Spelling-sound regularity effects on eye fixations in reading

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An interaction of word frequency and word regularity has typically been observed in naming and lexical decision experiments in which, in addition to an overall effect of word frequency, responses to low-frequency exception words are slower than those to low-frequency regular words, while no such difference occurs with high-frequency words. The only eye movement study to examine this effect in reading (Inhoff & Topolski, 1994) reported only transient effects of regularity. In the present experiment, we examined the frequency $\times$ regularity interaction using different stimuli than those of Inhoff and Topolski and also varied the parafoveal preview of the target word prior to fixation. When the preview was valid, the frequency $\times$ regularity interaction appeared. However, with an invalid preview, the effect of regularity disappeared. The results suggest that the activation of phonological codes is a very early component of reading.

How important are spelling-sound regularities in word recognition and reading? Many word recognition studies have shown that spelling-sound regularities influence naming and lexical decision times when target words are presented in isolation (see, e.g., Bauer & Stanovich, 1980; Glushko, 1979; Inhoff & Topolski, 1994; Seidenberg, Waters, Barnes, & Tanenhaus, 1984; Stanovich & Bauer, 1978; Waters & Seidenberg, 1985). Although the pattern of results across studies is somewhat complex (depending on specific characteristics of the stimuli and the task used), the general conclusion is that regularity has little effect on high-frequency (HF) words, but that responses to low-frequency (LF) exception words are slowed relative to LF regular words. Regular words, such as *time*, have predictable pronunciations because all words that end in *ime* rhyme with each other (e.g., *dime* and *slime*). On the other hand, exception words, such as *good*, are not predictable on the basis of their spelling pattern, either because word neighbors that share the *ood* coda (e.g., *food* and *mood*) do not rhyme or, in the case of words like *doubt* or *weird*, that have no such neighbors, the spelling-sound mapping is idiosyncratic. If phonological information is

important in recognizing words, exception words should be more difficult to process than regular words. For HF words, the meaning of the word is apparently accessed from its orthography independent of its phonology; for LF words, phonological information plays a greater, detectable role.

Do these effects generalize to normal reading? Only one study has examined spelling-sound regularities in the context of reading (Inhoff & Topolski, 1994, Experiment 2). Inhoff and Topolski monitored participants' eye movements as they read sentences containing HF and LF regular and exception words. They found robust effects of word frequency: LF words were fixated longer than HF words, a finding consistent with a great deal of prior eye movement research (e.g., Henderson & Ferreira, 1990; Hyönä & Olson, 1995; Inhoff & Rayner, 1986; Just & Carpenter, 1980; Rayner & Duffy, 1986; Rayner & Raney, 1996; Rayner, Sereno, & Raney, 1996; Schilling, Rayner, & Chumley, 1998; Sereno, 1992). Inhoff and Topolski, however, failed to find an interaction between frequency and regularity, as prior naming and lexical decision experiments had. These results merit further investigation.

Inhoff and Topolski examined both first-fixation and gaze duration measures on target words. First-fixation duration is an average of the first fixations made on words, disregarding any additional fixations; gaze duration is the average of the sum of all fixations made on a word prior to an eye movement to another word. While most words are typically fixated only once (in which case first-fixation and gaze duration are the same), gaze duration has generally been favored in eye movement studies as the best estimate of processing time on a word. In their first-fixation data, Inhoff and Topolski found overall effects of frequency and regularity but no significant interaction. The

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pattern of regularity differences, however, did correspond to that of prior word recognition studies: The difference between regular and exception words was 6 msec for HF words and 17 msec for LF words. With gaze duration, they found only a main effect of frequency. The effect of regularity had decreased to 6 msec and did not approach significance. Inhoff and Topolski concluded that effects of phonological regularity were relatively transient. On the other hand, other experiments reported by Inhoff and Topolski provided evidence for the early use of phonology during reading.

In the present study, we examined the interaction between frequency and regularity, but with certain critical changes in stimuli and design from Inhoff and Topolski (1994). Inhoff and Topolski used stimuli from Seidenberg et al.'s (1984) Experiment 3. They chose 10 words from each of the four word conditions (HF regular, HF exception, LF regular, LF exception) and embedded these as targets in separate sentences. These words, however, sampled many different syntactic categories that varied systematically across conditions (e.g., HF words were mostly verbs, with some determiners, whereas LF words were mostly nouns, with some verbs and adjectives). In our study, we used 24 sets of words from the four conditions (mostly nouns and a few verbs and adjectives). Each set of four words appeared within identical sentence frames so that sentence structure and, hence, viewing conditions were controlled across conditions.

