What Eye Fixations Tell Us About Phonological Recoding During Reading

MEREDYTH DANEMAN and EYAL REINGOLD
Erindale College, University of Toronto

Abstract Evidence for phonological recoding during reading has depended on paradigms requiring readers to make some response in addition to reading (e.g., proofreading, concurrent speaking). Our subjects simply read text for comprehension, and their eye movements were monitored for spontaneous disruptions when encountering homophonic errors (e.g., *He wore blew jeans*) versus nonhomophonic errors (e.g., *He wore blow jeans*). Eye fixation behaviour revealed that readers initially experienced as much difficulty when encountering a homophonic error as a nonhomophonic one; however homophony facilitated the recovery process, at least for homophones that shared the same length as their context correct mates (e.g., *blew/blue* but not *wart/wore*). The results support a theory of lexical access in which phonological sources of activation and influence are delayed relative to orthographic sources, rather than a theory in which phonological codes predominate.

Résumé Les éléments de preuve à l'appui de l'enregistrement phonologique durant la lecture reposent sur des paradigmes selon lesquels les lecteurs doivent non seulement lire un texte, mais également fournir une certaine réponse (p. ex. correction d'épreuves, langage simultané). Dans notre expérience, les sujets devaient simplement lire un texte et le comprendre, tandis que leurs mouvements oculaires étaient enregistrés pour y détecter les perturbations spontanées en présence d'erreurs homophoniques (p. ex. *He wore blew jeans*) par opposition à des erreurs non homophoniques (p. ex. *He wore blow jeans*). D’après les fixations oculaires, les lecteurs éprouvaient d’abord autant de difficulté avec les erreurs homophoniques qu’avec les autres erreurs; cependant, l’homophonie facilitait le processus de redressement, du moins dans le cas des homophones de même longueur (p. ex. *blew/blue*, mais non *wart/wore*). Plutôt que d’appuyer une théorie de la prédominance des codes phonologiques, les résultats corroborent une théorie de l’accès au lexique, selon laquelle les sources d’activation et l’influence d’ordre phonologique interviennent après les sources orthographiques.

Consider encountering the following passage during the course of reading a short story about a bank holdup:

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The teller ducked his head and saw a vein little man only for feet high who paced up and down, stopping at intervals to flex his impressive arm muscles. He wore a tee shirt, suede jacket, and blew jeans. Over his furrowed forehead and apelike brows perched a wig, apparently put on with glue. His nose went straight for a bit, then took a sharp turn to the side. Yet Harry 'Peewee' Farplotz, the world's smallest and most inept bank robber, had style...

Did you notice that there were three spelling errors in the passage? Now consider the following version:

The teller ducked his head and saw a vine little man only fir feet high who paced up and down, stopping at intervals to flex his impressive arm muscles. He wore a tee shirt, suede jacket, and blow jeans. Over his furrowed forehead and apelike brows perched a wig, apparently put on with glue. His nose went straight for a bit, then took a sharp turn to the side. Yet Harry 'Peewee' Farplotz, the world's smallest and most inept bank robber, had style...

Did you find it more difficult to detect the errors vein, for, and blew in the first version than the errors vine, fir, and blow in the second? All six words are semantically inconsistent in the context of the passage. However, vein, for, and blew happen to sound identical to the words vain, four, and blue which are perfectly consistent in that context, whereas vine, fir, and blow do not. If readers are less likely to notice an error that was a homophone of the correct word, this might suggest that they translate orthographic representations to phonological representations when comprehending printed text. By translating the orthographic representation vein to its phonological representation /veɪn/, the clause ...and saw a vein little man would still sound correct and the error may be more likely to go undetected.

