the saccade to the target word, which minimized the chance that an individual would notice the change occurring. The three types of previews were counterbalanced across participants. (See the Appendix for a complete list of target words and previews.)

We also compared the frequencies of the letter bigrams (as measured in the MRC Psycholinguistic Database (Coltheart, 1981)) that contained the one letter that changed for the high-frequency, low-frequency, and orthographic nonword previews (e.g., *sw* and *we* for high-frequency word *sweet*, *sl* and *le* for the low-frequency word *sleet*, and *sp* and *pe* for the nonword *speet*). The frequencies for the two bigrams for each item were summed, and this combined frequency was compared between the different items. There were no significant differences between the combined bigram frequencies of the high-frequency, low-frequency, and nonword conditions (all ts < 1.51, ps $> .10$).

Finally, we also examined lexical decision times[2] for the high-frequency and low-frequency target words in the experiments reported here by submitting the items to the English Lexicon Project (Balota, et al., 2002). There was a difference in the mean lexical decision times for the high-frequency and low-frequency words, 618 ms and 673 ms, respectively, $t(93) = 3.75$, $p < .001$. This difference replicates the standard word frequency effect indicating that the materials in this study were not unusual. In addition, regression analysis indicated that the frequency of a word's neighbors impacts the lexical decision time over and above the word's frequency and overall neighborhood size, $F(1, 82) = 9.11$, $p = .003$. This analysis supports the previous contention (Perea & Pollatsek, 1998) that not only is the size of the orthographic neighborhood important, but that the frequency of those neighbors is also important.

Procedure. Before beginning the experiment, participants were given the experimental instructions. A bite plate was also prepared for each participant to minimize head movements during the experiment. Once the bite plate was prepared, the experimenter described the procedure to the participant and acquainted him or her with the eye-tracking equipment. Participants were told that they would read the sentences presented on a computer screen for comprehension. They were also informed that, after some sentences, a question would appear to test their comprehension of the sentence. Simple yes/no comprehension questions appeared after one-quarter of the sentences. Participants had little difficulty in answering the comprehension questions (i.e., they were correct approximately 90% of the time). After answering any questions regarding the procedure, the experimenter calibrated the eye tracker and began the experiment. Calibration was considered acceptable if it was better than 10 minutes of arc of visual angle. Calibration was checked between every trial, and recalibration was

[2] Schilling, Rayner, and Chumbley (1998) compared eye fixation times to lexical decision times and naming times and found that fixation times and naming times were highly correlated. Although fixation time and lexical decision time were not as highly correlated, the correlation was still significant.

performed when necessary. Participants were informed that they could take a break whenever they needed one.

Apparatus. Eye tracking was performed using a Dual Purkinje Eye tracker. This eye tracker is sensitive to less than 10 minutes of arc and has millisecond precision in timing. The monitor was set to a refresh rate of 200 Hz. The delay in detecting an eye movement into the target word and changing the display was typically 5 ms, and changes in the display were typically completed during the saccade into the target word.[3] Sentences were presented at a distance in which 3.8 characters subtended approximately 1 deg.

Results

Of particular interest was the effect of the different types of preview on the reading of the low-frequency target word. The specific comparisons of interest were whether or not the identical preview would lead to faster reading (or shorter eye fixation times) than the high-frequency neighbor and the orthographic nonword previews and whether or not high-frequency previews would be different than the orthographic nonword preview controls. As the two nonidentical previews each differed from the target word by one letter in the same serial position, any difference in reading the target word would be attributable to the fact that the high-frequency previews were true orthographic lexical neighbors of the target word. In particular, we expected that activating a high-frequency neighbor of the target word would create competition between the neighbors and interfere with encoding of the target word and would be slower than the orthographic controls.

All eye-tracking analyses described here were performed for the target word region. Fixations less than 80 ms or greater than 800 ms were eliminated from the analyses. Additionally, as noted previously, in order to ensure that the preview was visible before the display change, we only used trials in which the eye was fixated six characters or fewer from the beginning of the target word on the fixation prior to landing on it. Five separate eye movement measures will be discussed: first fixation duration, single fixation duration, first pass gaze duration, total time spent on the target word, and the first fixation upon leaving the target word region (spillover). The results for each of these measures can be found in Table 1. For all analyses described here, the counterbalancing factor was included to remove variance attributable to the counterbalancing of the items for the subject analyses or participants for the item analyses (Pollatsek & Well, 1995).

First fixation duration. First fixation duration is the mean duration of the first fixation on the target word—conditional on the word being fixated—regardless of the number of fixations on the target word. As can be seen in Table 1, first fixation durations in the orthographic nonword condition were almost 30 ms longer than in the other two conditions. The difference among the three preview conditions was significant, $F1(2, 30) = 7.63$, $p = .002$, $MSE = 557.5$, $F2(2, 72) = 4.79$, $p = .011$, $MSE = 2{,}838$.[4] The contrasts between the identical and orthographic nonword previews and the high-frequency and the orthographic nonword previews were both highly significant as well, $F1(1, 15) = 9.84$, $p = .007$, $MSE = 702.9$, $F2(1, 36) = 7.56$, $p = .009$, $MSE = 2703$, $F1(1, 15) = 11.92$, $p = .004$, $MSE = 486.9$; $F2(1, 35) = 9.46$, $p = .004$, $MSE = 2{,}150$, respectively. The 2 ms difference between the identical and high-frequency preview conditions (0 ms in the item analysis) was not close to significant, $F\text{s} < 1$.