Additionally, in our design, we varied whether readers received a valid parafoveal preview of the target word prior to fixating it. Reliable preview effects have been widely demonstrated (Balota, Pollatsek, & Rayner, 1985; Blanchard, Pollatsek, & Rayner, 1989; Inhoff & Rayner, 1986; Kennison & Clifton, 1995; Rayner, 1975; Rayner, Well, Pollatsek, & Bertera, 1982). When participants receive an invalid preview of the to-be-fixated word (i.e., something other than the target initially occupies its location, e.g., a letter string or a string of Xs), their fixation time on that word generally increases by 20–50 msec. Our rationale in using the preview manipulation was to more closely approximate the situation in naming and lexical decision where words presented in isolation are viewed only foveally. With an uninformative preview, more robust regularity effects might emerge, particularly in gaze duration.

METHOD

Participants

Thirty-two members of the University of Massachusetts community were paid \$5 to participate in the experiment. They either had normal, uncorrected vision or wore soft contact lenses. They were all naive concerning the purpose of the experiment.

Apparatus

Eye movements were recorded via a Stanford Research Institute Dual Purkinje Eyetracker (Generation 3), which has a resolution of less than 10 min of arc. Although viewing was binocular, recording was from the right eye. The output of the eyetracker was sampled every millisecond by a 486 computer that was also interfaced to a

Conrac 9317 RGB Auto-Trak monitor on which the sentences were displayed. At a viewing distance of 63 cm, 3 letters subtended 1° of visual angle. All sentences were presented in a nonproportional font on a single line with a maximum of 60 characters. Luminance of the monitor was adjusted to a comfortable level and held constant throughout the experiment. The monitor had a P22 phosphor with the characteristic that display blanking resulted in a drop to 10% of maximum brightness in 0.06 msec for the cyan characters that were used.

Materials

The target words were 24 HF regular words, 24 HF exception words, 24 LF regular words, and 24 LF exception words with average frequencies of 150, 146, 6, and 6 per million, respectively, as computed from the Francis and Kučera (1982) norms. Target words were all 4, 5, or 6 letters long (average = 4.75) and word length was equated across conditions. Sentence frames were prepared so that one of each type of target could be inserted. For example, the sentence frame "*It was a lonely ____ during those eight days.*" could accommodate the HF regular word *race*, the HF exception word *tour*, the LF regular word *hike*, and the LF exception word *isle*. For each set of four targets, four such sentence frames were constructed, giving rise to a total of 96 sentence frames for the 24 sets of targets. A complete listing of the materials appears in the Appendix. The targets for the present experiment were a subset of materials taken from a lexical decision experiment that used 72 sets of HF and LF regular and exception words. In that experiment, a significant frequency $\times$ regularity interaction was obtained (Sereno, Rayner, & Posner, 1998).

Design

The 2 (preview: valid vs. invalid) $\times$ 2 (frequency: HF vs. LF) $\times$ 2 (regularity: regular vs. exception) design gave rise to eight experimental conditions. With a total of 96 sentences, there were 12 items per condition. With a total of 32 participants, there were 4 participants per item per condition. Because there were four possible sentence frames generated for a set of four targets, all participants were presented with all of the target words.

Procedure

When a participant arrived for the experiment, a bite bar was prepared to minimize head movements. The initial calibration of the eyetracking system generally required about 5 min. A calibration display appeared between every trial so that calibration could be checked throughout the experiment. Participants were asked to read sentences as their eye movements were monitored. They were instructed to read for comprehension.

Participants read eight practice sentences to become familiar with the procedure. Prior to reading each sentence, participants looked at the leftmost calibration box, which marked the first character position of the sentence. The experimenter checked to ensure that the participant was fixated there, gave a ready signal, then pressed a button to present the sentence. After reading the sentence, the participant pressed a button for the next trial. Then, either the sequence resumed without interruption or the participant was asked a yes–no comprehension question. After the practice sentences, participants read the 96 experimental sentences. Questions were asked on approximately one third of the trials. Participants had no difficulty answering the questions correctly.