Rather than asking their subjects simply to read the passage (as we asked you in the opening paragraph of this article), Daneman and Stainton (1991) had them proofread the text for incorrect words as they read. When deliberately instructed to proofread, readers were less likely to detect homophonic error words than nonhomophonic ones, a finding that Daneman and Stainton (1991) took as evidence for the activation of phonological codes during normal silent reading. Although Daneman and Stainton's (1991) comprehension-sensitive proofreading task 1 approximated real-life reading more than any of the tasks

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1 The proofreading task was comprehension-sensitive in the sense that only errors producing legal English words were introduced into the text (e.g., vain misspelled as vein or vine); this meant that an error could only be detected if the reader understood the semantic and syntactic context in which the error word occurred. Indeed, there is some evidence to suggest (e.g., Daneman, 1988) that this kind of proofreading task is more likely to correlate with reading
used in previous studies of homophone confusion effects, there is still the
concern that the proofreading requirement changed the nature of the reading
process itself. In this study we looked for evidence of phonological recoding
in a task that demanded nothing other than normal reading for comprehension.
Our readers were not asked to proofread for errors while they read. In fact,
they were not required to perform any other secondary task (e.g., concurrent
speaking); nor were they required to make any unnatural judgements about
what they were reading (e.g., decide on the lexical status of a letter string, or
the semantic acceptability of a sentence). They were simply given the goal of
reading for comprehension, and we monitored their eye fixation behaviour for
evidence of disruptions when encountering homophonic errors (e.g., a vein
little man for feet high) versus nonhomophonic errors (e.g., a vine little man
fir feet high). As we will show, not only did the eye fixation data provide
evidence for the activation of phonological codes during natural silent reading,
but they provided evidence concerning the time course of the activation. We
will first describe the kinds of homophone tasks on which previous evidence
has been based, paying particular attention to the Daneman and Stainton
(1991) task. Then we will describe the unobtrusive technique used here.

Although our review of the literature will be limited to research based on
homophone confusions, this is not the only paradigm that has been used to
investigate phonological processes during silent reading. Edfalt (1960) used
electromyography (EMG) recordings to determine whether there was any
muscular activity in the area of the larynx during reading. Numerous other
researchers (e.g., Daneman & Newson, 1992; Kleiman, 1975; Levy, 1977,
1978; Slowiaczek & Clifton, 1980; Waters, Caplan, & Hildebrandt, 1987)
have used a speech suppression paradigm; in this paradigm, subjects are given
a concurrent speaking task while reading a set of sentences or passages; they
may be asked to count out loud from 1 to 10 over and over, repeat the same
irrelevant word (e.g., cola, cola), or listen to and repeat (shadow) a list of
spoken words as quickly as possible. Any evidence that the speaking task
interferes with reading performance is taken to suggest that concurrent
speaking competes for the speech codes and mechanisms normally used
during silent reading (although see Waters, Komoda, & Arbuckle, 1985, for
an alternative interpretation). Of course, the concurrent speaking paradigm has
the same disadvantage as the proofreading paradigm in that it requires some
response from the subject in addition to reading.

In the homophone research tradition, much of the evidence for the recoding
of print to sound comes from lexical decision tasks in which subjects judge

comprehension ability than is the more typical proofreading task (e.g., Haber & Schindler,
1981; Healy, 1980; Levy, 1983) in which misspellings always produce nonwords (e.g., vain
misspelled as woin) that can be detected simply on the basis of word-nonword discriminations.
whether a given letter string is a word. Subjects typically take more time to reject pseudohomophone foils, such as brane, than to reject control foils, such as brene (Coltheart, Davelaar, Jonasson, & Besner, 1977; Rubenstein, Lewis, & Rubenstein, 1971). A common explanation for the effect is that a pseudohomophone such as brane activates the phonological representation /breIn/, which in turn activates the lexical entry for the word brain. The activation of a lexical entry makes brane more difficult to classify as a nonword.²

There are at least two problems in generalizing from the pseudohomophone effect to normal reading. The first problem is that the effect is observed on no trials which are usually slower than yes trials. Hence, the nonword’s effect in the lexical decision task may occur after the time has elapsed that is typically needed for word identification. This means that the pseudohomophone effect may have no relevance with respect to whether phonological processes are involved in real word recognition (Coltheart et al., 1977; McCusker, Hillinger, & Bias, 1981; Van Orden, 1987). And even if the pseudohomophone effect were relevant to word identification, there remains the more pervasive problem of generalizing from word identification in the laboratory-created lexical decision task to word identification in the more natural reading of connected text.

