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Phonological Codes and Eye Movements in Reading

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A number of recent studies using eye movement data have yielded evidence suggesting that phonological codes are activated early in an eye fixation. However, experiments reported by M. Daneman and E. Reingold (1993; M. Daneman, E. M. Reingold, & M. Davidson, 1995) yielded data that led them to argue that phonological codes are primarily activated after lexical access has occurred. In this study, 3 experiments were carried out that were conceptually similar to those of M. Daneman and E. Reingold, and the resulting data supported the position that phonological codes are activated very early in an eye fixation.

The extent to which phonological codes are used in accessing the meaning of words during reading has been a topic of considerable debate. Although this issue has provoked a large amount of research (see Rayner & Pollatsek, 1989, for a summary), the results are somewhat mixed. Specifically, the results of some studies have suggested that phonological codes are used in arriving at the meaning of a printed word (Daneman & Stainton, 1991; Perfetti, Bell, & Delaney, 1988; Van Orden, 1987; Van Orden, Johnston, & Hale, 1988), whereas the results of other studies have indicated that they are not (Daneman & Reingold, 1993; Daneman, Reingold, & Davidson, 1995). In the present experiments, eye movement data were used to examine this issue. There are a number of recent relevant eye movement studies that are consistent with the notion that phonological codes are activated early during eye fixations. We first focus on studies by Pollatsek, Lesch, Morris, and Rayner (1992) and by Rayner, Sereno, Lesch, and Pollatsek (1995).

Pollatsek et al. (1992) found that phonological codes are used in integrating information across saccades in reading. They used the boundary paradigm (Rayner, 1975) in which a target location is identified in the text, and a boundary location is specified just to the left of the target location. The boundary location is not visible in the text but is simply a location specified to a computer that samples the eye position on a moment-to-moment basis. Prior to the reader's eye movement crossing the boundary location, an initially displayed stimulus (the *preview*) is presented in the target location. When the reader's saccade crosses the boundary, the computer replaces the initially displayed stimulus with the target stimulus. In the critical condition of the Pollatsek et al. experiment, the preview and the target were homophone pairs (such as *beech–beach* and *shoot–chute*). In the primary control condition, the preview and target stimuli were as visually similar to each other as the two homophones were to each other (such as *bench–beach*). Pollatsek et al. found that fixation times on the target word were shorter when the preview was a homophone of the target than when the preview was the visually similar control, indicating that phonological codes are used in integrating information across saccades in reading. That is, phonological codes extracted from a word before it is fixated appear to be used in identifying the word when it is later fixated (see Henderson, Dixon, Petersen, Twilley, & Ferreira, 1995, for an experiment with similar conclusions).

Rayner et al. (1995) used the "fast priming paradigm" developed by Sereno and Rayner (1992) to investigate the use of phonological information early in an eye fixation. In the fast priming paradigm, the sequence of events for the reader is similar to that which occurs in the boundary paradigm, but the preview is withheld until the beginning of the initial fixation on the target word. A random string of letters initially occupies a target location, and when the reader's eye movement crosses the boundary location, the random string of letters is replaced by a briefly presented prime word. The prime word is then replaced by a target word that remains in the text until the reader finishes reading. Rayner et al. used target words that were homophones (*beach*) and the primes were either (a) the other member of the homophone pair (*beech*), (b) a visually similar word (*bench*), or (c) an unrelated word (*house*). They found phonological priming effects (the difference between the visually similar and homophone primes) and orthographic priming (the difference between the visually similar and unrelated primes) when the primes were presented for 36 ms; when the primes were presented for 24 or 30 ms, there was orthographic priming but not phonological priming. The fact that there was priming at the 36-ms prime duration suggests that phonological codes are available very

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early in a fixation. In addition to the experiments by Pollatsek et al. (1992) and Rayner et al. (1995), Inhoff and Topolski (1994) and Folk and Morris (1995, 1996) have also reported eye movement data that they interpreted as being consistent with the idea that phonological codes are used early in identifying a word during reading.

In contrast to the aforementioned studies that indicate that phonological codes are active very early in identifying a word, Daneman and Reingold (1993, Daneman et al., 1995) concluded that phonological codes enter into the reading process at a later, postlexical, stage. In their experiments, participants read passages of text that contained homophones as their eye fixations were monitored. In the critical conditions, either (a) the correct homophone was present, (b) the correct homophone was replaced by the incorrect homophone (*brake* was present in the text when *break* was appropriate), or (c) a spelling control replaced the correct homophone (*broke* was substituted for *break*). The two key comparisons in the data were (a) the fixation time on the correct homophone versus the fixation time on the incorrect homophone, and (b) the fixation time on the incorrect homophone versus the fixation time on the spelling control. Given that our experiments were an attempted replication of Daneman and colleagues' findings (with additional manipulations), we now outline the logic for interpreting their results as evidence for or against early, prelexical activation of phonological codes.

One plausible pattern of data is that fixation times on the correct homophone are shorter than those on the incorrect homophone and that fixation times on the incorrect homophone and spelling control are equal. Such a pattern of results would indicate that (at least some of the time) the appropriate meaning has been activated prior to the decision to move the eyes to the next word but that the phonological code has not yet been activated at this time. This pattern would thus suggest that accessing the meaning of a word is more rapid than accessing its sound and would be consistent with a view that phonological coding is largely postlexical.

A second plausible pattern of data is that fixation times on the correct homophone are shorter than those on the incorrect homophone, which in turn are shorter than those on the spelling control. This pattern would be fairly inconclusive because it would indicate (a) that the appropriate meaning of the target word has been activated at least some of the time prior to the decision to move the eyes to the next word and (b) that phonological codes have also been activated at this time and are influencing interpretation of the fixated word. Such a pattern of data is consistent with phonological involvement with lexical access (e.g., many forms of dual-access models; Carr & Pollatsek, 1985), but it could also be consistent with a postlexical view in which lexical access precedes the phonological involvement.

A third plausible pattern of data is that fixation times on the correct and incorrect homophones are about equal and less than those on the spelling control. This pattern would suggest that phonological codes have been activated by the time the decision is made to move the eyes to the next word but that orthographic coding has not progressed fully enough to distinguish between homophones. Such a pattern of data would be consistent with a phonological coding model of lexical access (e.g., Van Orden, 1987), which posits a primacy for phonological coding and that direct orthographic analysis is largely a second, "spelling check," stage of lexical access.

Some of the results of Daneman and Reingold (1993) and Daneman et al. (1995) were close to the first idealized pattern, which indicated that phonological involvement comes after orthographic analysis and is likely to be postlexical. They reported a total of four experiments in the two articles,[1] and in all four, they reported significant differences in *gaze duration* (which is the sum of all fixations on a word before the eyes move to another word) between the correct homophone and the incorrect homophone conditions. Only two had comparisons between the incorrect homophone and spelling control conditions, and neither obtained a significant difference between the two conditions, although the effect was about 15 ms in one of the experiments. Assuming that the latter difference was Type I error, Daneman et al. concluded that they had observed the first of the three patterns we described earlier in both of their studies and thus that phonological coding does not affect accessing the meaning of the target word. Their data indicated, however, that homophony had a strong effect later in reading (e.g., it decreased the number of regressions back to the target word); presumably, the correct phonological code allowed the reader to reanalyze the sentence more gracefully to determine what word was intended when the target word was misspelled.[2]

Given the strong evidence for early phonological coding found by Pollatsek et al. (1992), Rayner et al. (1995), Henderson et al. (1995), Inhoff and Topolski (1994), and Folk and Morris (1995, 1996), some resolution of the difference between these studies and the findings of Daneman and Reingold (1993; Daneman et al., 1995) is needed. The present experiments were an attempted replication and further exploration of their paradigm. Like the participants in the experiments by Daneman and Reingold (1993) and Daneman et al. (1995), our participants read text in which homophone target words were present or replaced by either the other member of the homophone pair or by a spelling control word. Our experiments included two other stimulus manipulations: (a) the predictability of the target word given the prior sentence context, and (b) the orthographic similarity of the homophone to the appropriate word. Given Daneman and Reingold's apparently negative findings with respect to early phonological involvement, we hoped to

[1] We are excluding Experiment 2 of Daneman et al. (1995) from consideration here and in the rest of the article because it was a proofreading task: Participants were required to push a button whenever they detected a misspelling. This makes the conditions of this experiment different from all the others of Daneman and Reingold (1993) and Daneman et al. (1995) and the current experiments.

[2] Daneman and Reingold (1993) and Daneman et al. (1995) did not report regressions per se, but the fact that the total fixation time was less in the homophone condition than in the spelling control condition is clearly due to participants' making fewer regressions to the target word in the former condition.

uncover conditions that were more conducive to uncovering early phonological involvement in accessing the meaning of words in reading.

The first stimulus manipulation that we introduced was varying how predictable the target word was from prior context in the passage. The motivation for this was that we thought that top-down processes might defeat spelling-check stages and reveal the involvement of phonological processing in lexical access if there were more contextual support for a target word. Some work using the semantic categorization paradigm suggests that this may be the case. The primary finding in this paradigm relevant to phonological coding is that when participants are first given a category label (e.g., *flower*) and are then asked to judge whether the next word is a category member, they falsely respond "yes" to homophones of category members such as *rows* much more frequently than to spelling controls such as *robs* (Van Orden, 1987; Van Orden et al., 1988). These data were taken to mean that phonological coding is rapid and automatic in accessing the meaning of words. Jared and Seidenberg (1991) subsequently argued, however, that the category label "primed" the category member and that this priming situation was a special case that facilitated early involvement of phonological coding. They showed that the homophone effect described above was significantly attenuated when the category was a "broad" one (e.g., *living thing*) that would not plausibly prime exemplars. Leaving aside the questions of which category condition is a special case or what the exact interpretation of these studies is, the data from the categorization experiments indicate that when the prior material has primed a category exemplar, one observes a clearer indication of early phonological involvement. Although priming is not exactly the same thing as predictability, we took these studies to suggest that we would have a better chance of observing early phonological effects in accessing the meaning of words when the prior context is highly constraining.

Our second manipulation was to vary the orthographic similarity of the homophone pair. The motivation for this was that rapid disambiguation of homophones through a verification process may be rapid only if the homophones are orthographically dissimilar. The experiments of Daneman and Reingold (1993), however, suggested otherwise; they varied orthographic similarity and found it had little effect on the pattern of data.[3] However, in their experiments they used passages in which the target words were generally not predictable, and perhaps orthographic similarity plays a role only in conditions in which the target words are highly constrained.

The primary measure that Daneman and Reingold (1993) used to assess early processing on the target word was the gaze duration on the target word. However, they reported that a similar pattern was obtained when the *first fixation duration* (the duration of the first fixation on a word independent of the number of fixations) was examined; first fixation duration should be an indicant of even earlier processing than gaze duration (Inhoff, 1984; Rayner & Pollatsek, 1987; Rayner, Sereno, Morris, Schmauder, & Clifton, 1989). If one is examining the time course of phonological processing, it would seem advisable to get the earliest measure of processing that is possible. In particular, if there are some circumstances in which phonological coding enters early into lexical processing, but verification stages often take over quickly and indicate to the reader that the incorrect homophone is indeed wrong (as argued by Van Orden, 1987), then one might find evidence for phonological coding with first fixation duration but not gaze duration. As a result, our analyses focus on what are likely to be the measures of earliest processing, first fixation duration and *single fixation duration* (cases when only one fixation is made on a word). However, we also report the gaze duration, as well as a wide variety of measures, to obtain a full picture of the time course of phonological coding in reading.