On half of the trials (valid preview trials), the sentences appeared normally with one of the target words in the target location. On the other half of the trials (invalid preview trials), a letter string equal in length to the target initially occupied the target location. The letter string was generated based on the probability that a given letter appears in a given letter position of four-, five-, and six-letter words (Mayzner & Tresselt, 1965). Thus, many of these letter strings, though not all, were somewhat "wordlike." For example, *fhmt*, *ched*, *kesk*, and *nreh* were the preview letter strings used with the *race*, *tour*, *hike*, and *isle* set described above. There was no letter overlap

Table 1
Mean First-Fixation Duration and Gaze Duration
(in Milliseconds) for HF and LF Regular and
Exception Words as a Function of Parafoveal Preview

	Valid Preview		Invalid Preview	
	Regular	Exception	Regular	Exception
First-fixation duration				
LF	267	283	292	294
HF	257	260	283	277
Gaze duration				
LF	281	306	320	326
HF	273	278	303	296

Note—LF, low frequency; HF, high frequency.

between a given preview letter string and its four possible targets. An invisible boundary located between the final letter of the word preceding the target and the space before the target was established in each sentence. When a reader's eye movement crossed this boundary, the letter string was replaced with the appropriate target word (see Rayner, 1975, for a description of the boundary technique). This change was accomplished within 7.7 msec. Because the change took place during the saccade, it was not noticed by the readers. Valid and invalid preview trials were intermixed and the sentences were presented in a different random order to each participant.

RESULTS

We examined first-fixation and gaze duration times on the targets.¹ The target region included the space before the word and the word itself. Data were excluded from analyses for the following reasons: (1) There was a blink or a track loss; (2) the display change was triggered on the word before the target by a momentary intrusion into the target region as a result of dynamic overshoot of the saccade (Becker, 1989); and (3) readers initially or completely skipped the target word. Altogether, 25% of the data were eliminated, leaving 9 data points per condition on average.

First-Fixation Duration

The first-fixation duration data are shown in Table 1. A 2 (preview: valid vs. invalid) $\times$ 2 (frequency: HF vs. LF) $\times$ 2 (regularity: regular vs. exception) analysis of variance (ANOVA) yielded main effects of preview [$F_1(1,31) = 26.50$, $MS_e = 909$, $p < .001$; $F_2(1,95) = 39.83$, $MS_e = 1,907$, $p < .001$] and frequency [$F_1(1,31) = 13.41$, $MS_e = 1,050$, $p < .001$; $F_2(1,95) = 21.80$, $MS_e = 2,063$, $p < .001$]. Readers' first fixations were shorter both when the preview was valid (267 msec) versus invalid (286 msec) and when the target was a HF (269 msec) versus a LF word (284 msec). Both of these results replicate a number of previous studies. The effect of regularity was not significant [$F_1(1,31) = 2.52$, $MS_e = 341$, $p = .12$; $F_2(1,95) = 1.28$, $MS_e = 341$, $p > .25$]. The frequency $\times$ regularity interaction was marginal by participants [$F_1(1,31) = 3.5$, $MS_e = 462$, $p = .07$] and nonsignificant by items [$F_2(1,95) = 1.53$, $MS_e = 2,720$, $p > .25$]. In addition, the preview $\times$ frequency interaction and the three-way inter-

action were both nonsignificant ($F_s < 1$). However, since regularity interacted with preview [$F_1(1,31) = 6.53$, $MS_e = 358$, $p < .05$; $F_2(1,95) = 3.55$, $MS_e = 1,787$, $p = .06$], we examined the valid and invalid preview conditions in separate 2 (frequency) $\times$ 2 (regularity) ANOVAs.

In the valid preview condition, there were significant effects of frequency [$F_1(1,31) = 10.10$, $MS_e = 881$, $p < .01$; $F_2(1,95) = 13.03$, $MS_e = 1,640$, $p < .001$] and regularity [$F_1(1,31) = 9.39$, $MS_e = 321$, $p < .01$; $F_2(1,95) = 5.59$, $MS_e = 1,721$, $p < .05$]. First fixations were shorter for HF (259 msec) than for LF words (275 msec) and shorter for regular (262 msec) than for exception words (272 msec). The frequency $\times$ regularity interaction was marginally significant by participants [$F_1(1,31) = 3.40$, $MS_e = 388$, $p = .07$], but not significant by items [$F_2(1,95) = 1.08$, $MS_e = 1,543$, $p > .30$]. Contrasts revealed that LF regular and exception words differed significantly [267 vs. 283 msec, respectively; $F_1(1,31) = 10.72$, $MS_e = 388$, $p < .01$; $F_2(1,95) = 6.25$, $MS_e = 1,543$, $p < .05$], while no such difference was present with HF words [257 vs. 260 msec, respectively; $F_1 < 1$; $F_2(1,95) = 1.06$, $MS_e = 1,543$, $p > .30$].