Single fixation duration. Single fixation duration is the mean of all fixation durations on those trials in which there was exactly one fixation on the target word. The pattern of data and sizes of the effects were about the same as for the first fixation duration, $F1(2, 30) = 6.88$, $p = .003$, $MSE = 769.5$; $F2(2, 70) = 4.55$, $p = .018$, $MSE = 3154$. Both the 29-ms difference between the identical and orthographic nonword previews and the 30-ms difference between the high-frequency and orthographic nonword previews were again significant, $F1(1, 15) = 7.59$, $p = .015$, $MSE = 1{,}020$; $F2(1, 35) = 6.17$, $p = .018$, $MSE = 3{,}157$, $F1(1, 15) = 12.51$, $p = .003$, $MSE = 650.1$; $F2(1, 36) = 11.16$, $p = .002$, $MSE = 2{,}097$, respectively. The 1-ms difference between the identical and high-frequency preview conditions was not significant, $F\text{s} < 1$.

Gaze duration. Gaze duration is the sum of all of the fixations on a target word before leaving that word for the first time. The pattern is slightly different from the prior two measures, as there appeared to be a difference between the identical and high-frequency preview conditions. Again, the overall difference among the preview conditions was significant, $F1(2, 30) = 3.35$, $p = .049$, $MSE = 1{,}732$; $F2(2, 72) = 6.86$, $p = .002$, $MSE = 3{,}353$. The 35-ms difference between the identical and orthographic nonword preview conditions was significant by items but only marginally significant by participants, $F1(1, 15) = 4.11$, $p = .061$, $MSE = 2{,}783$; $F2(1, 36) = 14.4$, $p = .001$, $MSE = 3{,}119$, but the 21-ms difference between the high-frequency and orthographic nonword previews was significant in both analyses, $F1(1, 15) = 6.18$, $p = .025$, $MSE = 662.9$; $F2(1, 36) = 5.35$, $p = .027$, $MSE = 3{,}389$. The 14-ms difference between the identical and high-frequency preview conditions, however, was not close to significant, $F1(1, 15) = 1.06$, $p > .20$, $MSE = 1{,}750$; $F2(1, 36) = 1.68$, $p > .20$.

Total time. Total time is the total fixation time that is spent on the target word regardless of when that fixation took place. The pattern was different than for the previous measures, as the total time in the identical preview condition was considerably less than in the other two preview conditions. The overall test of preview condition was marginally significant in the participant analysis and significant in the item analyses, $F1(2, 30) = 2.84$, $p = .074$,

Table 1
Eye Movement Measures for Experiment 1

		Preview condition	
Eye movement measure	Identical	High-frequency neighbor	Nonword orthographic control
First fixation duration	258	260	286
Single fixation duration	266	265	295
Gaze duration	273	287	308
Total time	311	351	359
Spillover	265	271	260

Note. Measurements shown are in milliseconds.

[3] Any display changes that did not occur during the saccade were readily identified via off-line analysis, and the trial was eliminated.

[4] All items for which a mean in a cell that was more than 3.5 standard deviations from the mean for that measure were removed from the item analysis. The same procedure was employed in Experiment 2.

MSE = 4,302; *F2*(2, 76) = 4.42, *p* = .015, *MSE* = 9,324. The 48-ms difference between the identical and orthographic nonword previews was significant, *F1*(1, 15) = 4.54, *p* = .05, *MSE* = 4,691; *F2*(1, 38) = 9.36, *p* = .004, *MSE* = 8,116. Somewhat surprisingly, however, the 40-ms difference between the identical and high-frequency preview conditions was not close to significant in the participant analysis, *F1*(1, 15) = 2.35, *p* = .146, *MSE* = 6,254; *F2*(1, 38) = 3.43, *p* = .072, *MSE* = 12,495. The 8-ms difference between the high-frequency and orthographic nonword preview conditions was also not significant, *F*s < 1.

Spillover. Spillover measures attempt to assess whether manipulations on the target word have somewhat delayed effects. One commonly used measure of spillover is the duration of the first fixation to the right of the target word. Although there was a suggestion of an inhibitory effect in the high-frequency preview condition (see Table 1), no differences among the conditions were close to significant in the analyses of variance, *F*s < 1, and all *F*s were less than 1 for all paired comparisons.