In short, we hoped that the predictability of the target word and the orthographic similarity of the incorrect homophone to the true homophone would modulate the pattern of phonological code involvement. We expected that under optimal conditions—high predictability and orthographically similar homophones—we would observe a pattern similar to that predicted by a dual route or phonology-first model but would observe a pattern similar to that found by Daneman and Reingold (1993) for orthographically dissimilar and/or low predictable homophones.

In Experiment 1, we embedded the target words in contexts that made one member of the homophone pair highly predictable. Moreover, we did not use spelling controls in Experiment 1. Instead, the focus was on the similarity of the homophone pair. In particular, we were interested in seeing whether we could get evidence for early phonological coding—little difference between correct and incorrect homophones in first fixation duration—in those conditions that we thought would be most conducive for revealing this coding (high predictability and high visual similarity of the homophones). In addition, as indicated earlier, we also examined a number of other measures of the eye movement record. Experiment 2 was a more complete design in which spelling controls were included and in which the predictability of the target word from prior context was varied. Experiment 3 was a replication of Experiment 2, with a different version of the low-predictability condition.

Experiment 1

In Experiment 1, participants read short passages of text that contained either a correct homophone target or an incorrect homophone mate. In addition, as noted earlier, we varied the orthographic similarity of the homophone pairs.

Method

Participants. Thirty-two undergraduate students at the University of Massachusetts at Amherst participated in the experiment. They were either paid or received course credit for their participa-

[3] The homophone pairs used by Daneman and Reingold (1993) and Daneman et al. (1995) were orthographically similar in that they all began with the same letter and most of the pairs had the first two letters in common. Daneman and Reingold's (1993) manipulation of orthographic similarity was to compare same-length pairs (*beat–beet*) to different-length pairs (*wade–weighed*).

Table 1
Example Passages for the Homophone Pair: Brake–Break

High-constraint target	Example
Brake	Kari was nervous for her driving exam. She was doing fine until she came to a turn. She realized that she was going too fast and needed to slam on the *brake* (*break*) to slow down. She slowed down just in time to avoid another car. Despite the bad turn, she still received her license.
Break	Nancy brought her Grandmother an expensive vase when she was on vacation. She wrapped it well so that it wouldn't *break* (*brake*) and sent it in the mail. When her Grandmother received the vase she was delighted at Nancy's thoughtfulness.

Note. The word in italics represents the target word; only one of the two words was present in the text. Also, passages were arranged so that the target word was always in the middle of the line.

tion. They all had normal vision, and they were all naive concerning the purpose of the experiment.

Apparatus. Eye movements were recorded by a Fourward Technologies Dual Purkinje Eyetracker, which has a resolution of less than 10 min of arc. The eyetracker was interfaced with an Epson Equity 2 computer. The position of the eye was sampled every millisecond, and the computer stored data on the duration and location of each fixation for later analysis. The computer was also interfaced with a Sony Trinitron display on which the passages were presented. The display was 61 cm from the participant's eye, and four characters equaled 1° of visual angle. Viewing was binocular, but eye movements were recorded from the participant's right eye. A bite bar was used to eliminate head movements in the experiment.

Materials. Short passages were prepared that were highly constraining of one member of a homophone pair. Table 1 shows two example passages. There were four types of homophone pairs that we refer to as the (a) *first-two-letters-same* (*break–brake*), (b) *first-letter-same* (*bear–bare*), (c) *dissimilar* (*chute–shoot*), and (d) *pseudohomophone* (*brain–brane*) conditions.[4]

Eight pairs of each type of homophone were identified. For each word-homophone pair, two passages were written such that each of the two passages was highly constraining for one member of the pair. Thus, one passage was written in which *break* was highly predictable from the prior context, and one was written in which *brake* was highly predictable. For the word-pseudohomophone pairs, only a single passage was written, in which the word (*brain*) was highly predictable.

To ensure that the passages highly constrained the appropriate target words, a modified cloze procedure was used in which 25 undergraduate students were presented the passages up to the occurrence of the target word and were asked to guess what the next word would be. Passages in which the target words were judged to be the best completion over 60% of the time were then retained and refinements were made to those passages that did not reach this criterion level. The refined passages were then given to another group of participants in the modified cloze task. This process was repeated until all target words were judged to be the best completion at least 60% of the time. Overall, the predictability of the target word was 84%, and the level of predictability did not differ among the conditions. The average word length of the target words was 4.23 letters. The average frequency of the target words according to Francis and Kučera (1982) for first-two-letters-same, first-letter-same, dissimilar, and pseudohomophone conditions were 39, 27, 126, and 85, respectively. Appendix A lists the target words.

Procedure. When a participant arrived for the experiment, the bite bar was prepared and the eyetracking system was calibrated. The calibration period usually lasted less then 5 min. After the calibration was completed, participants were told that they would be given short passages of text to read. They were told that the purpose of the experiment was to determine what people look at as they read. They were also told that some of the passages may contain a misspelled word, but that they should not worry about that and that they should focus on understanding the passage. They were also told that they would periodically be asked to answer comprehension questions about the passages. On approximately one third of the trials, the experimenter asked the participant to release the bite bar and answer a question. Participants had little difficulty answering these questions; the questions were simple true–false questions, and the participants were correct about 90% of the time.

Following the initial calibration, participants read six practice passages before reading the 32 experimental passages. The experimental passages were mixed with 24 filler passages. Appropriate counterbalancing procedures ensured that each participant read only one passage for each homophone pair (with each member of the pair being read equally often).

To make certain that any effects we obtained were not due to participants' spelling deficiencies, a spelling test was administered at the conclusion of the experiment. The experimenter read a homophone target word and then used the word in a sentence. Participants were asked to write down the correct spelling of the word. Participants were initially presented with one member of each of the 32 homophone pairs and then presented with the other member of the 24 word pairs. They spelled the target words correctly 99% of the time; participants clearly knew the correct spelling of each member of the homophone pair.

Results and Discussion

A number of different eye movement measures were examined with respect to the target word: (a) first fixation duration (which is the duration of the first fixation on the word independent of the number of fixations on the word), (b) single fixation duration (which is the fixation duration when only one fixation is made on the word), (c) gaze duration (which is the sum of all fixations on a word prior to moving to another word), (d) total fixation time (which is the

[4] The pseudohomophone condition was included in Experiment 1 because such a condition has been used in many prior studies that examined phonological coding, and we were curious to see whether it would yield results consistent with our other conditions. Because this condition did not yield any interesting conclusions, it was eliminated from subsequent experiments.

Table 2
Fixation Times, Probability of Regression to Target Word, and Probability of Fixating on the Target Word as a Function of Homophone Correctness

	Fixation time measures (ms)				Fixation probability measures	
Meaning of homophone	First fixation duration	Single fixation duration	Gaze duration	Total time	Prob. fixation	Prob. regression
Correct	222	222	229	246	.68	.11
Incorrect	245	249	270	395	.70	.30
Difference	23	27	41	149	.02	.19

Note. Prob. fixation = probability of fixating on the target word; Prob. regression = probability of a regression back to the target word.

sum of all fixations on a word, including regressions), (e) the probability of a regression back to the target word, and (f) the probability of a first pass fixation on the target word.

The region used for computing the probability of fixating on the target word was the letters in the target word and the space preceding the target word. However, because the target words in the study were relatively short, a broader region was used for computing the various fixation time measures if readers did not fixate directly on the target word. Specifically, the region used for computing first fixation, single fixation, gaze duration, and total time was the target word, the space prior to it, and the last three characters of the word preceding it.[5] The rationale for doing this was that readers often identify a short word when they are fixating just to the left of the word (see Rayner & Pollatsek, 1989). In the computations for the mean first fixation duration, mean single fixation duration, and mean gaze duration, only trials on which the target region was fixated on the first pass were included; that is, these means are conditional on the target region being fixated. Approximately 4% of the data were eliminated either because of track losses or because the fixations were shorter than 100 ms; see Morrison (1984) and Rayner et al. (1989) for justifications for eliminating fixations shorter than 100 ms.[6]

A 4 (homophone type) × 2 (correctness) analysis of variance (ANOVA) on each of the dependent variables was carried out. We first discuss the effect of having the correct versus incorrect member of the homophone pair present. Then we discuss the effect of homophone types, followed by analyses focusing on the extent to which readers may have noticed the incorrect spellings as a function of homophone type.

Effect of correct meaning. Table 2 shows the means for all of the dependent variables as a function of whether the target homophone had the correct meaning. To facilitate comparison with the data reported by Daneman and Reingold (1993; Daneman et al., 1995), the means were first collapsed across the type of homophone. ANOVAs on these data, using both subjects (F_1) and items (F_2) as random effects, yielded significant differences as a function of the correctness of the meaning of the homophone on all of the measures, except the probability of fixating on the target word (Fs < 1): for first fixation duration, $F_1(1, 31) = 15.84$, $MSE = 534$, $p < .001$, and $F_2(1, 31) = 9.30$, $MSE = 910$, $p < .01$; for single fixation duration, $F_1(1, 31) = 19.10$, $MSE = 611$, $p < .001$, and $F_2(1, 31) = 8.30$, $MSE = 1{,}405$, $p < .01$; for gaze duration, $F_1(1, 31) = 17.98$, $MSE = 1{,}496$, $p < .001$, and $F_2(1, 31) = 20.34$, $MSE = 1{,}322$, $p < .001$; and for total time, $F_1(1, 31) = 48.58$, $MSE = 7{,}312$, $p < .001$, and $F_2(1, 31) = 50.98$, $MSE = 6{,}968$, $p < .001$.

To summarize these global analyses, the presence of the incorrect member of the homophone pair resulted in longer fixation times on the target word for all of the fixation time measures. In addition, there were more regressions back to the target word when the incorrect member of the pair was present in the text, $F_1(1, 31) = 24.90$, $MSE = 232$, $p < .001$, and $F_2(1, 31) = 25.10$, $MSE = 230$, $p < .001$. These analyses, then, are consistent with those reported previously by Daneman and Reingold (1993). On the basis of these analyses, one would be tempted to conclude that phonological coding occurs late in processing even in conditions when the target words were highly predictable. However, closer examination of the data as a function of the type of homophone revealed some striking exceptions to the overall pattern presented in Table 2.

Effects of orthographic similarity. Table 3 shows the fixation time measures on the target word as a function of correctness and homophone type. For first fixation duration and single fixation duration, the ANOVAs revealed a significant interaction of correctness and homophone type (Fs > 3.36, ps $< .05$). To clarify this interaction, we carried out separate analyses for each homophone type for first fixation duration and single fixation duration. As seen in Table 3, for these two measures, in the first-two-letters-same condition, fixation times were actually a little shorter in the

[5] In calculating both the probability of a regression and total time, all instances on which the target region were fixated as a result of regressive fixations were counted, not just those on which a regression immediately preceded the fixation on the target word. In addition, it is important to note that in the experiments reported here, the pattern of means was the same when the expanded region was used and when the means were conditional on the word being fixated.

[6] Fixations that were shorter than 100 ms but were either preceded or followed by another fixation on the target word were included in the analyses. Thus, only fixations shorter than 100 ms in isolation were eliminated for the data analyses.