In the invalid preview condition, there was a significant effect of frequency [$F_1(1,31) = 4.73$, $MS_e = 1,144$, $p < .05$; $F_2(1,95) = 10.60$, $MS_e = 2,229$, $p < .01$]. Again, first fixations were shorter for HF (280 msec) than for LF (293 msec) words. The effect of regularity was nonsignificant ($F_s < 1$), as was the frequency $\times$ regularity interaction [$F_1(1,31) = 1.09$, $MS_e = 387$, $p > .30$; $F_2 < 1$].

In sum, there were reliable first-fixation effects of preview and frequency. The effect of frequency was independent of preview condition. The overall pattern of the frequency $\times$ regularity results suggests that the advantage for LF regular words (or disadvantage for LF exception words) appeared only when the parafoveal preview was valid.

Gaze Duration

The gaze duration data are also shown in Table 1. A 2 (preview) $\times$ 2 (frequency) $\times$ 2 (regularity) ANOVA again yielded significant main effects of preview [$F_1(1,31) = 30.11$, $MS_e = 1,535$, $p < .001$; $F_2(1,95) = 46.65$, $MS_e = 3,681$, $p < .001$] and frequency [$F_1(1,31) = 22.68$, $MS_e = 1,241$, $p < .001$; $F_2(1,95) = 35.52$, $MS_e = 2,366$, $p < .001$]. Readers' gaze durations were shorter with a valid (284 msec) versus an invalid preview (311 msec) and with a HF (287 msec) versus a LF word (308 msec). Unlike the first-fixation data, the effect of regularity was significant [$F_1(1,31) = 4.93$, $MS_e = 728$, $p < .05$; $F_2(1,95) = 4.30$, $MS_e = 4,081$, $p < .05$], as was the frequency $\times$ regularity interaction [$F_1(1,31) = 5.41$, $MS_e = 769$, $p < .05$; $F_2(1,95) = 4.04$, $MS_e = 2,263$, $p < .05$]. As with the first-fixation data, the preview $\times$ frequency interaction and the three-way interaction were nonsignificant ($F_s < 1$). Regularity interacted with preview in the participants analysis [$F_1(1,31) = 4.85$, $MS_e = 736$, $p < .05$], but was only a trend in the items analysis [$F_2(1,95) = 1.88$, $MS_e =$

3,218, $p = .17$]. Again, we examined the valid and invalid preview conditions in separate 2 (frequency) $\times$ 2 (regularity) ANOVAs.

In the valid preview condition, there were significant effects of frequency [$F_1(1,31) = 10.60$, $MS_e = 1,000$, $p < .01$; $F_2(1,95) = 13.40$, $MS_e = 2,266$, $p < .001$] and regularity [$F_1(1,31) = 12.71$, $MS_e = 563$, $p < .01$; $F_2(1,95) = 9.78$, $MS_e = 2,262$, $p < .01$]. Gaze durations were shorter for HF (275 msec) versus LF words (294 msec) and for regular (277 msec) versus exception (292 msec) words. The frequency $\times$ regularity interaction was significant by participants [$F_1(1,31) = 4.30$, $MS_e = 728$, $p < .05$], and marginally so by items [$F_2(1,95) = 3.05$, $MS_e = 2,293$, $p = .08$]. Contrasts revealed that LF regular and exception words differed significantly [281 vs. 306 msec, respectively; $F_1(1,31) = 13.57$, $MS_e = 728$, $p < .001$; $F_2(1,95) = 11.78$, $MS_e = 2,293$, $p < .001$], while no such difference was present with HF words (273 vs. 278 msec, respectively; $F_s < 1$).