Van Orden’s (1987) categorization task avoids the problem of extrapolating from no trials. In his task, subjects are presented a category name (e.g., type of flower) followed by a target word (e.g., rows, robs, or tulip), and their task is to decide whether or not the target word is a member of the category. The key dependent measure is the number of false yes responses to a homophone word foil (e.g., rows which sounds like a genuine category member rose) as compared with the number of false positives to nonhomophonic control words matched for orthographic similarity (e.g., robs which looks but does not sound like a genuine category member). Van Orden (1987) found that homophonic word foils were erroneously categorized as category exemplars in 18.5% of trials as compared with only 3% false positive categorizations for the nonhomophonic control words, a finding that has since been replicated (Van Orden, Johnston, & Hale, 1988) and taken to suggest that the phonological representations of words are activated during word identification. Because the categorization task draws on a homophone effect for yes trials, it avoids the problem of making inferences based on the slower no latencies. However, like the lexical decision task, it involves an artificial or laboratory-created response to isolated words. Thus, there still remains the need to demonstrate homophone effects in a more normal reading situation.

The sentence decision experiments are somewhat more reading-like in that

² See also Lukatela and Turvey (1991) for a more recent demonstration of pseudohomophone effects in an associative-priming paradigm.
subjects' decisions depend on the comprehension of an entire sentence rather than an isolated word. In these experiments, subjects are required to judge the acceptability of short sentences, with some of the incorrect sentences containing a homophonic word that makes the sentence sound correct, for example, *She has blond hare.* (Treiman, Freyd, & Baron, 1983), *The none says her prayers.* (Coltheart, Avons & Trollope, 1990). These studies have consistently shown that both adults and children make more errors (false-positive decisions) on incorrect sentences that sound correct, for example, *She has blond hare,* than on incorrect sentences that do not sound correct, for example, *She has blond harm.* (Coltheart, Laxon, Rickard, & Elton, 1988; Coltheart et al., 1990; Doctor & Coltheart, 1980; Johnston, Rugg, & Scott, 1987; Treiman, et al., 1983). It is important to note that error rates to sentences with homophones tend to be rather low for adults, in the 10-25% range; thus, when orthographic and phonological codes suggest different decisions, orthography is still more likely to determine the decision (see also Patterson & Coltheart, 1987). Nevertheless, the presence of a small but reliable homophone effect has usually been taken to imply that fluent adult readers access the phonological representations of all words during silent reading, with misleading phonology only sometimes duping them. Daneman and Stainton (1991) argued that the low error rates for homophone sentences and even lower rates for nonhomophone controls (0-6%) are indicative of a reading comprehension task that is altogether much too easy. The stimulus sentences all tend to be short, stereotyped expressions that are very simple to comprehend. In other words, even though the sentence decision paradigm involves reading for meaning, it does not draw on the kinds of complex comprehension processes that are part and parcel of full-blown reading.

Daneman and Stainton (1991) improved upon the ecological validity of the homophone paradigm by having subjects read a fairly lengthy prose passage rather than a list of unrelated words or sentences; and by showing that their proofreading task was not only much more difficult than the sentence decision tasks (overall error detection rates were less than 64%), but that it was significantly and positively correlated with an independent, standardized test of reading comprehension ability. There were two versions of their comprehension-sensitive proofreading task. In one version, readers had to identify the error words; in a second version they had not only to identify the error words but repair them as well. When readers merely had to identify the error words, evidence for phonological recoding came in the form of a homophone interference effect; phonological likeness interfered with the detection of homophonic error words, presumably because the printed word *vein* activated the phonological code *veln* which in turn activated the contextually consistent homophone *vain*, making the inconsistency in the phrase *vein little man* go unnoticed. When subjects had to identify *and* repair the inconsistent words, evidence for phonological recoding was in the form
of a facilitation effect; phonological likeness facilitated the recovery of correct words, presumably because for those cases in which the reader had successfully detected the inconsistent impostor word *vein*, that same activated phonological code /væn/ could be used as a retrieval route to the correct alternative *vain*. Thus, there was a cost and benefit associated with the availability of lexical phonological codes in Daneman and Stainton’s (1991) proofreading tasks; the activation of contextually consistent homophones interfered with the initial detection of semantic inconsistencies, but facilitated the process of recovering the correct word for those inconsistencies that were detected.