Discussion

The results of this experiment were surprising, as there was no evidence for an inhibitory effect from the high-frequency neighbor previews. Instead, they indicated that, on first-pass measures, having a high-frequency neighbor as a preview for a low-frequency word is as advantageous to reading as having the identical low-frequency word as a preview. Because both of these previews led to shorter first fixations on the target word than the orthographic nonword preview, it is not simply the match of the letters of the preview to the target word. Instead, the difference between the high-frequency word neighbor and orthographic nonword previews (which are equally neighbors in the orthographic sense) has to be due, in some way, to the fact that one is a word and the other is a nonword. In past experiments (Rayner, 1975; Rayner, McConkie, & Zola, 1980), however, there was little evidence for any substantial difference in preview benefit between words and nonwords that were equated on their orthographic similarity to the target word.[5] Instead, it seems more likely that the difference we observed was specifically due to the fact that the preview word was a high-frequency neighbor of the target word. We will return later to the question of why there would be facilitation rather than inhibition resulting from this relationship.

Experiment 2

Experiment 2 examined the effect of previewing a low-frequency neighbor on the subsequent reading of a high-frequency target word. If the mere presence of an orthographic word neighbor as a preview allows the reader to integrate the information from the preview with the information from the target word, then previewing a low-frequency neighbor of a high-frequency word should lead to shorter reading times than the orthographic nonword. On the other hand, if the good performance in the high-frequency preview condition in the first experiment was dependent on being a high-frequency neighbor, then previewing a low-frequency neighbor may provide little or no additional benefit than when previewing a matched orthographic nonword.

In order to determine if the presence of an orthographically related nonword caused specific difficulty in integrating the preview with the target word, in Experiment 2, we included a nonword control that contained visually similar letters (referred to as the *visual control preview*). Although the letters in the preview were visually similar to those in the target word, there was not the level of orthographic overlap between the visual control condition and the target word as there was in the orthographic nonword condition. The extent to which the orthographic nonword is particularly disruptive to reading can be examined by comparing the results of that condition to the visual control condition.

Method

Participants. Twenty-four members of the University of Massachusetts community participated in the experiment (for pay or course credit). As in Experiment 1, we only analyzed participants who retained more than 75% of the trials from this experiment once blinks and erroneous change trials were eliminated and those who did not have any missing cells in their data.

Materials. Forty-eight sentences were constructed in which the target words were the low-frequency member of the same orthographic neighbor pairs employed in Experiment 1. As in Experiment 1, an eye movement contingent boundary change paradigm was used. In contrast to Experiment 1, there were four different preview conditions: identical, low-frequency (a lower-frequency neighbor of the target word), orthographic nonword (the same stimuli as in Experiment 1), and visual control (a nonword preview whose letters were visually similar to those of the target word, such as *zmcol* for the target word *sweet*). Other than the addition of the visual control condition, the design and procedure was the same as Experiment 1, and as in Experiment 1, we only used trials in which the eye was fixated six characters or fewer from the beginning of the target word on the fixation before landing on it. (See the Appendix for a list of all the targets and previews.)

Results

First fixation duration. There was a reliable effect of the preview on the first fixation duration, *F1*(3, 60) = 6.41, *p* = .001, *MSE* = 1,145; *F2*(3, 117) = 8.53, *p* = .001, *MSE* = 2,243 (see Table 2). The pattern, however, was different from that of Experiment 1. First fixations in the identical preview were 26 ms shorter than in the low-frequency neighbor preview condition, *F1*(1, 20) = 10.72, *p* = .004, *MSE* = 776.0; *F2*(1, 39) = 8.92, *p* = .005, *MSE* = 2,335, and 28 ms shorter than in the orthographic nonword preview condition, *F1*(1, 20) = 6.84, *p* = .017, *MSE* = 1,342, *F2*(1, 39) = 8.22, *p* = .007, *MSE* = 2,412. The 2-ms difference between the low-frequency neighbor and orthographic nonword preview conditions was not close to significant, *F*s < 1. First fixation durations in these latter two conditions were each about 15 ms shorter than in the visual control condition, although the differences were marginally significant at best: low-frequency neighbor versus visual control, *F1*(1, 20) = 3.12, *p* = .093, *MSE* = 934.7, *F2*(1, 39) = 2.81, *p* = .102, *MSE* = 2,785,

[5] The extent to which the present experiments replicate these earlier studies is not really at issue because the earlier studies did not manipulate neighborhood characteristics. The results from Experiment 2 are quite similar to the general pattern observed in those studies, however, suggesting that the earlier studies used high-frequency target words with low-frequency neighbors as previews more often than they used low-frequency target words with high-frequency neighbors as previews.

Table 2
Eye Movement Measures for Experiment 2

Eye movement measure	Identical	Preview condition: Low-frequency neighbor	Nonword orthographic control	Visual similarity control
First fixation duration	257	283	285	299
Single fixation duration	257	287	285	305
Gaze duration	268	291	293	315
Total time	278	308	319	321
Spillover	274	283	276	270

Note. Measurements shown are in milliseconds.

orthographic nonword versus visual control, $F1(1, 20) = 1.36$, $p > .20$, $MSE = 1{,}799$, $F2(1, 39) = 4.01$, $p = .052$, $MSE = 2{,}537$.