The gaze duration results in the invalid preview condition were similar to those in the first-fixation data. There was a significant effect of frequency [$F_1(1,31) = 16.68$, $MS_e = 1,081$, $p < .001$; $F_2(1,95) = 16.98$, $MS_e = 3,271$, $p < .001$], with gaze durations shorter for HF (299 msec) versus LF words (323 msec). The effect of regularity was not significant ($F_s < 1$), nor was the frequency $\times$ regularity interaction [$F_1(1,31) = 1.61$, $MS_e = 774$, $p > .21$; $F_2 < 1$].

Overall, the gaze duration results were similar to the first-fixation data, with significant effects of preview and frequency. In addition, there was a main effect of regularity. As before, LF exception words were fixated longer than LF regular words only when the parafoveal preview was valid.²

DISCUSSION

The results of the normal reading (valid preview) condition of our experiment are quite consistent with prior word recognition studies that have demonstrated a frequency $\times$ regularity interaction in which, in addition to an overall frequency effect, responses to LF exception words are slower than those to LF regular words (Inhoff & Topolski, 1994; Seidenberg et al., 1984; Waters & Seidenberg, 1985). However, since Inhoff and Topolski obtained similar effects of regularity in naming and delayed naming tasks, they raised the question of whether the naming results can be taken as evidence for early activation of phonological codes. If evidence were found with eye movement data that clearly showed regularity effects in fixation times, there would be good support for the early activation of phonological codes and for the importance of spelling-sound regularity in silent reading. As we noted in the introduction, Inhoff and Topolski's eye movement data were somewhat equivocal: While they did find a reliable main effect of regularity in first fixations, they did not observe a significant frequency $\times$ regularity interaction in their data; in addition, the regularity effect they

obtained in first fixations declined to nonsignificance in their gaze duration data.

Our results clarify the situation somewhat since we found a significant 16-msec difference between LF regular and exception words in first fixations, which increased to a 25-msec difference in gaze duration under similar conditions of normal preview. While the frequency $\times$ regularity interaction was only marginally significant by participants in the first-fixation duration data, it was significant in the gaze duration data. Perhaps the most obvious explanation for why our results differ from Inhoff and Topolski's (1994) has to do with our materials: We used more than twice the number of target items, and our items were better matched across experimental conditions with regard to word class and sentence position.

One result from our study that deserves further explanation was the occurrence of a first-fixation frequency effect on targets in the invalid preview condition. A study reported by Inhoff and Rayner (1986), conceptually quite similar to ours, yielded contrary results. Inhoff and Rayner examined word frequency effects under valid and invalid preview conditions. With a valid preview, they found that LF words were fixated longer than HF words both in first-fixation and gaze duration. However, with an invalid preview, frequency effects were absent from first fixations and appeared only in gaze duration. More recently, Kennison and Clifton (1995) found that, with an invalid preview, readers' first fixations were 15 msec longer on LF words than on HF words (similar to our 13-msec effect). Kennison and Clifton speculated on possible reasons for the difference between their results and those of Inhoff and Rayner. One difference not discussed was the manner in which preview was manipulated across studies. Inhoff and Rayner used a moving window paradigm in which preview was denied: All words to the right of the fixated word were replaced with either Xs or visually similar letters. In contrast, in the present experiment and in Kennison and Clifton's, a boundary paradigm was used in which only a single word of each sentence was altered. Perhaps readers noticed that there was typically inaccurate information to the right of fixation in Inhoff and Rayner's study and applied different processing strategies.

We are left to explain why we obtained evidence for a frequency $\times$ regularity interaction with a valid preview but not an invalid preview. As we noted in the introduction, we anticipated that we might obtain clearer evidence for the interaction in the invalid preview condition since it is arguably more analogous to word recognition studies in which participants do not receive any preview of the word before processing it. However, we obtained just the opposite result. Why might this be?