Not only did Daneman and Stainton (1991) establish that phonological codes are activated during the silent reading of normal connected prose, but they claimed to provide evidence for the locus and function of these codes. Psychologists have proposed two possible roles for phonological codes. On the one hand, the reader might generate transient phonological representations that are used, in conjunction with the orthographic representations, by the processes involved in word identification and lexical access (Besner, Davies, & Daniels, 1981; Coltheart, 1978; Meyer, Schvaneveldt, & Ruddy, 1974; Rubenstein et al., 1971; Van Orden, 1987; Van Orden, et al., 1988). In this case, observed homophone effects would arise during the process of lexical access itself. However, phonology may have its influence beyond the level of individual word comprehension. During reading, sequences of words must be held in a temporary storage buffer while the comprehension processes integrate them into a meaningful conceptual structure that can be stored in long-term memory (Daneman & Carpenter, 1983; Kintsch & van Dijk, 1978). It has been argued that the most stable and retrievable short-term memory (or working memory) code is a sound based one (see Baddeley, 1986, for an extensive discussion of the properties of working memory and its articulatory loop). By generating phonological representations that are less vulnerable to memory loss, the reader could keep track of exact words rather than rough meanings (Baddeley, 1979; Baddeley, Eldridge, & Lewis, 1981). According to this account, the availability of phonological codes in working memory would be responsible for any observed homophone effects during proofreading. Daneman and Stainton (1991) claimed that their findings supported the former position, that the phonological codes are transient and activated as part of the lexical access process itself. Their claim was based on their finding that a concurrent speaking manipulation did not abolish or even reduce the homophone interference effect. Because previous researchers have argued that concurrent speaking interferes with the reader’s ability to maintain phonological codes in working memory (Baddeley, 1979; Baddeley et al., 1981) but not with the reader’s ability to generate the kind of phonological code that is used for lexical access (Baddeley, 1986; Besner, 1987; Besner & Davelaar, 1982; Besner, et al., 1981), Daneman and Stainton (1991) took the persistence of a homophone effect to mean that the locus of the effect was at
although Daneman and Stainton (1991) acknowledged that their results were consistent with "any number of models that allow lexical phonology to combine with or dominate orthographic information in guiding the reader to the meaning of a word" (p. 624), they opted for a model in which phonology plays the dominant role. In their model (a context-sensitive adaptation of Van Orden's 1987 model), the phonological code is computed immediately and used exclusively to gain access to a word's meaning representation in memory, with the orthographic code playing a post-activation verification role. For example, when a reader encounters a printed word (e.g., vein), its phonological representation (/veɪn/) is immediately computed from the orthographic features (see also Perfetti, Bell, & Delaney, 1988), and it is this phonological representation that activates candidate lexical entries (e.g., vain meaning "conceited" and vein meaning "blood vessel"). However, before an activated lexical entry can be selected, it must pass a verification test or spelling check. The orthographic representation associated with the most active candidate is retrieved from memory and compared with the orthographic representation of the word being read. If a match occurs, the lexical entry is selected; if not, the verification process is repeated on the next most active candidate lexical entry. According to this model, the printed word vein might occasionally be mistaken for vain if the false candidate vain were made available to the verification procedure and the mismatch in spelling slipped by undetected. Vein would be even more likely to be mistaken for vain if readers had previously been exposed to The teller ducked and saw a vain little man; according to the context-sensitive feature of the model, rereading or "expectancy-driven" reading leads to a relaxation of the orthographic verification standards, allowing even more spelling mismatches to slip by undetected.