Single fixation duration. The pattern of data for single fixation duration was similar to that for first fixation duration. Again, the four conditions reliably differed, $F1(3, 60) = 7.55$, $p < .001$, $MSE = 1{,}221$; $F2(3, 111) = 7.87$, $p < .001$, $MSE = 2{,}322$. Fixation durations were 30 ms shorter in the identical preview condition than in the low-frequency neighbor preview condition, $F1(1, 20) = 12.33$, $p = .002$, $MSE = 892.8$, $F2(1, 37) = 7.77$, $p = .008$, $MSE = 2{,}556$ and 28 ms shorter than in the orthographic nonword preview condition, $F1(1, 20) = 5.95$, $p = .002$, $MSE = 892.8$, $F2(1, 37) = 7.17$, $p = .011$, $MSE = 2{,}706$. The 2-ms advantage of the orthographic nonword condition over the low-frequency neighbor condition was not significant, Fs < 1. The differences between the visual control preview condition and the other nonidentical preview conditions were somewhat larger than for first fixation duration, but the differences were only marginally significant: low-frequency neighbor versus visual control, $F1(1, 20) = 3.75$, $p = .067$, $MSE = 916.2$, $F2(1, 37) = 3.01$, $p = .091$, $MSE = 2{,}733$, orthographic nonword versus visual control, $F1(1, 20) = 2.60$, $p = .123$, $MSE = 1{,}824$, $F2(1, 37) = 3.47$, $p = .070$, $MSE = 2{,}455$.

Gaze duration. The pattern for gaze duration was similar to the other two measures. Again, there was a reliable difference among the four conditions, $F1(3, 60) = 7.80$, $p < .001$, $MSE = 1{,}146$; $F2(3, 117) = 6.65$, $p < .001$, $MSE = 2{,}670$. Both the 23-ms advantage for the identical preview over the low-frequency neighbor preview and the 25-ms advantage for the identical preview over the orthographic nonword preview were significant, $F1(1, 20) = 11.81$, $p = .003$, $MSE = 575.1$, $F2(1, 39) = 5.36$, $p = .026$, $MSE = 3{,}095$, $F1(1, 20) = 6.78$, $p = .017$, $MSE = 1{,}103$, $F2(1, 39) = 4.11$, $p = .050$, $MSE = 2{,}783$, respectively, but the 2-ms difference between the low-frequency and orthographic nonword previews was not significant, Fs < 1. The 24-ms advantage for the low-frequency neighbor preview condition over the visual control was significant in the participant analysis and marginal in the item analysis, $F1(1, 20) = 6.36$, $p = .020$, $MSE = 1{,}035$, $F2(1, 39) = 3.42$, $p = .072$, $MSE = 29{,}722$, whereas the 22-ms advantage for the orthographic nonword previews over the visual control was marginally significant in the participant analyses and significant in the item analysis, $F1(1, 20) = 3.13$, $p = .092$, $MSE = 1{,}900$, $F2(1, 39) = 6.07$, $p = .018$, $MSE = 2{,}485$.

Total time. The pattern for total time was fairly similar to that for the first pass measures. There was a significant difference among the four conditions, $F1(3, 60) = 4.56$, $p < .006$, $MSE = 2{,}054$; $F2(3, 117) = 4.14$, $p = .008$, $MSE = 4{,}097$. The 30-ms advantage of the identical preview over the low-frequency preview and the 41-ms advantage of the identical preview over the orthographic nonword preview were significant, $F1(1, 20) = 9.88$, $p = .015$, $MSE = 1{,}127$, $F2(1, 39) = 4.99$, $p = .031$, $MSE = 4{,}040$; $F1(1, 20) = 7.17$, $p = .014$, $MSE = 2{,}762$, $F2(1, 39) = 6.37$, $p = .016$, $MSE = 4{,}249$, respectively, but the 11-ms difference between the low-frequency and orthographic nonword conditions was not reliable, Fs < 1. The advantages of the nonidentical conditions over the visual control were small: 13 ms for low-frequency versus visual control, $F1 < 1$, $F2(1, 39) = 1.12$, $p > .20$, $MSE = 4{,}424$ and 2 ms for orthographic nonword versus visual control, Fs < 1.

Spillover. As can be seen in Table 2, there were no overall effects of the preview condition on the first fixation after leaving the target word, $F1 < 1$; $F2 < 1$, and no contrasts reached significance (all Fs < 2.89, all ps $> .10$).