Table 3
Fixation Times (in Milliseconds) on the Target Word as a Function of Homophone Type and Correctness

	Measure of reading			
Condition	First fixation duration	Single fixation duration	Gaze duration	Total time
First two letters same				
Correct	231	232	231	245
Incorrect	227	230	266	418
Difference	−4	−2	35	173
First letter same				
Correct	221	222	228	240
Incorrect	239	245	254	316
Difference	18	23	26	76
Dissimilar				
Correct	229	228	241	274
Incorrect	266	262	287	420
Difference	37	34	46	146
Pseudohomophone				
Correct	207	205	215	226
Incorrect	247	251	280	428
Difference	40	46	65	202

incorrect homophone condition than in the correct homophone condition (though ts < 1). In the first-letter-same condition, although there were slightly longer fixation times for the incorrect homophones, none of the effects approached significance (all $ps > .30$). In contrast, for the dissimilar and pseudohomophone conditions, there were highly reliable differences between the correct and incorrect homophones for both measures, $t_1(31) = 4.78, p < .001$, and $t_2(7) = 2.95, p < .05$, for the dissimilar condition, and $t_1(31) = 3.15, p < .01$, and $t_2(7) = 2.91, p < .05$, for the pseudohomophone condition. For gaze duration and total time, the difference between the correct and incorrect homophones was significant for all homophone types (all $ps < .01$).

The most interesting result from these analyses is that there was no difference in first fixation duration or single fixation duration between the correct and incorrect homophone conditions when the two members of the homophone pair were most orthographically similar (the first two letters same condition). This indicates that when the two members of the homophone pair were orthographically similar, the readers did not initially notice that the incorrect member of the pair was present in the sentence. (The difference between the correct and incorrect homophones was not significant for the first-letter-same condition, suggesting that readers noticed the difference on only a small percentage of the trials in this condition.) In contrast, the gaze duration and total time measures yielded significant differences between these conditions, indicating that even though the difference in meaning was not noticed initially for the orthographically similar conditions, it was noticed a bit later on some trials, even on the first-pass processing of the target word.

The failure to find a difference between the correct and incorrect homophone conditions, however, does not necessarily implicate phonological coding. Perhaps if two words are orthographically similar enough, the discrepancy will not be picked up early enough to affect the duration of the first fixation even if the words are not homophones. This concern is addressed in Experiments 2 and 3.

Fixation pattern analyses. To get a better handle on the frequency with which readers gave no evidence of having noticed the incorrect member of the homophone pair, we carried out additional analyses involving the frequencies of various fixation patterns (see Table 4). In columns 2 and 3 are measures of fixation patterns on the *first pass* (i.e., before the eye goes further than the target word): the probability of fixating the target word and its complement (the probability of skipping the target word) and the probability of making a single fixation. In the right-hand three columns are measures of whether readers needed to do *second-pass* processing (i.e., regress back to the target word). Because our focus is on those trials in which there was no evidence of disruption from the incorrect member of the pair, we report the instances on which they did not regress. In particular, we report the joint probability of fixating once and not regressing, the joint probability of skipping the target word and not regressing, and the sum of those two probabilities. These events are important because they indicate the percentage of times that readers showed no indication of processing difficulty after leaving the target region.[7]

As seen in Table 4, there was little difference between

[7] It should be noted that our skipping rates are much higher than those of Daneman and Reingold (1993), who reported that the target words were skipped less than 1% of the time. Their finding that relatively short words are virtually never skipped is at variance with much of the reading literature and could be because of either (a) the fact that their text was quite large (about two characters per degree) or (b) their passages were longer and more complex than ours, thus requiring more careful reading. Their fixation duration measures, however, are similar to those in most other studies (and ours).

Table 4
Fixation Patterns for Target Words as a Function of Similarity Between Homophones

	Fixations on target word		Nonregressions back to target		
Condition	Prob. of fixating target word[a]	Prob. of a single fixation on target word	Prob. of a single fixation on target and no regression back to it	Prob. of skipping target and no regression back to it	Prob. of either a single fixation or a skip and no regression back to target
First two letters same					
Correct	.69 (.31)	.68	.62	.23	.85
Incorrect	.71 (.29)	.67	.33	.08	.41
First letter same					
Correct	.66 (.34)	.62	.55	.30	.85
Incorrect	.65 (.35)	.61	.32	.17	.49
Dissimilar					
Correct	.71 (.29)	.66	.57	.23	.80
Incorrect	.75 (.25)	.70	.33	.05	.38
Pseudohomophone					
Correct	.65 (.35)	.63	.59	.19	.78
Incorrect	.69 (.31)	.61	.28	.01	.29

Note. Prob. = probability.
[a]Probability of skipping in parentheses.

correct and incorrect homophones in the first-pass fixation probabilities on the target word. In particular, there was virtually no difference in the probability of a single fixation in any of the conditions. There was a marked difference between correct and incorrect homophones, however, in the frequency of regressions. As shown in the rightmost column of Table 4, readers fixated the target word at most once and did not regress back to it 82% of the time when the correct homophone was present in the text, in contrast to 42% of the time when the incorrect homophone was present. Thus, readers were much more likely to regress when the incorrect homophone was present, indicating that they noticed the incorrect homophone on a reasonable percentage of the trials and regressed back to the target region to help repair the damage. As seen in Table 4, there were marked differences in the number of regressions for all levels of orthographic similarity.

Because there was little difference between the correct and incorrect homophones for the first-two-letters-same and first-letter-same conditions in either (a) the probability of making a single fixation on the target word or (b) the single fixation duration, we can infer that readers did not notice that an incorrect member of the homophone pair was present in the text at the time of the fixation on the target word or the decision to skip the target word. Moreover, because readers failed to regress back to the target region almost half of the time in these conditions, we can infer that on about half of the trials readers processed the sentence as well with the incorrect homophone as with the correct homophone.

Using the same logic and procedure with the dissimilar and pseudohomophone conditions is somewhat problematic because there were significant single fixation duration differences between the correct and incorrect homophones. However, even in these conditions, it seems reasonable to assume that readers did not notice the incorrect homophone on some percentage of the trials.

In summary, the data of Experiment 1 were consistent with results reported by Daneman and Reingold (1993; Daneman et al., 1995) either (a) when collapsed across the type of homophone or (b) when the analysis was restricted to gaze durations and total time measures. That is, there was a significant difference between the correct and incorrect homophone. However, more fine-grained analyses revealed that when the target word was both predictable from the prior text and the incorrect member of the homophone pair was orthographically similar to the correct member, the first fixation and single fixation durations did not differ between the correct and incorrect homophones. Because gaze duration and total time did differ, it is clear that on some trials readers became aware of the discrepancy. The fixation pattern analyses revealed, however, that on 41% and 49% of the trials (for the first-two-letters-same and first-letter-same conditions, respectively), there was little indication that the incorrect homophone was ever noticed.

Experiment 2

The data of Experiment 1 suggest that phonological coding occurs early in the processing of a word because the incorrect homophone was apparently not noticed about half of the time when it was orthographically similar to the correct homophone. However, this finding is qualified by two considerations. First, as we mentioned earlier, Experiment 1 had no control for visual similarity. That is, there was no direct evidence from Experiment 1 that indicates that the failure to notice the incorrect spelling was dependent on homophony; perhaps a similar result would have been obtained even if the words were not homophones.

To remedy this problem, we included a spelling control condition in the design of Experiment 2. In the spelling control condition, the target word was replaced with a word that was as orthographically similar to the target as was the homophone in the incorrect homophone condition. Thus, if *shoot* was the target, it was replaced by either *chute* (incorrect homophone condition) or *chart* (spelling control). Because both the incorrect homophone and spelling control substitutions were intended to yield words that were anomalous in the context, the pseudohomophone condition from Experiment 1 was dropped because we did not want too many anomalous trials.

Another qualification on the finding of Experiment 1 is that the target words were highly constrained by the preceding context. As indicated earlier, this was done intentionally to maximize the likelihood that readers would not notice the incorrect member of the homophone pair. However, it still leaves open the question of whether the incorrect homophone would be noticed when it was less predictable. Thus, in Experiment 2, the extent to which the context constrained one member of the homophone pair was also manipulated; on half of the trials, the target word was highly constrained by the context, whereas on the other half of the trials, the target word was embedded in an unpredictable context.

Method

Participants. Eighteen undergraduate students at the University of Massachusetts at Amherst participated in the experiment for either money or course credit. They had normal uncorrected vision, were naive regarding the purpose of the experiment, and had not participated in Experiment 1.

Apparatus. The apparatus was identical to that used in Experiment 1.

Materials. Twenty-seven pairs of homophones were used in the experiment. For each pair, spelling control words were identified that were as orthographically similar to the correct target word as was the incorrect member of the homophone pair. In some cases, to match for orthographic similarity it was necessary to use two different words as the spelling control (see Appendix B). Thus, for example, when *bear* was the correct homophone, *bare* was the incorrect homophone and *barn* was the spelling control; when *bare* was the correct homophone, *beer* was the spelling control. Three levels of orthographic similarity for the homophones and their spelling controls were used: first two letters same, first letter same, and dissimilar. Thus, there were 9 pairs of homophones for each of the three similarity levels.

For each member of a homophone pair, a passage that was highly predictable or constraining of each member of the homophone pair was used (taken from Experiment 1), and two additional passages were prepared (one for each member of the homophone pair) in which the target homophone was not constrained by the prior context. Thus, four passages were prepared for each homophone pair; for each member of a homophone pair, there was a passage that was highly constraining of the target word and one that was neutral (i.e., low constraint). Counterbalancing procedures ensured that each participant saw a passage in which each member of a homophone pair was the correct target: They saw a constrained passage for one member of the pair and an unconstrained passage for the other member of the pair, but the target word they saw (the correct, incorrect homophone, or spelling control word) was counterbalanced across subjects. The combination of 18 homophone targets (9 pairs) with 2 levels of constraint (high versus low) and 3 different target words (correct homophone, incorrect homophone, and spelling control) meant that there were 108 different passages. Thirty-six filler passages were interspersed among the experimental passages. These passages were narratives that were roughly equated in length to the experimental passages.

The mean predictability of the target word in the high-constraint passage was .86, compared with .03 in the low-constraint passage (as determined by norms collected from 15 undergraduate students), and the level of predictability did not differ among the orthographic similarity conditions. The average word length of the target words was 4.15 letters. The average word frequencies for the homophones and the spelling controls were as follows: for first two letters same, 40 and 48; for first letter same, 42 and 51; and for dissimilar, 267 for the homophones (but when an outlier value was removed, the average frequency was 121) and 111 for the spelling controls. Table 5 presents examples of high- and low-constraint passages. The complete set of words is listed in Appendix B.

Procedure. The procedure was the same as in Experiment 1. Following the initial calibration, each participant read 10 warm-up passages, followed by 108 experimental passages that were mixed with 36 fillers. As in Experiment 1, participants were asked comprehension questions after 33% of the passages; they had little trouble answering these questions and were typically correct about 90% of the time. Also, as in Experiment 1, a spelling check was completed at the end of the experiment, and participants were able to correctly spell the appropriate homophone 99% of the time.

Results and Discussion

The data were analyzed in the same way as in Experiment 1. Four percent of the data were lost because of track losses or short fixations (i.e., less than 100 ms) on the target word. A series of 2 (constraint: high vs. low) × 3 (correctness: correct, incorrect homophone, spelling control) × 3 (homophone type: first two letters same, first letter same, and dissimilar) ANOVAs were carried out on (a) first fixation duration, (b) single fixation duration, (c) gaze duration, (d) total time, (e) probability of fixating the target word, and (f) regressions to the target word.