Based on the findings from our more unobtrusive and naturalistic reading task, we will argue that orthographic information plays a much more dominant role in lexical access than Daneman and Stainton's model allows, and the phonological activation appears to be postlexical rather than prelexical; that is, it appears to be a by-product of lexical access rather than a route to it (see also McCutchen & Perfetti, 1982).

The Experiments
Our experiments looked for evidence of phonological recoding during the most natural or typical of reading situations possible, reading for comprehension and entertainment. The basic task was as follows. Adult subjects were asked to read the same text used in the Daneman and Stainton (1991) study: an 1,100-word story about the misadventures of a bank teller named Russell Wood. However, two important modifications were introduced. The first was to the Russell Wood text. Daneman and Stainton's (1991) manipulation
involved the introduction of 48 errors to homophonic words (e.g., \textit{vain}), half of which produced the homophone mate (e.g., \textit{vein}), and the other half, a nonhomophonic orthographically similar control word (e.g., \textit{vine}). In the present experiments, some of the target words were retained in their original contextually correct form (e.g., \textit{vain}). In Experiment 1, half the target words appeared in their correct form, half as the contextually inconsistent homophone mate. In Experiment 2, one third of the target words appeared in their correct form, one third as homophone errors, and one third as orthographically similar nonhomophone errors. The second modification was to the reading task itself. Daneman and Stainton's (1991) subjects were told that inconsistent words had been introduced into the text and they were given explicit instructions to proofread the text for the inconsistent words as they read; the activation of phonological codes was inferred from the proofreading response rather than from the reading \textit{per se}. In the present experiments, we neither forewarned our subjects about the presence of the errors, nor gave them any instructions to proofread for the errors; rather, we simply had them read for comprehension and we recorded their eye fixations to examine whether phonological involvement is spontaneously revealed in the moment-to-moment computational processes of regular reading. Previous research has shown that readers pause longer on words that are inconsistent with previously read information (Carpenter & Daneman, 1981; Just & Carpenter, 1980) and frequently make regressive fixations as they attempt to resolve the inconsistencies (Carpenter & Daneman, 1981). Thus, any additional time spent fixating an inconsistent phrase (e.g., \textit{vein little man}) relative to the consistent one (e.g., \textit{vain little man}) could be attributed to the processes involved in inconsistency detection and recovery. If the Daneman and Stainton (1991) proofreading tasks reflected what occurs more spontaneously during natural reading and comprehension monitoring, then we might expect to find that readers frequently fail to detect homophone errors, showing no additional processing time when first encountering \textit{vein} relative to processing time spent when first encountering the contextually appropriate \textit{vain}. However, for those homophones that \textit{are} detected, readers should show quicker error recovery than for the nonhomophone errors, with less time spent in regressive fixations after encountering the inconsistency.

The rationale for including an experiment without the nonhomophone control errors was as follows. We were concerned that the potentially easy-to-detect nonhomophone errors might draw attention to the manipulation and somehow interfere with natural reading; by excluding these error types in Experiment 1, we could observe any possible phonological influences uncontaminated by the other errors. For example, strong evidence for phonologically-mediated lexical access would be a null finding in Experiment 1; that is, no difference in the processing of homophone errors relative to their contextually compatible homophone counterparts. It is not that we predicted
this finding. Previous homophone research has shown that readers are only sometimes seduced by homophone impostors (see also Patterson & Coltheart, 1987; Van Orden, 1987); consequently, the mean processing time for the contextually inconsistent homophones should be greater than for the contextually consistent ones. Nevertheless, we included this experiment to see whether we could replicate the pattern for homophone errors across texts that did and did not contain the nonhomophonic errors.

Not only did we include two kinds of errors (e.g., vein; vine) in order to examine the effects of homophony independent of orthographic similarity, but we also included two kinds of homophones (e.g., vein/vain; for/four) in order to examine the effects of orthographic similarity independent of homophony. As in the Daneman and Stainton (1991) study, half our homophone errors shared considerable spelling similarity with their contextually correct homophone mates because they were the same length as them (e.g., vein which is the same length as vain; blew which is the same length as blue); the other half were less similarly spelled because they were a different length than their contextually correct homophone mates (e.g., for which is shorter than four, none which is longer than nun). Daneman and Stainton (1991) were not able to demonstrate consistent differences in either detection rates or repair rates for the two kinds of homophone errors. However, it is possible that our on-line reading measure might expose processing differences that their proofreading measures were not sensitive enough to do.