Discussion

Overall, the results of this experiment indicate that the encoding of a high-frequency word is not affected by the low-frequency orthographic neighbor beyond the overlap of the letters that orthographic neighbors have. This finding is similar to Pollatsek, Perea, & Binder (1999), who found limited impact of the orthographic neighborhood on the amount of time required to read a target word. The fact that the low-frequency previews and the orthographic nonword previews yielded similar preview effects indicates that there was no advantage or disadvantage to having previously processed an orthographic word neighbor. This result indicates that there is no general advantage to processing a word over a string of letters that is equally matched orthographically to the target word. Thus, our findings in Experiment 1 do not indicate a preference for orthographic neighbor words, generally. Instead, the results of Experiments 1 and 2 indicate that there is a distinct advantage resulting from a preview of a higher-frequency word before reading a neighbor of that word. We will examine this relationship more fully in the next section and the general discussion. Additionally, the results of Experiment 2 indicate that the more letter overlap a preview has with the target, the shorter reading times tended to be on the target word: both the low-frequency orthographic and the orthographic nonword conditions were read somewhat faster than the visual control.

Between-Experiment Comparisons

We compared the preview effects across the two experiments for each of the measures in order to obtain a better assessment of whether the pattern of results in the two experiments was different. Specifically, we were interested in whether or not an interaction of the experiment and the preview condition would be found for the measures of early processing (i.e., first fixation duration and single fixation duration) for both types of preview effects (neighbor word vs. neighbor nonword preview and identical vs. neighbor word preview).

The key comparison was the interaction across experiments of the word neighbor previews with the orthographic nonword previews. That is, was the high-frequency neighbor a significantly better preview for the low-frequency target than the low-frequency neighbor was for the high-frequency target? This interaction was significant for both first fixation duration, $F1(1, 35) = 4.82$, $p = .035$, $MSE = 618.1$; $F2(1, 75) = 6.13$, $p = .016$, $MSE = 2{,}035$ and single fixation duration, $F1(1, 35) = 7.64$, $p = .009$, $MSE = 734.1$; $F2(1, 72) = 6.64$, $p = .012$, $MSE = 1{,}872$. For gaze duration, the interaction between preview and experiment was not significant in the participant analysis, $F1(1, 35) = 2.81$, $p = .10$, $MSE = 743.4$ but was significant in the item analysis, $F2(1, 75) = 4.43$, $p = .039$, $MSE = 2{,}853$. Finally, there were no interactions for either the total time or the spillover measures [$F1$s < 1; $F2$s < 1.3].

A second contrast of interest is the interaction of experiment with the difference between the identical preview and the orthographic neighbor word preview, as there was little difference between the two in Experiment 1 and a significant difference between them in Experiment 2. Here, the interaction across experiment was significant in the participant analysis for both first fixation duration and the single fixation duration, but it was marginal in the item analyses for both, $F1(1, 35) = 4.56$, $p = .040$, $MSE = 650.3$; $F2(1, 75) = 3.58$, $p = .062$, $MSE = 3{,}128$, and single fixation duration, $F1(1, 35) = 6.31$, $p = .017$, $MSE = 783.7$; $F2(1, 72) = 3.43$, $p = .068$, $MSE = 3{,}359$. These interactions support the differences that were highlighted in the two experiments where previews of high-frequency neighbors lead to faster reading than previews of lower-frequency words. In contrast, there were no interactions that were close to significant between experiment and preview condition for gaze duration, total time, or spillover [$F1$s < 1; $F2$s < 1.5].

Overall, the interactions in first fixation duration and single fixation duration between the preview condition and experiment support the claims made earlier that the frequency of the neighbor serving as a preview has a dramatic impact on early reading processes. The interactions for the identical and neighbor previews bolster the argument that was made earlier that a high-frequency neighbor does not impede reading of a low-frequency word in the same manner as a low-frequency neighbor preview impacts the reading of a high-frequency word. We will examine this relationship in the following section.

General Discussion

The current study explored how a parafoveal preview of an orthographic neighbor of a target word affected the encoding of that target word. To summarize, in Experiment 1, we found that a preview of a high-frequency orthographic neighbor led to shorter first fixation durations and single fixation durations on a low-frequency target word than a nonword preview that was matched to the high-frequency orthographic neighbor in its orthographic similarity to the target word. In addition, the high-frequency neighbor preview was almost as good a preview of the target word as the target word itself. In contrast, in Experiment 2, a low-frequency neighbor of a high-frequency target word was little better as a preview than the nonword orthographic control and was significantly worse as a preview than when the target word was its own preview. The results indicate that the benefit from the preview information is influenced by more than the orthographic overlap between preview and target, especially for the earliest measures of processing.

The beneficial effect of a high-frequency orthographic neighbor preview on reading seems to contradict previous findings of inhibitory effects of neighborhood frequency in reading (Pollatsek, Perea, & Binder, 1999). That is, Pollatsek et al. found that a word with a higher-frequency neighbor had a longer total fixation time on it and more regressions back to the target word than to a frequency-matched control word. This finding led them to argue that having a higher-frequency orthographic neighbor primarily produced inhibitory effects late in the processing of a word. That study, however, did not employ display changes. In contrast, the present study shows that if a higher-frequency neighbor is actually present in the parafovea, then one gets a facilitative effect. This is different from saying that having a higher-frequency neighbor in one's lexicon produces a facilitative effect. Nonetheless, the facilitative effect of having a higher-frequency neighbor as a preview seems somewhat surprising. That is, the inhibitory effects of having a higher-frequency neighbor are usually attributed to some sort of competition between the lexical entry of the word actually presented and the lexical entry of its higher-frequency neighbor, and it is not immediately clear why such competition does not occur in the parafovea as well.