Although the more important manipulation of the experiment was the introduction of the spelling control condition, we first discuss the effects of the constraint manipulation. A problem that emerged after the data were collected was that the low-constraint condition did not yield much interesting data because the constraint was low enough that the incorrect homophone (and the spelling control) words were often not perceived as being inconsistent with the prior context when fixating the target word. In this case, one would expect little disruption from either condition when the target word was fixated but then get disruption subsequently (when the text following the target word would become anomalous given either the incorrect homophone or the spelling control word in the target position). One might expect, however, that reanalysis of the sentence would be easier in the incorrect homophone condition than in the spelling control condition. This is essentially the pattern that was observed in the low-constraint condition; however, it may say little about whether phonological coding occurs early in the word-identification process.

Effects of constraint. To simplify the presentation of the constraint manipulation, we collapsed the data for the correct homophone, incorrect homophone, and spelling controls in the high- and low-constraint conditions over orthographic similarity (see Table 6). Examination of the

Table 5
Examples of High- and Low-Constraint Passages

Target	Example
High constraint	
Serial	Murderers who kill many people according to a pattern are referred to as *serial* (*cereal, verbal*) killers. Those who kill many people at the same time are referred to as mass murderers.
Cereal	Breakfast is the most important meal of the day. Even a cold bowl of *cereal* (*serial, verbal*) is better than nothing at all.
Low constraint	
Serial	Most psychology experiments are interesting. In an exercise of *serial* (*cereal, verbal*) recall one must recall all of the items in the order in which they are presented.
Cereal	Craig got up early this morning. He was in the mood for some *cereal* (*serial, verbal*) but he was out of milk. He was too tired to go to the store so he had toast instead.

Note. The word in italics represents the target word; only one of the three words was present in the text. Also, passages were arranged so that the target word was always in the middle of the line.

data revealed that the high-constraint condition typically resulted in shorter first pass fixations on the target word than did the low-constraint condition. The difference was significant ($ps < .05$) for all of the initial fixation duration measures (first fixation, single fixation, and gaze duration), except for F_1 for single fixation duration. Constraint also influenced the probability of fixating on the target word: Readers fixated on the high-constraint target word 67% of the time versus 73% for the low-constraint target word, $F_1(1, 17) = 6.82$, $MSE = 456$, $p < .01$, and $F_2(1, 53) = 7.53$, $MSE = 406$, $p < .01$. These data are consistent with prior research that has demonstrated differences in first pass fixation time and the probability of fixating a word as a function of contextual constraint (Altarriba, Kroll, Sholl, & Rayner, 1996; Balota, Pollatsek, & Rayner, 1985; Ehrlich & Rayner, 1981; Rayner & Well, 1996).

Finally, with respect to the first-pass effects, when the target word was in a low-constraint context, the means of the correct and incorrect homophone and spelling control conditions did not differ significantly from each other. Indeed, for all of the first pass measures, there was a significant interaction ($Fs > 4.22$, $ps < .05$) of Constraint × Correctness. This is consistent with the hypothesis that when the target word was encountered in a low-constraint context, readers often could not determine if the word was appropriate or anomalous at that point because any of the three target words could have fit with the prior context.

Turning now to the second pass effects, the probability of regressing to the target word and the total time readers spent on the target words were both strongly influenced by the level of constraint. Readers regressed more frequently into the target word when it was in a low-constraint sentence

Table 6
Fixation Times (in Milliseconds), Probability of Fixating on the Target Word, and Probability of Regressing Back to the Target Word as a Function of Homophone Correctness and Constraint

	Fixation time measure				Fixation probability measure	
Condition	FFD	SFD	Gaze	TT	Prob. fix.	Prob. reg.
High constraint						
Correct homophone	236	240	250	273	.65	.05
Incorrect homophone	250	256	269	340	.69	.24
Spelling control	266	278	294	444	.67	.37
Incorrect–correct	14	16	19	67	.04	.19
Control–incorrect	16	22	25	104	−.02	.13
Low constraint						
Correct homophone	259	274	278	326	.72	.14
Incorrect homophone	261	273	282	409	.72	.32
Spelling control	270	278	292	522	.76	.39
Incorrect–correct	2	−1	4	83	.00	.18
Control–incorrect	9	5	10	113	.04	.07

Note. FFD = first fixation duration; SFD = single fixation duration; TT = total time; Prob. fix. = probability of fixating on the target word; Prob. reg. = probability of a regression back to the target word.

(28% of the time) than when it was in a high-constraint sentence (22%), $F_1(1, 17) = 12.91$, $MSE = 267$, $p < .01$, $F_2(1, 53) = 4.33$, $MSE = 717$, $p < .05$, and the total time that readers fixated on the target word was considerably greater when the word was in a low-constraint sentence (418 ms) than in a high-constraint sentence (354 ms), $F_1(1, 17) = 24.80$, $MSE = 13{,}292$, $p < .001$, $F_2(1, 53) = 30.15$, $MSE = 15{,}292$, $p < .001$. These data are consistent with the hypothesis that readers in the low-constraint condition were less often aware of the anomaly of the sentence when they fixated the target word than they were in the high-constraint condition. Because they had to rely on later context more often to identify the anomaly, there was greater cost in reanalyzing the sentence to determine what was intended than when the prior context indicated what word was intended. However, as can be seen in Table 6, the total time spent on the word was much less when the incorrect homophone was present than when the spelling control was present, even in the low-constraint condition, indicating that repair of the sentence was easier when the incorrect and correct words sound the same. This latter conclusion is in complete agreement with that of Daneman and Reingold (1993).

To summarize, it appears that readers in the low-constraint condition often integrated a correctly encoded version of either the incorrect homophone or the spelling control into the sentence at the time the target word was fixated (as indicated by approximately equal processing times and fixation probabilities on the first pass). Because the succeeding context made the sentence anomalous with these encodings, there was significant disruption later on, and this disruption was even greater than in the high-constraint condition. However, if the target word was a homophone, reanalysis of the sentence was facilitated. As indicated earlier, the overall differences between the correct homophone, incorrect homophone, and orthographic control conditions on first-pass measures were not significant. As a result, our subsequent discussion primarily focuses on the high-constraint condition. It is worth noting, however, that the pattern of first-pass fixation durations for the low-constraint data suggests that there was a small disruption in the control condition and none in the incorrect homophone condition, consistent with early phonological coding in this condition.

Effects of correct meaning and homophony. As in Experiment 1, the correctness of the target word had a significant effect for most first pass fixation time measures. Averaged over high- and low-constraint conditions, there were significant differences among the correct and incorrect homophone and spelling control condition for first fixation duration, $F_1(2, 34) = 12.93$, $MSE = 797$, $p < .001$, and $F_2(2, 106) = 6.47$, $MSE = 1{,}583$, $p < .01$; for single fixation duration, $F_1(2, 34) = 4.55$, $MSE = 2{,}778$, $p < .05$, and $F_2(2, 106) = 3.44$, $MSE = 3{,}158$, $p < .05$; and for gaze duration, $F_1(2, 34) = 12.62$, $MSE = 2{,}048$, $p < .001$, and $F_2(2, 106) = 7.73$, $MSE = 2{,}959$, $p < .001$. In addition, as in Experiment 1, there was little effect of the correctness of the target word on the probability of a first-pass fixation on the target word (Fs < 1).

Also, as in Experiment 1, the correctness of the target word strongly influenced later processing of the sentence. There were large and significant effects of correctness on regression probability, $F_1(2, 34) = 33.47$, $MSE = 675$, $p < .001$, and $F_2(2, 106) = 46.39$, $MSE = 484$, $p < .001$, and on total time, $F_1(2, 34) = 24.79$, $MSE = 35{,}512$, $p < .001$, and $F_2(2, 106) = 63.72$, $MSE = 14{,}810$, $p < .001$.

As was the case in Experiment 1, closer examination of the data indicated that on many trials when the homophone pairs were orthographically similar to each other, readers did not notice the irregularity, and thus they identified the word on the basis of its phonological code. Although the main effect of orthographic similarity was not significant, the interaction between it and constraint was significant for most of the first-pass fixation duration measures: first fixation duration, $F_1(2, 34) = 3.54$, $MSE = 1{,}496$, $p < .05$, and $F_2(2, 51) = 2.99$, $MSE = 1{,}602$, $p < .06$; single fixation duration, $F_1(2, 34) = 4.74$, $MSE = 3{,}380$, $p < .05$, and $F_2(2, 51) = 2.93$, $MSE = 2{,}018$, $p < .06$; and gaze duration, $F_1(2, 34) = 5.64$, $MSE = 2{,}986$, $p < .01$, and $F_2(2, 51) = 5.13$, $MSE = 2{,}969$, $p < .01$. As can be seen in Table 7, the general pattern is that fixation durations for the incorrect target words generally increase with increasing orthographic dissimilarity for the high-constraint condition but that the pattern is essentially random for the low-constraint condition. As in Experiment 1, we carried out more specific analyses as a function of homophone type.

Effects of orthographic similarity. The important point to be gleaned from the analyses of homophone type in the high-constraint condition is that the results replicated those of Experiment 1. For the first-two-letters-same condition, in the high-constraint condition, there was no reliable difference between the correct and incorrect homophone conditions for either first fixation or single fixation duration (ts < 1). However, these two conditions each differed from the spelling control condition: For the correct condition versus the spelling control, $t_1(17) = 2.55$ and 2.77, $p < .05$, and $t_2(17) = 3.11$ and 2.89, $p < .05$, for first and single fixation duration, respectively; for the incorrect homophone condition versus the spelling control, $t_1(17) = 2.28$ and 2.85, $p < .05$, and $t_2(17) = 2.94$ and 2.72, $p < .05$, for first fixation and gaze duration, respectively. On the other hand, for the gaze duration measure, the difference between the correct and incorrect homophone condition was significant, $t_1(17) = 2.21$, $p < .05$, and $t_2(17) = 2.16$, $p < .05$. In the low-constraint condition, the only difference that was either significant or approaching significance was between the correct and spelling control conditions, $t_1(17) = 2.71$ and 2.33, $p < .05$, and $t_2(51) = 1.89$ and 1.77, $p < .10$, for first fixation and gaze duration, respectively.

The pattern in the high-constraint condition for the first letter same condition was quite similar (see Table 7). For first fixation and single fixation duration, the correct condition did not differ from the incorrect homophone condition, whereas it did differ from the spelling control conditions (ps $< .05$). Unlike the first-two-letters-same condition (and Experiment 1), there was no significant difference in gaze duration between the correct and incorrect homophone condition ($t < 1$), and the difference between the correct and

Table 7
Fixation Times (in Milliseconds) as a Function of Homophone Correctness and Similarity of Homophone Pair

Condition	High constraint				Low constraint			
	FFD	SFD	Gaze	TT	FFd	SFD	Gaze	TT
First two letters same								
Correct homophone	234	234	240	266	251	275	268	321
Incorrect homophone	239	239	261	323	262	280	285	446
Spelling control	268	281	293	386	277	288	289	491
Incorrect–correct	5	5	21	57	11	5	17	125
Control–incorrect	29	42	32	63	15	8	4	45
First letter same								
Correct homophone	236	246	249	275	272	284	290	335
Incorrect homophone	247	255	258	311	256	269	283	378
Spelling control	253	267	271	404	276	275	298	500
Incorrect–correct	11	9	9	36	−16	−15	−7	43
Control–incorrect	6	12	13	93	20	6	15	122
Dissimilar								
Correct homophone	243	239	259	277	255	262	278	322
Incorrect homophone	267	273	289	386	264	271	278	404
Spelling control	277	287	318	542	257	270	289	574
Incorrect–correct	24	34	30	109	9	9	0	82
Control–incorrect	10	14	29	156	−7	−1	11	170

Note. FFD = first fixation duration; SFD = single fixation duration; TT = total time.

spelling control was only marginally significant, $t_1(17) = 1.88$, $p < .10$, and $t_2(17) = 1.78$, $p < .10$. None of the differences between conditions for either first, single, or gaze duration were significant in the low-constraint condition.