METHOD

Subjects
The subjects were 50 University of Toronto undergraduates who were all fluent speakers of English; 20 participated in Experiment 1, and the other 30 participated in Experiment 2. Each subject was tested individually in a session lasting approximately 50 minutes.

Materials and Procedure
The experimental manipulation involved 48 homophonic words that appeared in the Russell Wood story; all 48 original words and their two corresponding error forms are listed in the Appendix. The Russell Wood text was selected by Daneman and Stainton (1991) because it was a fairly complex yet engaging piece of prose and because it contained a large number of homophonic words. Of these, the 48 that were selected for the experimental manipulation met the following criteria: (a) They were distributed across the entire story with no more than 2 occurring in the same sentence; (b) each was

3 The Russell Wood text is an extensively edited version of a story entitled “Good Knight, Suite Prints” by Mary Ellen Slate that appeared in an issue of a magazine called Games (Chicago: Playboy Enterprises).
spelled with the same initial letter as its homophone mate (e.g., steal-steel but not night-knight); (c) readers were likely to know the meanings and spellings of both homophones in the pair; (d) in half of the cases, the homophone pairs were identical in length (e.g., vain and its substitute form vein; bored and its substitute form board); in the other half they were not (e.g., four and its substitute for; nun and its substitute none); in the case of the 24 different-length homophone pairs, 12 appeared as the longer of the two in the original story (e.g., four, which is one character longer than its mate, for), and 12 appeared as the shorter of the two (e.g., nun, which is shorter than its mate, none); and (e) a nonhomophonic control word could be created such that it shared the same consonant sounds as the correct word and its homophone mate, but differed only in the vowel sound (e.g., vine for vain/vein and fir for four/for). This consonant-same manipulation ensured that the homophonic and nonhomophonic error words had equal orthographic similarity to the correct word, and that the nonhomophonic control was as phonologically similar to the homophones as it could be.4

In Experiment 1, subjects read a version of the text in which 24 of the homophonic words appeared in their original contextually correct form, and 24 appeared as homophone errors. Counterbalancing of target words across the two word forms (correct word or homophone error) was accomplished by creating two versions of the Russell Wood story; a target word that appeared in its contextually correct form in the one version appeared as its homophone mate in the other. Each subject was randomly assigned to read one of the two error-filled versions.

In Experiment 2, subjects read a version of the text in which 16 of the target words appeared in their correct form, 16 as homophone errors, and 16 as nonhomophone errors matched for orthographic similarity to the correct word. Counterbalancing of target words was accomplished by creating three versions of the text; a target word appeared in a different form (correct word, homophone error, nonhomophone error) in each version. Each subject was randomly assigned to read one of the three error-filled versions.

4 To rule out alternative interpretations of a homophone effect, care must be taken in constructing and matching homophonic and nonhomophonic error words (Martin, 1982; Patterson & Coltheart, 1987). For example, most words that sound alike are also spelled alike; hence it is necessary to ensure that homophone errors are not going undetected because of spelling similarity. Recent investigations of the homophone effect in reading have taken great care to ensure that homophone and nonhomophone alternatives have equal orthographic similarity to the words in question (e.g., Coltheart et al., 1988; Treiman et al., 1983). Daneman and Stainton (1991) matched each homophone error with four kinds of nonhomophone control words in an attempt not only to control for orthographic similarity but phonological similarity and semantic similarity too. In this study we use Daneman and Stainton’s “consonant-same” controls, the ones most orthographically and phonologically similar to the correct word.
The procedure was identical for both experiments. Subjects were told that they would be presented with a short story on successive screens of a computer monitor. They were instructed to read the story silently at their own pace, making sure that they understood it well enough to answer questions about its content later. The text was displayed on a VGA monochrome monitor in conventional upper and lower case black font with white background. In all, there were 20 screens of text, each containing no more than eight double-spaced lines of text. Subjects controlled the rate of presentation of each screen by pressing a start button to initiate presentation of the screen display and a stop button to remove it.