We turned to the E-Z reader model (Pollatsek, Reichle, & Rayner, 2006; Rayner, Ashby, Pollatsek, & Reichle, 2004; Reichle, Pollatsek, Fisher, & Rayner, 1998; Reichle, Rayner, & Pollatsek, 2003) as a way to provide a structure for a possible explanation for this apparent contradiction. The E-Z reader model of reading attempts to explain the pattern of eye movements that occurs during normal reading, and a key assumption is that only one word at a time is attended. The E-Z reader posits two stages of lexical access (which are referred to as *L1* and *L2*) that occur during the processing of a word in text. Complete lexical access is only accomplished when both stages are completed. It is important to note that, for the current explanation, both of these stages are sensitive to word frequency with higher-frequency words taking less time to complete these stages than lower-frequency words. When a word is first attended in the text, the L1 stage begins; this usually begins before the word is fixated. Usually, L1 continues when the word is fixated, and at the completion of L1, a signal to the eye movement system is sent to program a saccade to the next word, and L2 begins. When L2 is complete, the reader shifts his or her attention to word $n + 1$ and starts the L1 stage on word $n + 1$, and the same process occurs for word $n + 1$. Note that L2 is usually completed before the eye movement program is executed, and this interval between the completion of L2 and the time when new information from the next fixation reaches the brain is the time in which parafoveal processing of words occurs. (Quick parafoveal processing of the next word leads to skipping, but as this is outside our current focus, we will only briefly discuss this issue further on.) We should add that in the versions of the model that have been published, the simplifying assumption has been made that the durations of L1 and L2 are merely functions of the frequency of a word and its predictability from the prior words in the text. The results of the current study indicate that this is likely to be an oversimplification, however.

In the context of the E-Z Reader model, we think that the simplest account of the present results that is consistent with the prior results on neighborhood effects in reading is the following. According to the model, virtually all the processing occurring in the parafovea is L1 processing (the duration of L1 is typically about twice that of L2 in all the simulations that have been done). Thus, the preview effects are largely reflecting L1 processing. If we assume something like a two-stage model of word processing (Paap, Newsome, McDonald, & Schvaneveldt, 1982), one might loosely associate L1 with the earlier activation stage and L2 with the later verification stage. The activation stage largely consists of (position-dependent) letter identities being activated as well as lexical entries being activated.[6] (We would also posit that phonological entities such as phonemes and syllables are also activated.) Our data, however, would require a major change to the first stage of the activation-verification model. That is, in the Paap et al. (1982) model, the initial stage has no feedback from lexical entries to activation of letters or phonemes. Thus, it would predict no effects (either facilitative or inhibitory) from the lexical status or frequency of the preview. Thus, one would have to modify the model to posit that there is feedback from lexical entries to letter detectors, with greater feedback from higher-frequency lexical entries than from lower-frequency lexical entries.

We should emphasize that, in the activation-verification model, a final solution has not been achieved in the activation stage; usually several lexical entries are activated (all presumably orthographically and/or phonologically close to the word that the reader is trying to identify), and there would often be activation of multiple letters (e.g., *d* may activate the *b* detector as well as the *d* detector). In the E-Z Reader, the end of L1 is thought to be the point at which there was sufficient activation from all this lexical activity so that the reader was assured that there was a high probability that L2 would be achieved before the eyes moved to the next word. After this activation has proceeded to a high level, there is then a “verification” stage in which there is competition among the various lexical entries, and success in the competition is determined both by the bottom-up support from the visual evidence, by the frequency of a word in the lexicon, and by other top-down factors such as the predictability of the word from prior context. Presumably, the later, inhibitory, effects of higher-frequency neighbors that have been observed in the literature come from the verification stage.

We now return to consider preview effects beginning with the results from Experiment 1. If a higher-frequency neighbor is the preview, the L1 process proceeds more rapidly than when the low-frequency target word is the preview. Given an interactive model of word recognition, this implies that both the lexical entry of the higher-frequency neighbor and its component letter detectors are activated more strongly. (We will omit discussing phonological entries here for simplicity.) Thus, the preview of the higher-frequency neighbor is likely to produce both costs and benefits relative to the (identical) preview of the lower-frequency target word. There would be two potential costs: (a) the lexical entry of the higher-frequency word is likely to be activated as well as the entry of the target word; and (b) one incorrect letter entry is activated. For benefits, however, the higher-frequency neighbor may provide much stronger activation of all of the letters that the two words share. Moreover, if only something like the first half of L1 is completed before the target word is fixated, this increased letter activation may offset any inhibitory effects of the partial activation of the lexical entry of the higher-frequency neighbor. In contrast, the nonword orthographic preview would have no advantage over an identical preview. It is activating one incorrect letter and, being a nonword, it is also activating the shared letters less well than the identical preview.