In the dissimilar condition, however, the pattern was somewhat different because the correct condition differed from the incorrect homophone condition, $t_1(17) = 2.14$, 2.19, and 2.42, and $t_2(17) = 2.33$, 2.23, and 2.36 (all $ps < .05$), for first, single, and gaze duration, respectively. Likewise, the correct condition differed from the spelling control condition on all three measures (all $ps < .05$). The difference between the incorrect homophone and spelling control was significant only in the gaze duration measure, $t_1(17) = 2.65$, and $t_2(17) = 2.39$ ($ps < .05$). For the low-constraint condition, none of the pairwise comparisons were significant.

In total time, there were large differences between all conditions. For the sake of brevity, we do not discuss the results in any detail. However, as should be obvious from an examination of Table 7, all pairwise comparisons between the correct and incorrect homophone and spelling control yielded significant differences for both the high-constraint and low-constraint situations (all $ps < .05$). Thus, as we argued before, when regressions on the target word were included in the data analysis, clear effects of homophony and constraint emerged.

Analyses of patterns of fixations. The same measures were computed as in Experiment 1, and the results can be seen in Table 8. As in Experiment 1, the most relevant column is the last one, the measure of the extent to which readers made a single fixation on the target or skipped the target and then did not make a regression to the target word. Most importantly, as in Experiment 1, in the high-constraint condition, readers made at most a single fixation on the incorrect homophone target word and then did not regress about 40% of the time in the first-two-letters-same and first-letters-same conditions. Because the fixation times in these conditions differed little, it appears that the incorrect homophone had virtually no effect on about 40% of the trials, suggesting that the readers proceeded through the text on the basis of the target word having the right sound on a significant fraction of the trials. In contrast, readers made at most a single fixation and did not regress on only about 20% of the trials in the orthographically comparable spelling control conditions, indicating that the effect was not merely due to orthographic similarity. (Initial fixation times were also longer in these conditions as well.)

Two other results are of interest. First, readers in the high-constraint incorrect homophone condition avoided regressing more in the first-two-letters-same and the first-letter-same conditions (.34 and .46) than in the dissimilar condition (.23); in addition, the latter value is no higher than in its spelling control condition. This suggests that when the homophones are orthographically dissimilar, it is harder for the phonological code to facilitate reanalysis of the sentence (see Daneman & Reingold, 1993, for a similar finding). Second, it is interesting that this regression measure shows an effect of constraint: The three high-constraint correct conditions have a value of approximately .78, whereas the low-constraint correct conditions have a value of approximately .56. This indicates that constraint not only facilitates the first-pass processing of a word but also minimizes the need to reanalyze that region of the text.

The data from the high-constraint conditions of Experiment 2 then are consistent with the data from Experiment 1: When the context is highly constraining, initial fixation times and probability of skipping the word suggest that roughly 40% of the time readers did not notice the incorrect member of the homophone pair. When gaze duration and

Table 8
Fixation Patterns for Target Words as a Function of Similarity Between Homophones and Constraint

	Fixations on target word		Nonregressions back to target		
Condition	Prob. of fixating target word[a]	Prob. of a single fixation on target word	Prob. of a single fixation on target and no regression back to it	Prob. of skipping target and no regression back to it	Prob. of either a single fixation or a skip and no regression back to target
High constraint					
First two letters same					
Correct	.64 (.36)	.62	.49	.27	.76
Incorrect	.70 (.30)	.64	.26	.08	.34
Spelling control	.66 (.34)	.63	.16	.00	.16
First letter same					
Correct	.58 (.42)	.52	.39	.33	.72
Incorrect	.64 (.36)	.60	.26	.20	.46
Spelling control	.62 (.38)	.57	.17	.05	.22
Dissimilar					
Correct	.72 (.28)	.63	.60	.19	.79
Incorrect	.74 (.26)	.65	.23	.00	.23
Spelling control	.72 (.28)	.60	.22	.00	.22
Low constraint					
First two letters same					
Correct	.64 (.36)	.59	.33	.22	.55
Incorrect	.67 (.33)	.61	.25	.00	.25
Spelling control	.83 (.17)	.75	.19	.00	.19
First letter same					
Correct	.75 (.25)	.65	.42	.12	.54
Incorrect	.70 (.30)	.65	.13	.05	.18
Spelling control	.67 (.33)	.61	.01	.01	.02
Dissimilar					
Correct	.77 (.23)	.71	.55	.05	.60
Incorrect	.80 (.20)	.73	.17	.00	.17
Spelling control	.77 (.23)	.65	.09	.00	.09

Note. Prob. = probability.
[a]Probability of skipping in parentheses.

total time are examined, the data suggest that the difference is noticed some of the time: Either an occasional refixation is made on the target word (lengthening gaze duration) or, more frequently, a regression is made back to the target word. But, as we argued earlier, these two measures reflect later processing than the initial fixation time measures. Moreover, the initial processing measures are sensitive to the difference between the incorrect homophone and its spelling control. We return to this issue in the General Discussion.

Experiment 3

The data of Experiment 1 and the high-constraint condition of Experiment 2 imply that phonological coding affects reading at relatively early stages of processing (i.e., those that can affect first fixation duration). First, Experiment 2 indicated that all fixation measures on the target word were affected by the difference between the incorrect homophone and the spelling control, indicating a sensitivity of these measures to phonological coding. Second, in the most visually similar homophone conditions of both experiments, there was no difference between the correct and incorrect homophones on first fixation duration, indicating that phonological incorrectness was being picked up at an earlier stage than orthographic incorrectness. Because these data and conclusions are clearly at variance with those of Daneman and Reingold (1993), it suggests that there may be something special about phonological coding in the high-constraint condition. In Experiment 2, unfortunately, our low-constraint condition was inconclusive with respect to phonological coding because there were no reliable differences among conditions. As argued earlier, this was likely to be due to the fact that these materials were too unconstrained. As a result, we attempted a replication of Experiment 2 in which the low-constraint condition was changed. In Experiment 3, the sentences were changed in the low-constraint condition so that the prior context made both the incorrect homophone and the spelling control anomalous. Thus, the information of the semantic "incorrectness" of these target words was potentially available to the reader at the time of fixating them. However, because of the lower constraint, the fact that they are anomalous may not be as quickly available as in the high-constraint condition.

Method

Participants. Eighteen undergraduate students at the University of Massachusetts at Amherst participated in the experiment either for money or for course credit. They had normal uncorrected vision, were naive regarding the purpose of the experiment, and had not participated in Experiments 1 or 2.

Apparatus. The apparatus was identical to that used in Experiments 1 and 2.

Materials. The materials in the high-constraint conditions were identical to those of Experiment 2. The materials of the low-constraint condition were similar frames to those in the low-constraint condition of Experiment 2, except the incorrect homophone and spelling control were anomalous at the point of the target word. To ensure that these words were anomalous in the low constraint context, we conducted a norming task. Fifteen undergraduate students were presented with the low-constraint passages up to and including the target word. Their task was to indicate, on a scale of 1 to 7, how well the target word fit into the context. A 1 meant that *the word made no sense in the context,* whereas a 7 meant that *the word was a good, reasonable continuation of the passage.* The mean ratings for the correct homophone, incorrect homophone, and spelling control were 6.8, 1.1, and 1.3, respectively.

Procedure and design. The procedure and design were identical to Experiment 2, with one exception. In Experiment 2, participants had been warned about the misspellings prior to reading the sentences, but in Experiment 3, they were not. As shown later, however, the data in the high-constraint condition replicated Experiment 2 quite well, so this difference in procedure is unlikely to have been important. As in the prior experiments, participants were asked comprehension questions after 33% of the passages; they had little trouble answering these questions and were correct 93% of the time. Also, as in the prior experiments, a spelling check was completed at the end of the experiment, and participants were able to correctly spell the appropriate homophone 97% of the time.

Results and Discussion

The data were analyzed in the same way as in Experiments 1 and 2. Five percent of the data were lost because of track losses or short fixations on the target word. For the sake of consistency with Experiment 2, we first discuss the effect of contextual constraint and then discuss the effect of the correct meaning followed by a discussion of homophone types.

Effects of constraint. To simplify the presentation of the constraint manipulation, we collapsed the data for the correct homophone, incorrect homophone, and spelling controls in the high- and low-constraint condition over orthographic similarity (see Table 9). As in Experiment 2, the high-constraint condition resulted in significantly shorter first-pass fixations on the target word than did the low-constraint condition: The differences on first fixation duration, single fixation duration, and gaze duration were all significant ($ps < .05$). Constraint also influenced the probability of fixating the target word: High-constraint target words were fixated 63% of the time versus 70% for low-constraint target words, $F_1(1, 17) = 4.67$, $MSE = 210$, $p < .05$, and $F_2(1, 53) = 4.25$, $MSE = 529$, $p < .05$.

Turning now to the second-pass effects, the probability of regressing to the target word and the total time readers spent on the target words were both strongly influenced by contextual constraint. Readers regressed somewhat more frequently into the target word when it was in a low-constraint sentence (31% of the time) than when it was in a high-constraint sentence (24%), $F_1(1, 17) = 6.25$, $MSE = 231$, $p < .05$; $F_2(1, 53) = 3.89$, $MSE = 530$, $p < .06$, and the total time that readers fixated on the target word was considerably greater when the word was in a low-constraint sentence (464 ms) than in a high-constraint sentence (379 ms), $F_1(1, 17) = 32.42$, $MSE = 6{,}044$, $p < .001$; $F_2(1, 53) = 19.47$, $MSE = 25{,}793$, $p < .001$.

Effects of correct meaning and homophony. As in Experiments 1 and 2, the correctness of the target word had a significant effect for most first-pass fixation time measures. Averaged over high- and low-constraint conditions, there were significant differences among the correct and incorrect homophone and spelling control conditions for first fixation duration, $F_1(2, 34) = 52.69$, $MSE = 551$, $p < .001$, and $F_2(2, 106) = 21.04$, $MSE = 3151$, $p < .001$; for single fixation duration, $F_1(2, 34) = 17.22$, $MSE = 4{,}286$, $p < .01$, and $F_2(2, 106) = 12.56$, $MSE = 2{,}987$, $p < .01$; and for gaze duration, $F_1(2, 34) = 26.03$, $MSE = 1{,}493$, $p < .001$, and $F_2(2, 106) = 23.56$, $MSE = 5{,}657$, $p < .001$. In addition, as in the first two experiments, there was no effect of correctness of the target word on the probability of a first-pass fixation on the target word ($Fs < 1$).