First, while an invalid preview in reading insures only foveal processing of a target, it may not be comparable to the naming or lexical decision situation, in which participants, presented with a single target, prepare a response to it alone. Henderson, Petersen, Dixon, Twilley, and Ferreira (1995) had participants saccade to a parafoveal letter string. During the saccade, a target for lexical deci-

Table 2
Mean Gaze Duration (in Milliseconds) for HF and
LF Regular and Exception Words as a Function of
the Pronounceability of the Parafoveal Preview
That Occurred in the Invalid Preview Condition

	Valid Preview		Invalid Preview	
	Regular	Exception	Regular	Exception
Pronounceable previews				
LF	281 (279)	307 (301)	325 (322)	317 (327)
HF	278 (273)	274 (280)	292 (300)	306 (298)
Nonpronounceable previews				
LF	282 (287)	305 (312)	320 (322)	340 (338)
HF	270 (272)	282 (278)	310 (309)	300 (308)

Note—Means in parentheses represent gaze durations based on the pronounceability of only the first three letters of the invalid preview. LF, low frequency; HF, high frequency.

sion replaced the string. The targets were words that contained regularly or irregularly pronounced initial trigrams (e.g., *button* or *butane*, respectively). Each target (e.g., *button*) was preceded by three possible parafoveal previews (e.g., *button*, *butane*, or *xxxxxx*). Henderson et al. found that responses to targets with phonologically regular initial trigrams were slowed more by an invalid preview, a finding that is consistent with our results. In our study, the preview $\times$ regularity interaction in both first-fixation and gaze duration indicated that the cost of an invalid preview was greater for regular than for exception words. This is consistent with the notion that phonological processing of a word begins on the prior fixation and a greater degree of such processing occurs when that word has a regular spelling–sound mapping.

Second, there is evidence from reading that phonological codes are activated parafoveally (Pollatsek, Lesch, Morris, & Rayner, 1992). Pollatsek et al. found that readers are able to use phonological codes in integrating information across an eye movement. Specifically, they found that when readers were given a homophone as a preview (e.g., *beech* as a preview for *beach*, or *chute* as a preview for *shoot*), fixation time³ on the target word (*beach* or *shoot*) was facilitated relative to a visually similar spelling control preview (e.g., *bench* or *chart*). Their results indicate that phonological codes for the to-be-fixated word are activated in advance (see also Henderson et al., 1995). These findings, together with other related evidence (Rayner, Pollatsek, & Binder, 1998; Rayner, Sereno, Lesch, & Pollatsek, 1995), lead us to believe that phonological codes are activated early on in the word identification process. In our study, when preview information was invalid, the early activation of phonological codes prior to fixation was spurious and, thus, may have served to neutralize subsequent foveal phonological processing.

In order to test this explanation of the disappearance of the LF regularity effect in the invalid preview condition, we grouped our stimuli on the basis of the pronounceability of the invalid nonword previews.⁴ This partition resulted in one group of 35 target sets associated with pronounceable previews and a second group of 61 target sets asso-

ciated with nonpronounceable previews. The corresponding gaze duration means are shown in Table 2.⁵ An interesting pattern emerged that is consistent with the explanation we provided. Specifically, for the pronounceable previews in the invalid preview condition, there was a significant main effect of frequency but no hint of a frequency $\times$ regularity interaction. However, for the nonpronounceable previews, there was a significant effect of frequency as well as a significant frequency $\times$ regularity interaction. In another analysis, we grouped items based on the pronounceability of the first three letters of the preview. This partition resulted in one group of 57 pronounceable target sets and a second group of 39 nonpronounceable target sets, which yielded the same overall pattern of means (Table 2). Comparison of the LF regular and exception means in the invalid preview condition across the pronounceability groupings suggests that the LF regularity effect with nonpronounceable previews emerges because of a cost associated specifically with LF exception words. Nonpronounceable previews are similar in effect to orthographically and phonologically “strange” words. Just as exposure to “strange” words increases the likelihood of generating LF regularity effects (see, e.g., Waters & Seidenberg, 1985), the presence of nonpronounceable previews on a local level can similarly create greater phonological awareness and subsequent costs in foveal processing of LF exception targets. When nonword previews are pronounceable and generally regular in their orthography and phonology, early phonological processing does not elicit a conflicting influence.

We believe the present experiment has provided clear evidence of the frequency $\times$ regularity interaction in normal reading. First fixations and gaze durations on HF regular and exception words did not differ, but they were significantly longer on LF exception than on LF regular words. When readers were denied parafoveal access to a word, the LF regularity difference disappeared; we provided an account of this in terms of parafoveal phonological processing. We conclude that phonological codes are activated early enough under normal viewing conditions to facilitate reading.