Now consider the preview conditions of Experiment 2. Here, both the low-frequency preview and the nonword orthographic control are supporting letter identification from the preview stimulus less well than the (identical) high-frequency target word. In addition, of course, they also mismatch the target by one letter. Thus, they should both be worse previews than the identical preview. The low-frequency word might support identification of the shared letters with the target slightly better than the nonword would, but that might be offset by activating a competing lexical entry. On the other hand, because both of these previews activate some of the letters of the target word, they provide benefit over a preview that does not share any letters with the target word.

This explanation is clearly somewhat speculative. A key assumption is that because the processing occurring in the parafovea is early, the efficacy of the preview is determined chiefly by the letter information that is activated rather than the lexical entries that are partially activated. This assumption is reasonably consistent with the finding that a semantically related preview has no benefit over a semantically unrelated preview (Rayner, Balota, & Pollatsek, 1986) or that, for Spanish-English bilingual readers, a preview that is a translation of the target has no benefit over an orthographic control (Altarriba, Kambe, Pollatsek, & Rayner, 2001). That is, at present, there is little evidence that preview benefit is mediated very much at the lexical level, except, as indicated by the present experiment, where it appears that the lexical properties of the preview feed back to lower levels to facilitate word recognition. Another key assumption is that there is significant feedback from the word level to the letter level. Although such feedback is a key assumption of many models such as the interactive-activation model (McClelland & Rumelhart, 1981, information to follow), the activation-verification model does not assume it, and there are few key tests whether such feedback exists. One relevant experiment by Reynolds and Besner (2004) found that naming time for nonwords was facilitated by having many word neighbors, was inhibited by decreasing stimulus quality, and that the effects were additive. This additivity would appear to argue against an early role for neighborhood effects. Neighborhood size may mainly be affecting later stages, whereas having a

[6] It may be important to note that there is growing empirical evidence that shows that letters are not immediately assigned to their correct positions in the letter string (e.g., Grainger & Whitney, 2004; Perea & Lupker, 2004).

preview of a high-frequency neighbor as a stimulus may be primarily affecting earlier stages of processing. Another possibility is that the feedback mechanism mediating the facilitative effect of a high-frequency neighbor preview is from the word level to the phoneme level. That is to say, as we indicated earlier, orthographic neighborhood is confounded with phonological neighborhood, so that the facilitation could be through phonological codes. This is plausible, because phonological codes have been shown to be involved in parafoveal preview benefit (Pollatsek, Lesch, Morris, & Rayner, 1992).

One additional caveat needs to be provided. Previews are not merely a sequence of letters, as higher-frequency words and more predictable words are skipped more often than lower-frequency and less predictable words (Rayner, Sereno, & Raney, 1996; Rayner & Well, 1996). These phenomena indicate that—some of the time—processing of the parafoveal word is relatively complete and produces skipping. Thus, given the explanation just described, one might have expected more skipping of the higher-frequency preview than when the lower-frequency target word was the preview. In fact, although the difference was not reliable, the effect was in the opposite direction (21% for the higher-frequency neighbor and 28% for the lower-frequency target). An important part of the design of the current experiments is that virtually all the sentences made both the high-frequency previews of Experiment 1 and the low-frequency previews of Experiment 2 quite anomalous in context. This may have helped to suppress competition from the lexical entries of these previews. It is possible that one might get more lexical competition from contexts in which the target word and the neighbor fit in equally well. Such contexts would be difficult to create, however, because the neighboring words usually differ quite a bit in meaning and often in part of speech.

We also examined the frequency and pattern of regressions back to the target word in both experiments to get a feeling for whether there were any hints of delayed effects, especially in the case in which there was a high-frequency neighbor as a preview. There were more regressions back to the (low-frequency) target words in Experiment 1 (112 [on 13.0% of the trials]) than to the high-frequency target words in Experiment 2 (57 [on 4.9% of the trials]). There did not appear to be anything special about the high-frequency neighbor preview condition, however. There were a few more regressions back to the target word when the preview was not identical to the target than when it was identical in both experiments, but there was no clear difference between the two nonidentical preview conditions in either experiment. The numbers of regressions in Experiment 1 were 31, 39, and 42 for the identical, word neighbor and nonword neighbor, respectively, and in Experiment 2, the values were 9, 19, and 20, respectively (with 9 regressions occurring in the visual control condition). Thus, the regressions seem almost completely predictable by the frequency of the target word and the orthographic similarity of the preview to the target.