As in Experiments 1 and 2, the correctness of the target word strongly influenced later processing of the sentence. There were large and significant effects of correctness on regression probability, $F_1(2, 34) = 18.69$, $MSE = 277$, $p < .001$, and $F_2(2, 106) = 23.51$, $MSE = 677$, $p < .001$, and on total time, $F_1(2, 34) = 34.33$, $MSE = 11{,}424$, $p < .001$, and $F_2(2, 106) = 38.10$, $MSE = 30{,}761$, $p < .001$.

Table 9 presents the data collapsed across homophone type to facilitate comparison to the data of Daneman and Reingold (1993) and Daneman et al. (1995). Consistent with our first two experiments and with both of their studies, there were differences in first-pass times between the correct and incorrect homophone conditions. The data from Experiment 3 (like the data of Experiment 2) indicate that there were differences between the incorrect homophone and spelling control conditions. The latter finding is contrary to the conclusions of Daneman and Reingold (1993) and Daneman et al. (1995), although as we argue in the General Discussion section, contrary to only some of their findings.

The data from Experiment 3, like those from the earlier experiments, indicate that on many trials when the homophone pairs were orthographically similar to each other that readers did not notice the irregularity. Although the main effect of orthographic similarity was not significant, it did enter into a significant three-way interaction for all of the first-pass measures ($Fs > 3.35$). As seen in Table 10, the general pattern for the high-constraint conditions is that the difference for fixation durations between the correct homophone and the incorrect homophone are small or nonexistent when the pair is orthographically similar, and these two conditions are different from the spelling control. However, when the pair was dissimilar, there was a significant difference between the correct homophone and the incorrect homophone. For the low-constraint condition, however, the correct homophone, incorrect homophone, and the spelling control were generally all different from one another.

Effects of orthographic similarity. The important point to be gleaned from the analyses of homophone type in the high-constraint condition is that the results replicated those

Table 9
Fixation Times (in Milliseconds), Probability of Fixating on the Target Word, and Probability of Regressing Back to the Target Word as a Function of Homophone Correctness and Constraint

	Fixation time measure				Fixation probability measure	
Condition	FFD	SFD	Gaze	TT	Prob. fix.	Prob. reg.
High constraint						
Correct homophone	232	237	256	282	.62	.12
Incorrect homophone	242	246	271	367	.63	.23
Spelling control	284	285	322	487	.64	.36
Incorrect–correct	10	9	15	85	.01	.11
Control–incorrect	42	39	51	120	.01	.13
Low constraint						
Correct homophone	259	260	287	361	.70	.20
Incorrect homophone	286	282	315	458	.68	.30
Spelling control	315	311	355	573	.71	.44
Incorrect–correct	27	22	28	97	−.02	.10
Control–incorrect	29	29	40	115	.03	.14

Note. FFD = first fixation duration; SFD = single fixation duration; TT = total time; Prob. fix. = probability of fixating on the target word; Prob. reg. = probability of a regression back to the target word.

of Experiments 1 and 2, with one exception. For the first-two-letters-same condition, in the high-constraint condition, there was no difference between the correct and incorrect homophone conditions for first fixation, single fixation duration, or gaze duration (*ts* < 1). However, these two conditions each differed from the spelling control condition: For the correct condition versus the spelling control, $t_1(17)$ = 5.04, 3.36, and 3.67, *ps* < .05, and $t_2(17)$ = 4.2, 3.4, and 3.6, *ps* < .05, for first, single fixation, and gaze duration, respectively; for the incorrect homophone condition versus the spelling control, $t_1(17)$ = 2.28 and 2.85, *ps* < .05, and $t_2(17)$ = 2.94 and 2.72, *ps* < .05, for first fixation and gaze duration, respectively. The one aspect of these data that failed to replicate Experiments 1 and 2 was that there was no difference between the correct and incorrect homophone conditions in the gaze duration measure. In the low-constraint condition, all pairwise differences for first fixation, single fixation, and gaze duration were significant (*ps* < .05), with the exception of the difference between the incorrect homophone and spelling control for single fixation duration (*ts* < 1).

The pattern in the high-constraint condition for the first-letter-same-condition was quite similar (see Table 10). For first fixation and single fixation duration, the correct condi-

Table 10
Fixation Times (in Milliseconds) as a Function of Homophone Correctness and Similarity of Homophone Pair

	High constraint				Low constraint			
Condition	FDF	SFD	Gaze	TT	FFD	SFD	Gaze	TT
First two letters same								
Correct homophone	224	237	245	299	245	262	277	413
Incorrect homophone	229	234	243	340	287	293	329	455
Spelling control	282	305	320	467	340	305	364	484
Incorrect–correct	5	−3	−2	41	42	31	52	42
Control–incorrect	53	71	77	127	53	12	35	29
First letter same								
Correct homophone	226	233	243	254	270	252	298	339
Incorrect homophone	231	238	271	363	289	269	310	424
Spelling control	286	262	311	436	301	322	344	592
Incorrect–correct	5	5	28	109	19	17	12	85
Control–incorrect	55	24	40	73	12	53	34	168
Dissimilar								
Correct homophone	247	242	281	294	264	267	286	331
Incorrect homophone	267	265	300	399	282	278	307	495
Spelling control	284	287	335	557	303	307	357	643
Incorrect–correct	20	23	19	105	18	11	21	164
Control–incorrect	17	22	35	158	21	29	50	148

Note. FFD = first fixation duration; SFD = single fixation duration; TT = total time.

tion did not reliably differ from the incorrect homophone condition ($ts < 1$), whereas it did differ from the spelling control condition ($ps < .05$). Unlike the first-two-letters-same condition, there was a significant difference in gaze duration between the correct and incorrect homophone condition and the spelling control ($ps < .05$). For the low-constraint conditions, there were significant differences between the correct and incorrect homophone for first and single fixation duration ($ps < .05$). All of the pairwise differences were significant for the correct homophone compared with the spelling control for first fixation, single fixation, and gaze duration ($ps < .05$). In addition, there were significant differences between the incorrect homophone and the spelling control for single fixation and gaze duration ($ps < .05$).

In the dissimilar condition, however, the pattern was somewhat different. All pairwise comparisons between the correct and incorrect homophone and spelling control yielded significant differences for both the high-constraint and low-constraint conditions ($ps < .05$).

In total fixation time, there were large differences between all conditions. As should be obvious from an examination of Table 10, all pairwise comparisons between the correct and incorrect homophone and spelling control yielded significant differences for both the high-constraint and low-constraint situations (all $ps < .05$). Thus, as we argued before, when regressions on the target word were included in the data analysis, clear effects of constraint emerged.

Analyses of patterns of fixations. The same measures were computed as in Experiments 1 and 2, and the results can be seen in Table 11.[8] The most relevant column is the last one, the measure of the extent to which readers made a single fixation on the target or skipped the target and then did not make a regression to the target word. Most importantly, in the high-constraint condition readers made at most a single fixation on the incorrect homophone target word and then did not regress about 73% of the time in the first two letters same and first letters same conditions. Because the fixation times in these conditions differed little, it appears that the incorrect homophone had virtually no effect on about 73% of the trials, suggesting that the readers proceeded through the text on the basis of the target word having the right sound on a significant fraction of the trials. In contrast, readers made at most a single fixation and did not regress on only about 28% of the trials in the spelling control conditions, indicating that the effect was not merely due to orthographic similarity. (Initial fixation times were also longer in these conditions as well.)

The data from the high-constraint conditions of Experiment 3 then were consistent with the data from Experiments 1 and 2: When the context was highly constraining, the initial fixation times and the probability of skipping the word suggest that roughly 73% of the time readers did not notice the incorrect member of the homophone pair.[9] When gaze duration and total time were examined, the data suggest that the difference was noticed some of the time: Either an occasional refixation was made on the target word (lengthening gaze duration) or, more frequently, a regression was made back to the target word. But, as we argued earlier, these two measures reflect later processing than the initial fixation time measures. Moreover, the initial processing measures were sensitive to the difference between the incorrect homophone and its spelling control.

One final point needs to be raised with respect to the results of Experiment 3 (and Experiments 1 and 2). The frequency of the incorrect homophone and spelling control words was only approximately equated, leaving open the possibility that the difference we observed in first fixation duration between these two conditions was due to word-frequency differences rather than to phonology. To examine this possibility, we conducted regression analyses to test the extent to which the observed differences between conditions were influenced by word frequency. Two different regression analyses were conducted, one for the difference between the correct and incorrect homophone conditions and the other for the difference between the incorrect homophone and spelling control conditions. For the difference in first fixation duration between the correct homophone and incorrect homophone, the difference in log frequency between the correct and incorrect homophone was used as the predictor, whereas for the difference in first fixation duration between the incorrect homophone and the spelling control, the difference in log frequency between the incorrect homophone and the spelling control was used. Word frequency was never a significant predictor of the difference (all $Fs < 1$), accounting for at most 3% of the variance across items. In these analyses, the intercept of the regression line is the estimated value of the dependent variable when differences in frequency are controlled for. For both high- and low-constraint conditions, the intercept was significantly different from zero for the difference between the incorrect homophone and the spelling control. For the difference between the correct and incorrect homophones, the intercept was significantly different from zero only in the low-constraint conditions. Thus, the previously reported pattern of data does not appear to be significantly affected by uncontrolled differences in word frequency.

[8] A possible criticism of our analysis of regressions is that it overestimates the number of instances in which readers never were bothered by the misspelling of the target word. That is, in the analyses reported in Tables 4, 8, and 11, we only examined regressions back to the target word and not those instances in which the reader regressed back to the region prior to the target word, even though the latter may have been caused by the difficulty of the misspelling in the target-word region. To assess this possibility, we examined the probability of regressing to the region preceding the target word (i.e., the two words prior to the target word). We found absolutely no differences among any of the conditions (i.e., no differences between correct and incorrect spellings) on this measure (all $Fs < 1$).

[9] It is interesting to note that the percentage of times that participants appeared to be unaware of the incorrect homophone was much greater in Experiment 3 than in Experiments 1 and 2. This may have been because in Experiment 3 (contrary to Experiments 1 and 2) the misspelling manipulation was not explicitly pointed out to participants before reading the passages.

Table 11
Fixation Patterns for Target Words as a Function of Similarity Between Homophones and Constraint

Condition	Fixations on target word: Prob. of fixating target word[a]	Fixations on target word: Prob. of a single fixation on target word	Nonregressions back to target: Prob. of a single fixation on target and no regression back to it	Nonregressions back to target: Prob. of skipping target and no regression back to it	Nonregressions back to target: Prob. of either a single fixation or a skip and no regression back to target
High constraint					
First two letters same					
Correct	.60 (.40)	.58	.55	.32	.87
Incorrect	.56 (.44)	.53	.50	.20	.70
Spelling control	.62 (.38)	.59	.27	.02	.29
First letter same					
Correct	.57 (.43)	.56	.51	.36	.87
Incorrect	.64 (.36)	.62	.59	.17	.76
Spelling control	.57 (.43)	.54	.27	.00	.27
Dissimilar					
Correct	.70 (.30)	.67	.64	.12	.76
Incorrect	.68 (.32)	.64	.61	.03	.64
Spelling control	.72 (.28)	.70	.18	.00	.18
Low constraint					
First two letters same					
Correct	.69 (.31)	.66	.62	.18	.80
Incorrect	.65 (.35)	.63	.59	.02	.61
Spelling correct	.72 (.28)	.69	.20	.03	.23
First letter same					
Correct	.67 (.33)	.62	.50	.22	.72
Incorrect	.60 (.40)	.58	.50	.09	.59
Spelling control	.59 (.41)	.56	.15	.00	.15
Dissimilar					
Correct	.75 (.25)	.65	.59	.17	.76
Incorrect	.80 (.20)	.70	.45	.11	.56
Spelling control	.82 (.18)	.60	.15	.00	.15

Note. Prob. = probability.
[a]Probability of skipping in parentheses.