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NOTES

1. Other standard eye movement measures, such as total fixation time (the sum of all fixations on a word, including those from regressions), spillover time (the duration of the fixation immediately following the fixation[s] on the target word), and target skipping rates, were also examined. In general, lexical effects found in these measures dimly mirror those found in first-fixation and gaze duration. We found an overall effect of frequency that was significant in total fixation time and marginal in spillover time. Readers rarely skipped the target in the invalid preview condition; when they did, they immediately regressed to it. In the valid preview condition, there was a marginal effect of frequency with HF words skipped more often than LF words.

2. It was pointed out in the review process that the LF exception word list included a few homophones (e.g., *isle*, *pear*, or *cruise*). It was also pointed out that several "strange" words (i.e., words that are orthographically as well as phonologically irregular; see Seidenberg et al., 1984) were included in the LF exception list (e.g., *yacht*, *feud*, or *choir*). We eliminated these items and performed separate analyses. When an item (e.g., *yacht*) was removed from an analysis, the remaining items from that set (e.g., *shack*, *chair*, and *knife*) were also eliminated. In both analyses, the same pattern of results held for first-fixation and gaze duration as reported for the entire stimulus list.

3. Interestingly, Pollatsek et al. (1992) found a stronger effect on first-fixation than on gaze duration.

4. We thank an anonymous reviewer for suggesting this analysis.

5. In Table 2, when weighted averages across the two groups are taken in each condition, the resulting means represent the item means and are slightly different from the participant means reported in Table 1. It is also relevant to note that there were no differences in the pattern of valid preview means across the two groups; preview pronounceability is an arbitrary division within this condition.

APPENDIX

Experimental sentences and target words. The letter strings in parentheses are the invalid parafoveal previews that initially appeared in the target region on half the trials. The blank indicates one of four possible targets listed to the right. The target conditions are low-frequency (LF) and high-frequency (HF) regular (Reg) and exception (Exc) words.

Experimental Sentences	Target Words			
	LF		HF	
	Reg	Exc	Reg	Exc
Joseph felt rather (gron)___ after the long party.	limp	numb	flat	full
Our hearts were (gavs)___ but our minds were focused.				
I think my brain was totally (tase)___ before that exam.				
The breakup had left Melissa (dand)___ with all that sadness.				
Apparently, those (whle)___ children on the bus were orphans.	meek	deaf	dark	good
It seems that the (lusr)___ ones are rarely recognized.				
Anger had gotten the better of his (civr)___ brother that day.				
Alexander's (vule)___ sister tried to apologize to him.				
The animal's (Ints)___ was bruised from abuse.	rump	hoof	back	foot
The sore on Tam-Tam's (tnam)___ had swollen to twice its size.				
The antelope had an injured (sete)___ from fighting other males.				
The creature could not rest on its (lhir)___ for very long.				
Suddenly, a large (mhtm)___ appeared from nowhere.	crab	wasp	face	bear
It's hard to confront an angry (gpmr)___ without warning.				
We avoided looking right at the (toly)___ because it scared us.				
A happy-looking (thid)___ is not to be trusted.				
We listened for noises coming from the (frls)___ until morning.	dock	tomb	hall	door
Flashes from the shadowy (beih)___ sent shivers up my spine.				
When the (sevt)___ was reopened, we were surprised at the sight.				
After the (oirt)___ was examined, all fears were laid to rest.				
It was a lonely (fhmt)___ during those eight days.	hike	isle	race	tour
Ellen dreamed of an exciting (ched)___ to escape the daily grind.				
An unusual (kesk)___ seemed like a fine alternative to tax forms.				
Many had signed up to go to the scheduled (nreh)___ that weekend.				
At that moment, our trivial (hlvn)___ wasn't fun anymore.	cult	feud	game	work
The officials wanted the disruptive (riam)___ to be terminated.				
The long-lasting (thsg)___ finally ended.				
The newly created (shtr)___ was unpopular with my friends.				
He clutched the thin (beas)___ so hard his knuckles turned white.	cane	wand	club	post
The performer madly swung the long (trlm)___ back and forth.				
Grampa used the wooden (feml)___ to prop up his car hood.				
We found an ancient (fhvh)___ in Aunt Annie's attic.				
Harriet dangled the dirty (tasd)___ in front of his face.	sock	comb	file	shoe
The black (tait)___ had been left in the room.				
Mary returned to retrieve Ken's (latd)___ that was missing.				
There are many uses for an old (kvah)___ if one is inventive.				
When she returned, Sharon's (shle)___ was infested with insects.	fern	pear	land	wood
Wayne found that his precious (thme)___ had been stolen.				
George gave his most valuable (shse)___ to his partner.				
Rebecca sold her best (thie)___ for a cheap price.				
Mr. Thorpe filled the extra (anrd)___ with great purpose.	cask	pint	week	hour
Eric approached the chosen (eutd)___ with trepidation.				
Tony used the entire (grol)___ to no avail.				
Mike wasted the whole (yesm)___ and then regretted it.				
Every little (ovek)___ in this world deserves happiness.	pest	lamb	life	soul
The priest said that even the ugliest (tlis)___ is worth saving.				
My mother would help any lost (brtm)___ if she were able to.				
Reverend Bob said that every (whed)___ shall seek forgiveness.				