We had hoped to try to simulate our data with a modification of the activation-verification model, but unfortunately, there appear to be no extant working versions of this model. We also originally thought that an interactive-activation model (McClelland & Rumelhart, 1981) would also make a similar prediction. We did have a working version of this model (with a five-letter word vocabulary; see Perea & Pollatsek, 1998, for a similar procedure) and tried to simulate our data pattern. The patterns of data that were predicted when we used the default parameters of the model (and assuming that the preview was presented for two cycles, which is the usual duration to simulate "masked priming" experiments; see Perea & Rosa, 2000) were quite discrepant from the empirical data. Specifically, this version of the model predicted longer identification times for the word neighbor preview than for the nonword neighbor preview, which was independent of the prime/target relative frequency, and it seemed that the only chance of arriving at a prediction reasonably concordant with the data was to (a) increase the weights of the word to letter feedback connections and (b) decrease the weights of the interword competition connections. Our best fit, in terms of explaining the difference across the experiments between the word neighbor preview and the nonword neighbor preview used the following settings. First, the word-letter weights were increased from the default value of .30 to .50 and the word-word inhibition weights were decreased from the default value of .21 to .10. Second, the simulation was shown the preview for four cycles followed by being shown the target until a criterion of .70 was reached. In fact, the predicted difference in time (number of cycles to reach criterion) between the word and nonword previews was greater for the high-frequency neighbor preview (21.2 vs. 21.8 cycles) than for the low-frequency neighbor preview (20.2 vs. 20.4 cycles). Unfortunately, the simulation did not work out well comparing the word neighbor previews to the identical previews (20.3 vs 21.2 cycles for the high-frequency preview and 19.9 vs 20.2 cycles for the low-frequency preview). That is, the predicted pattern, which is not at all our observed pattern, seems best explained by the frequency of the target: preview effects were smaller for high-frequency targets.

Clearly, the results of such a simulation need to be viewed with caution, as such models are highly nonlinear, and one cannot say with any degree of certainty that it cannot explain our data pattern. Nonetheless, it suggests that explaining the pattern of data is not trivial and suggests that a model of the basic form of the McClelland and Rumelhart (1981) model may not be successful. Whether a modification of the activation-verification model would fare better (mainly because it would allow weights to change from L1 to L2) is clearly an open question. Again, what we think the pattern of data indicates is that it is necessary to posit strong word-letter feedback in the early stages of processing.

In summary, the results reported here indicate an interesting effect with respect to the nature of preview benefit in reading. On the one hand, it is "lexical" in that the frequency of a word influences the amount of benefit derived from the preview.[7] On the other hand, the fact that the effect is facilitative rather than inhibitory indicates that the facilitation is not at the lexical level, but rather at a lower level, presumably at the level of letter and perhaps phoneme excitation. More generally, the results suggest a process of word encoding in which (a) the important work in the earlier stages (which begin with parafoveal processing) is fixing letter identities, although excitation of lexical entries is occurring as well and influencing the letter identification process and (b) the important work in the later stages (which largely occur when a word is fixated) is sorting out the competition among lexical entries.

[7] This is not always the case and may be restricted to the situation when the preview and target word are very similar, such as in the present study.

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(*Appendix follows*)

Appendix

Target and Preview Stimuli

High-frequency word	Low-frequency word	Nonword orthographic control	Visual similarity control
faint	flint	foint	ketml
bench	bunch	banch	hsrok
swung	stung	spung	zmorp
grant	giant	glant	qncui
chest	crest	clest	okazl
shook	spook	stook	zbcel
stone	shone	spone	zlerc
thick	trick	twick	lbjef
frame	flame	feame	lnewo
fully	folly	felly	kvtrq
watch	witch	wetch	melob
carry	curry	cerry	eovnp
dance	dunce	donce	beuoc
share	snare	slare	zbenc
speak	steak	sheak	zgceh
daily	doily	deily	betfq
stock	smock	slock	zlceh
heard	hoard	hiard	kcenb
minor	manor	munor	wjucn
taken	token	teken	iehcr
point	print	peint	qcjrl
state	slate	shate	zleic
sweet	sleet	speet	zmcol
shock	shack	sheck	zbeok
brush	brash	brosh	hnvzk
skill	skull	skoll	zbjtf
fifth	filth	finth	ljkib
angle	ankle	andle	emqfc
theme	thyme	thome	ibcno
trace	truce	troce	lneoa
grave	grove	grive	pneuc
beach	bench	beich	hceok
chair	choir	cheir	obetn
metal	medal	mebal	ncief
crest	crust	crast	onczl
porch	pouch	ponch	qcnob
touch	torch	toach	icveb
check	chick	chack	obceh
glass	gloss	gliss	pfezc
hotel	hovel	hokel	bciof
stock	stack	steck	zieoh
paper	pacer	pader	qegcn
river	rider	riner	ntucv
space	spice	spuce	zqeoc
party	patty	pacty	qenlg
water	wager	waler	meicn
whole	whale	whele	vbcto

Note. The low-frequency word was the target in Experiment 1, and the high-frequency stimulus was the target in Experiment 2. Only the stimuli from the first three columns were previews in Experiment 1, but stimuli from all four columns were previews in Experiment 2.

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