General Discussion

The experiments reported here were undertaken to examine a discrepancy in prior studies dealing with phonological codes and eye movements in reading. As we noted in the introduction, a number of studies (Folk & Morris, 1995, 1996; Henderson et al., 1995; Inhoff & Topolski, 1994; Pollatsek et al., 1992; Rayner et al., 1995) presented evidence that phonological codes are activated early during eye fixations in reading. On the other hand, Daneman and Reingold (1993) and Daneman et al. (1995) presented evidence that indicated that phonological codes are not activated early in a fixation, but at a later, postlexical, stage. The present experiments were an attempt to clarify this discrepancy. Before doing so, however, we wish to summarize and explain our own data.

As we argued in the introduction, in this paradigm there are three plausible patterns for early measures of word encoding, such as first fixation duration and single fixation duration. One is that there is no difference between the correct and incorrect homophones, but there is a difference between incorrect homophones and the spelling controls. As argued earlier, such a pattern would indicate that phonological analysis had progressed to the stage in which the target word "sounds wrong" by the time the decision had been made to move the eyes, but orthographic analysis had not progressed to the stage where the target word "looks wrong." Thus, on these trials, the access of semantics from phonology appears to be faster than the access of semantics from orthography. In the high-constraint orthographically similar conditions of three experiments, we found such a lack of difference between the correct and incorrect homophone conditions, and in those conditions of Experiments 2 and 3, we found a difference between the incorrect homophones and the spelling controls (Experiment 1 did not contain the spelling control condition). Moreover, in these conditions, readers apparently never detected the incorrect homophone on an appreciable fraction of the trials. However, the anomaly of the incorrect homophone was discovered on about half of the trials, occasionally indexed by a second fixation on the word and lengthening the gaze duration, but most often indexed by a regression back to it.

In contrast, in the other conditions (i.e., the low-constraint conditions of Experiment 3 and the orthographically dissimilar high-constraint conditions of all three experiments), we found a different pattern in the first fixation duration data: a difference between the correct and incorrect homophones and a difference between the incorrect homophones and the spelling controls. This pattern indicates that readers (on some fraction of the trials) have detected that the target word "sounds wrong" and also have detected that the target word looks wrong. On these trials, it is ambiguous whether phonology or orthography has faster access to semantics; all we can say is that both have some access prior to the decision to move the eyes.

Our data appear to be compatible with a model of lexical access, such as the verification model, in which the initial stage of lexical access is activation of the relevant phonological code, followed by a "verification" stage, in which the orthographic code is subjected to further processing which, among other things, would disambiguate homophones. This is not to say that phonological processing in these conditions is *necessarily* logically prior to other types of processing. For example, in Van Orden's (see Van Orden, Pennington, & Stone, 1990) later modeling, the system converges on a "solution" for the phonological code, the orthographic code, and the semantic code, but it typically converges on a phonological solution most rapidly. Because there is extensive cross talk between processing systems, the phonological code has considerable control over semantic identification early in processing. Because it is easier to state predictions from the verification model than from such a model, we use the verification model as an explanatory mechanism in the subsequent discussion.

First consider the high-constraint conditions, in which prior context strongly indicates which word will be in the target-word position. In most versions of such a model, top-down expectations play a major part in the verification process and may abort (or at least slow down) the bottom-up verification processes coming from a more careful analysis of the orthographic code. In such a case, if the reader sees the "wrong" homophone, the initial phonological processing would indicate that the word makes sense (and is expected), followed by the verification process. Presumably, the speed of the verification process (which would indicate that the homophone is not the expected word) would depend partially on the orthographic similarity of the "wrong" homophone to the appropriate homophone: The mismatch would be harder to detect, the greater the orthographic similarity between the homophones. As a result, our observed pattern of data makes sense: The more orthographically dissimilar the homophones are, the more likely it is that the error is detected, and if so, the more rapidly the verification process is accomplished. In our experiments, under conditions of high constraint and with maximum orthographic similarity, the spelling check was apparently almost always too slow to be able to affect first fixation durations. In all other conditions, however, the spelling check appeared to be rapid enough (on at least some of the trials) to tell the reader that the word was not the predicted word and hence signal some processing difficulty that affected the eye movement system.

The only potential difficulty with this explanation of our data is that it does not naturally explain why orthographic similarity had no effect on the difference between the correct and incorrect homophone conditions in the low-constraint condition of Experiment 3. One possibility is that under low-constraint conditions, the bottom-up verification process works more efficiently with no top-down expectation process to abort it, and thus it operates rapidly enough to affect first fixation durations even when the homophones are orthographically similar. Although this is possible, it seems strange that there appeared to be no modulation of the size of the effect as a function of orthographic similarity. There is another possible explanation, but we defer discussion of it until we discuss the relation of our data to those of Daneman and Reingold (1993) and Daneman et al. (1995).

As indicated in the introduction, the paradigm of the current experiments was essentially the same as that of Daneman and Reingold (1993) and Daneman et al. (1995); however, they concluded that phonological coding occurred late in the process of word identification, after the target word had been fixated. To see why they concluded that and to see how their data actually look in relation to ours, a more detailed comparison of the studies may be helpful in considering what can be concluded from this paradigm (see Table 12). A few aspects of the table deserve some comment. First, as indicated earlier, Experiment 1 of Daneman and Reingold, Experiment 1a of Daneman et al., and our Experiment 1 did not include a spelling control condition, and so some cells are blank. Second, Daneman and Reingold did not always report first fixation duration differences for the orthographically similar conditions when an experiment varied orthographic similarity. Third, the values reported in Table 12 for our Experiment 1 do not include the pseudohomophone conditions in order to be comparable to the other experiments in the table.

Both our studies and theirs took the same two differences as the crucial data: the difference between the correct and incorrect homophones and the difference between the incorrect homophone and the spelling control. However, their focus was on the gaze duration measure and ours was on the first fixation duration measure. (To simplify exposition, we use "they" and "their" to refer to the Daneman & Reingold, 1993, and Daneman et al., 1995, studies.) First, consider the difference between the correct and incorrect homophones. For the gaze duration measure, the two sets of studies are in general agreement that there is a difference between these two conditions, although they tended to get larger differences than we did: They observed differences of 45–87 ms, and we observed differences of 15–41 ms. We are also in agreement with them that there are relatively small differences in first fixation duration: They obtained differences of 11–19 ms, and we obtained differences of 10–27 ms. The key difference is that they obtained about the same difference when the homophones were orthographically similar as when the homophones were orthographically dissimilar. In contrast, in our high-constraint conditions, the difference between the correct and incorrect homophones became quite small with increasing orthographic similarity: 7 ms on average across the three experiments when our two most orthographically similar conditions were combined and 2 ms on average across the three experiments when only our most orthographically similar condition was considered.

Second, consider the difference between the incorrect

Table 12
Principal Results of Daneman and Coworkers Compared With Those of the Current Experiments

Experiment and dependent variable	Incorrect homophone vs. correct homophone (ms)	Incorrect homophone vs. correct homophone for visually similar homophones (ms)	Spelling control vs. incorrect homophone (ms)
Daneman & Reingold (1993)			
Experiment 1			
FFD	19	NR	—
GD	48	43	—
Experiment 2			
FFD	14	NR	2
GD	45	47	−2
Daneman et al. (1995)			
Experiment 1a			
FFD	11	11	—
GD	87	87	—
Experiment 1b			
FFD	14	14	15
GD	47	47	16
Current Experiment 1			
High constraint			
FFD	23	7 (−4)	—
GD	41	30 (35)	—
Current Experiment 2			
High constraint			
FFD	14	8 (5)	16
GD	19	15 (21)	25
Current Experiment 3			
High constraint			
FFD	10	5 (5)	42
GD	15	13 (−2)	51
Low contraint			
FFD	27	31 (42)	29
GD	28	32 (52)	40

Note. Values in parentheses are from the first-two-letters-same conditions. The other values in that column from our experiments are the average of the first-two-letters-same and first-letter-same conditions. Dashes indicate that the condition was not included in the experiment. FFD = first fix duration; GD = gaze duration; NR = not reported.

homophone and spelling control conditions. For gaze duration, there is clearly a discrepancy between the two labs because we obtained clear differences in all three comparisons, whereas they failed to obtain significant differences in any experiment. This failure to find a significant difference between the incorrect homophone and spelling control conditions was the reason that they concluded that phonology entered the process of word identification only after orthography had made contact with semantics. However, when the values of the difference are examined, the −2 ms of Daneman and Reingold's (1993) Experiment 2 appears to be the outlier because the difference in Daneman et al.'s (1995) Experiment 1b of 16 ms is reasonably consistent with our obtained differences of 25–51 ms. For first fixation duration, they reported two relevant differences, −2 ms and 15 ms, and only the former is at variance with our values of 16–42 ms.

In summary, the values reported in our experiments are not wildly inconsistent with most of those reported by Daneman and Reingold (1993) and Daneman et al. (1995). One inconsistency is that we obtained clear differences between the spelling control and the incorrect homophone, whereas their results were more equivocal. Second, the overall difference between the correct and incorrect homophones was approximately the same in the experiments in both laboratories (especially for first fixation duration). The data from the two laboratories appeared to differ in that we observed a clear modulation of the difference by orthographic similarity in our high-constraint conditions, whereas they reported no modulation of the difference by orthographic similarity in their experiments, a pattern similar to what we observed in our low-constraint conditions. Thus, on some level, most of the data from both laboratories demonstrate the equivocal pattern that indicates that both phonology and orthography are having an effect. The only experiments differing from that pattern are Experiment 2 of Daneman and Reingold (1993), in which there was no difference between the incorrect homophone and spelling control conditions, and all three of our high-constraint, orthographically similar conditions, in which there was virtually no difference between the correct and incorrect homophone conditions.

Are there any differences in procedure that could explain the aforementioned differences between the two laboratories? One potentially relevant variable worth discussing is the frequency of the homophones. In Experiment 1b, Daneman et al. (1995) varied the frequency of the correct and incorrect homophone between the two stories that they used and found a different pattern in the two stories: When the correct homophone was more frequent, the difference between the correct and incorrect homophone conditions was about equal to that between the incorrect homophone and spelling control conditions. In contrast, when the incorrect homophone was less frequent, there was little difference between the incorrect homophone and spelling control conditions (although the interaction indicating a different pattern for the two stories was not significant). In Experiment 3, we analyzed our items for frequency differences and found no significant modulation of either difference as a function of frequency. Thus, at present, there is no conclusive evidence that the relative frequency of the homophones plays a large role in this phenomenon, although it seems plausible that it could.