APPENDIX (Continued)

Experimental Sentences	Target Words			
	LF		HF	
	Reg	Exc	Reg	Exc
Jason wore those (thlts)___ pants of his to the reception.	peach	plaid	beach	great
The poster with the (shile)___ design on it was on sale.				
The boutique's display of (motso)___ clothes amazed us.				
Donna had spotted that (thirl)___ shirt from across the mall.				
Lori could not get that awful (whuhl)___ stain out of her blouse.	grape	onion	grass	blood
The sinister wizard added a little (shret)___ to his potion.				
The formula required distilled (whdet)___ extract to be potent.				
One small (cmnah)___ smudge on Tom's sleeve proved him guilty.				
We inherited a worthless (leony)___ from our grandmother.	shack	yacht	chair	knife
Such a small (prgln)___ was too expensive.				
Everything but Elliot's (elotd)___ was destroyed in the fire.				
The beautiful (bienh)___ came in handy for the banquet.				
People stepped into the dilapidated (pumse)___ in single file.	shaft	choir	train	court
Floodlights lit up the famous (ntneh)___ for the press.				
The obsolete (atiud)___ had not functioned for years.				
Spectators gathered around the new (femle)___ in anticipation.				
Mother said it was inappropriate to (serwn)___ in public places.	cheer	cough	point	touch
We wanted to (salgs)___ too, but we thought people would stare.				
Whenever we would (rlasd)___ a lot, my brother would giggle.				
If we'd (drase)___ during the performance, we'd be kicked out.				
Kathy could (girtg)___ her boyfriend if she especially wanted to.	blast	shove	reach	doubt
Steve didn't want to really (ctnuy)___ his friend that night.				
If Ted needed to really (alers)___ someone, he'd go to the bars.				
Jim's parents found it hard to actually (taemy)___ their own son.				
The cruel (slouny)___ frightened the children.	hunter	plague	farmer	threat
Such an evil (crevth)___ should be combatted at all costs.				
The imaginary (dhcich)___ suddenly materialized to our horror.				
The strange (refiol)___ had made the community uneasy and afraid.				
The homeless sought out the warm (rmotet)___ on freezing days.	subway	hearth	church	school
The abandoned (blngne)___ was a favorite hangout for the gang.				
The runaway returned to the familiar (tromer)___ that night.				
The brand new (inthlr)___ was finally being used.				
Josh and I will never forget that (whrith)___ where we first met.	summit	cruise	stream	island
The extraordinary (mieltr)___ was the inspiration for the novel.				
The final (haokcn)___ turned out to be the best.				
The dangerous (litneg)___ did not please everyone.				
Jo's remarkable (dreadsd)___ was the subject of much conversation.	temper	wealth	throat	height
Ed's conspicuous (sunitm)___ caused strangers to take note.				
Scott's prominent (crekse)___ was disproportionate.				
The topic of Oliver's (stugnd)___ always seemed to arise.				
Gordon stumbled onto the (shalnr)___ quite accidentally.	casket	trough	market	police
Dick avoided the (feadsn)___ whenever possible.				
The agent even searched the (bumoun)___ for the missing gems.				
We could see the (weatos)___ from behind the bushes.				
Everyone thought that the (tampct)___ was obvious.	stripe	bruise	reason	answer
There was one (thidth)___ that could not be accounted for.				
The peculiar (nicknt)___ caught everyone's attention.				
The original (pomuls)___ faded in due course of time.				