A second potentially relevant variable is the nature of the spelling control. Daneman and Reingold (1993) and Daneman et al. (1995) matched the spelling control to the homophone on all the consonants. Although this achieved a high degree of matching on orthography, it might also achieve a high degree of matching on phonology. That is, there is evidence (Berent & Perfetti, 1995) that consonant sounds are particularly important in phonological coding, particularly at the early stages of processing. Thus, we think it is likely that one of the reasons why Daneman and Reingold and Daneman et al. obtained smaller differences between the incorrect homophone and spelling control conditions than we did is that their spelling controls may have been more phonologically similar to the target words than ours.

Two other differences are worth noting. Their passages were long (somewhat over 1,000 words) and were adapted from actual narratives, whereas ours were shorter (about 40 words) and were just constructed for the experiments. A second difference is that our misspelling occurred about half as often as theirs: once every two passages or about once every 80 words in our experiments and about once every 50–60 words in their experiments. Although either of these differences in procedure could have been a primary cause of the data discrepancies between the two sets of studies, we see no compelling argument for it.

In contrast, a variable that appears to play an important role, as we have argued earlier, is the degree of contextual constraint. In both Experiments 2 and 3 of the current study, we found that orthographic similarity played a part only under conditions of high constraint. Moreover, under our conditions of very low constraint in Experiment 2, there were only small differences between all three conditions. Because the data of Daneman and Reingold (1993) and Daneman et al. (1995) are most similar to those in our low-constraint condition of Experiment 3, it is tempting to conclude that their experiments used materials similar to ours in which (a) the correct homophone was not predictable from prior context, but (b) it was immediately apparent that either the incorrect homophone or the spelling control was not an appropriate continuation of the passage. However, a closer examination of the excerpt presented in Daneman and Reingold's experiment and the complete passages used in Daneman et al.'s Experiment 1 indicated to us that this was not always the case.[10] Consider the following example from the excerpt provided in Daneman and Reingold (1993): "*The teller ducked his head and saw a vain/vein/vine little man.* . . ." Neither *vein* nor *vine* seems completely implausible with the prior context. In fact, when we examined this excerpt and two complete 1,000-word passages of theirs, the target words seemed to be in all three constraint conditions that we used. Some, such as the above, seemed to be like our low-constraint conditions of Experiment 2. Some, such as "*Through the rest of the week/weak/woke* . . ." appeared to be like our low-constraint conditions of Experiment 3, and others appeared to be quite high constraint, such as "*One afternoon after the pouring rain/rein/ruin* . . ." or " *Over the years it had always been/bean/bone.* . . ." In summary, it is hard to make a definitive statement about how their materials corresponded to ours; however, it appears that a majority of them are like our low-constraint conditions in Experiment 3.

A dispassionate reader might conclude at this point that the evidence from this misspelling detection paradigm is inconclusive. That is, we observed a pattern that suggests that phonological coding enters early only in some conditions of high constraint, and we observed ambiguous patterns elsewhere, whereas Daneman and Reingold (1993) and Daneman et al. (1995) observed a pattern that suggests that phonology enters late in one experiment and observed ambiguous patterns elsewhere. In particular, one might conclude from our data that phonology appears early *only* in conditions of high constraint. However, as we indicated in the introduction, a major motivation for the current studies was that we had obtained evidence in several studies that phonology entered into the word-identification process early in reading and viewed the data of Daneman and Reingold and Daneman et al. as going against what had been observed in many other paradigms, both with silent reading of text and in identification of isolated words. Thus, we think that an important point of our experiments is that all of our data indicate that homophony is affecting first and single fixation durations; the only question is in which conditions it actually beats any awareness of a spelling mismatch.

We are still left with the potential problem of our strongest results being limited to a relatively unnatural situation in this paradigm, because a minority of content words are highly predictable from prior context. (One estimate is that about 20–40% of content words and 50–75% of function words in text are predictable; Haber, Haber, & Furlin, 1983.) However, we think an argument can be made that the high-

[10] We thank Eyal Reingold for sending the passages to us.

constraint conditions are the most diagnostic conditions in the present misspelling-detection paradigm. Remember that the paradigm is really not getting at word identification per se, but the detection that a word does not fit in with the prior text or seems odd in some way. First, consider the high-constraint condition. Here, the reader presumably expects a particular word to be in the text. Thus, a comparison of the three conditions (i.e., correct homophone, incorrect homophone, and spelling control) presumably is an index of the reader's ability to determine (a) whether the incorrect homophone is an orthographic mismatch with this expected target and/or (b) whether the spelling control is an orthographic and phonological mismatch with this expected target.

Now consider a low-constraint condition such as in Experiment 3 and in many of the trials of Daneman and Reingold (1993) and Daneman et al. (1995). Here, by the definition of "low constraint," there is no expected word, and hence the detection of anomaly is more complex than a determination that the target word is not the correct homophone word. Consider the following example from Daneman and Reingold: "*He wore a tee shirt, suede jacket, and blue/blew/blow jeans.*" In this sentence, as in many of the examples, the "incorrect" words are not completely anomalous. For example, "*blow dried hair*" is a possible continuation of the sentence, so that detection of the anomaly might often be delayed until the next word. Presumably, the immediacy of detecting that the actual word does not fit (and hence the degree to which it would affect early measures of processing such as first fixation duration and gaze duration) would depend on the degree to which it was anomalous with the prior context. Thus, a fair comparison of the homophone effect crucially depends on whether the words *blew* and *blow* (for example) are equally incompatible. We tried to equate this in Experiment 3 by getting subjective ratings, whereas Daneman and Reingold and Daneman et al. made an informal assessment in their studies.

Even if this incompatibility is equated, however, the interpretation of these data may still be complex. Consider the incorrect homophone condition. If one adopts the perspective of the verification model, one assumes that the phonological code of *blew* is accessed, which in turn activates both the *blew* and *blue* meanings. On the one hand, as in the high-constraint condition, access of the semantic codes for *blue* should make it harder to detect that the sentence is anomalous than for the spelling control because a meaning is accessed that makes sense (though a meaning that doesn't make sense is also accessed). On the other hand, access of the semantic code for *blue*, and the subsequent verification process, might make it easier to detect that *blew* does not make sense than to detect that *blow* does not make sense. That is, in the former case, the reader has presumably accessed (at least some of the time) a semantic code that is a good continuation, which should facilitate the process of judging that *blew* was not what was intended. In contrast, for the spelling control, *blow, blue* has been rarely if ever accessed, so the judgment of anomaly has no concrete referrent for a good continuation. In summary, if one assumes early phonological coding, homophony could have the following two opposite effects in the low-constraint condition: (a) activation of a semantic code that is a good continuation, which delays (or possibly aborts) judgments that the word does not make sense in context, but (b) activation of a semantic code that is a "model" of good continuation that makes detection of the meaning of the wrong homophone easier and faster. As none of the data that we reviewed indicate that homophones produce a greater anomaly effect than the spelling control, it appears that mechanism (a) is the dominant one. However, under certain circumstances, mechanisms (a) and (b) may be equally potent, and one could observe null effects (as did Daneman and Reingold, 1993, in some experiments).

More generally, it is our feeling that the low-constraint condition in this misspelling-detection task may not be particularly diagnostic because the initial detection of anomaly may be largely based on the degree of anomaly of the actual words to the preceding context rather than to any orthographic or phonological similarity to the correct homophone. One piece of data supporting this hypothesis is the finding that the orthographic similarity of the incorrect homophone and the spelling control to the correct homophone had little effect on first-pass processing times in low-constraint conditions. In terms of a verification model, this would merely mean that in conditions of low constraint, the verification process is largely finished by the time the reader attempts to integrate the word into the meaning of the passage. In addition, as noted in the preceding paragraph, there is a plausible mechanism (consistent with early phonological coding) in which the incorrect homophone may be more likely than the spelling control to bring to mind a good continuation of the passage (i.e., the correct homophone), facilitating the detection of anomaly for the incorrect homophone and lengthening first fixation or gaze durations. If so, this would make first fixation duration or gaze duration in these conditions a problematic measure of whether phonological or orthographic information got in first. This state of affairs contrasts with the high-constraint condition, in which a good continuation of the passage (i.e., the expected word) is present in both the incorrect homophone and spelling control conditions, and thus first fixation duration and gaze duration are more plausibly reflections of the relative speed of the detection of orthographic and phonological mismatch.

We should further emphasize that there are now a wide variety of paradigms that argue for early phonological involvement in word identification. These include misclassification of homophones in a categorization task (Van Orden, 1987), semantic priming by homophones of associates (Lesch & Pollatsek, 1993; Lukatela & Turvey, 1994a), masked phonological priming by homophones (Humphreys, Evett, & Taylor, 1982; Lukatela & Turvey, 1994b), release from backward masking by homophones (Perfetti et al., 1988), and the lack of an N400 (unexpectedness) effect in event-related potentials when encountering the wrong homophone (Forbes & Connolly, 1996). In addition, there are the studies that we reviewed in the introduction that indicated that phonological codes enter early into word identification in reading, before the word is fixated (Pollatsek et al., 1992) and also early in the initial fixation on the word (Rayner et al., 1995). Moreover, in the two reading paradigms and in many of the word-identification paradigms, the conditions were not of high constraint (i.e., the homophone was neither predictable nor semantically primed). Thus, we feel quite confident in concluding that early phonological coding is relevant to word identification more generally, not only in conditions in which the word is highly predictable.

Our data also clearly show that on some trials the detection of the incorrect word is made after the reader leaves the fixated word and comes back to it but that there is a large difference in how easy it is to repair the damage, depending on whether the incorrect word is a homophone of the correct word or not. In Experiment 2, the differences in total time spent on the target word were over 60 ms in the high-constraint condition and over 100 ms in the low-constraint condition. This aspect of our data was in complete agreement with the data of Daneman and Reingold (1993), Daneman et al. (1995), and many earlier studies (e.g., Levy, 1975; McCutchen & Perfetti, 1982; Slowiaczek & Clifton, 1980) that phonological codes are an integral part of the memory of the text that has just been read and are used in the construction of syntactic structures, discourse structures, or both.

In conclusion, our data indicate that phonological coding plays an important early role in the silent reading of text. Phonological codes appear to be accessed early in the encoding of a word and are maintained as part of the text representation that allows reinterpretation if there are problems in understanding the discourse structure.

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Appendix A

Target Words in Experiment 1

First two same	First same	Dissimilar	Pseudohomophone
brake–break	bear–bare	right–write	brain–brane
meat–meet	furs–firs	chute–shoot	scare–skair
rose–rows	dew–due	accept–except	comb–kome
pour–poor	pair–pear	sent–cent	cry–kry
mown–moan	peer–pier	jeans–genes	field–feeld
sole–soul	surf–serf	cell–sell	deal–deel
heal–heel	worn–warn	cite–site	soap–sope
arc–ark	rain–rein	serial–cereal	moon–mune

Appendix B

Target Words in Experiments 2 and 3

First two same	First same	Dissimilar
break–brake–bread	bare–bear–beer (barn)	right–write–wrath (rigid)
poor–pour–port	son–sun–sin	chute–shoot–shout (chant)
meet–meat–meal	due–dew–den (doe)	accept–except–expect (aspect)
rows–rose–robe	pair–pear–peek (part)	cent–sent–rent
sole–soul–solo	surf–serf–sort	sell–cell–well
heal–heel–hell	worn–warn–warm (worm)	cite–site–bite
ark–arc–art	rain–rein–ruin	serial–cereal–verbal
male–mail–mawl	ales–ails–awls (alas)	one–won–woe (own)

Note. Words in parentheses are the second spelling control.

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