Subjects viewed the screen with their heads positioned in a chin rest (to minimize head movements). Viewing was binocular but only the position of the right eye was measured and recorded. Subjects' eye fixations were recorded by an Iscan (Model RK-416) pupil-center eye tracking system which calculated the x and y coordinates of the reader's point of regard every 16.7 milliseconds. A 386 IBM-compatible microcomputer was used to record the eye movement data as well as to display the stimulus text on the subject's monitor and on the experimenter's monitor. In addition to the stimulus text, the experimenter's monitor displayed the subject's gaze position in real time via an overlaid circular cursor measuring one degree of visual angle in diameter. This display enabled the experimenter to monitor the quality of the subject's calibration throughout the experiment so that a recalibration could be implemented during the course of the experiment if necessary. Prior to reading, a formal nine-point calibration procedure assured that the tracker was accurate to one-half degree of visual angle to either side of the reader's fixation center (an area subtended by approximately 1.1 characters of print). For an in-depth description of the calibration system and other features of our eye tracker's capabilities, see Stampe (in press).

Because Daneman and Stainton (1991) found a greater homophone interference effect if subjects were exposed to an intact error-free version of the Russell Wood text before proofreading, we included a familiarization manipulation in our experiments too. Before the eye-tracking portion of the experiment, half of the subjects were given an error-free print-out of the Russell Wood story and asked to read it silently for comprehension; the other half were not familiarized on the error-free version first.

After completing the eye-tracking phase, subjects were given two tests, one that tested their comprehension of the Russell Wood story, and a second that tested their knowledge of how the 48 homophone pairs were spelled. Comprehension of the story was tested with ten questions of the following sort: "Who was Harry 'Peewee' Farplotz?" "Why couldn't Russell Wood see him at first?" In Experiment 1, the mean comprehension score was 7.50 out of a possible 10 (SD = 2.23); in Experiment 2, the mean comprehension score was 7.77 (SD = 2.05); the reasonably high performance on the comprehension
check indicated that readers had followed instructions to read for understanding. The purpose of the homophone spelling test was to ensure that any failure to detect a homophone error (e.g., vein substituted for vain) could not have been attributed to lack of knowledge about how the two different words were spelled. Subjects were given 48 fill-in-the-blank items of the following sort: (a) The needle entered the ____ (vain or vein); (b) The ____ corners of the room had cobwebs (four or for). In each case, their task was to circle which of the two words belonged in the sentence. For half the items, the correct word was the homophone that appeared in the original story; for the other half, the correct word was the homophone substitution. A second version of the spelling test was created by constructing 48 new items, each of which required the opposite solution to its counterpart in the first version: (a) The ____ woman looked at herself in the mirror (vain or vein); (b) The boy went to look ____ his younger brother (four or for). Subjects were randomly assigned to complete one of the two versions of the spelling test. In Experiment 1, the mean score on the homophone spelling test was 47.75 out of a possible 48 (SD = 0.55); in Experiment 2 it was 47.80 (SD = 0.48); the almost perfect performance indicated that any failure to detect homophone errors could not have been attributed to lack of knowledge about how the 48 homophone word pairs were spelled.

Data Analysis
Three dependent measures were used to determine whether an incorrect word was detected and error recovery processes initiated. They were (a) first pass reading time on the target word; (b) total time on the target word; (c) total repair time. An example from three readers’ eye fixation protocols will illustrate how the three dependent measures were computed. Figure 1 shows the three readers’ eye fixations while reading the phrase ...a vain/vein/vine little man... In each case, the sequence of fixations is denoted by the successive numbers below the word being fixated, with the duration of each fixation (in milliseconds) indicated in parentheses below the associated fixation. 5 The first pass reading time on the target word was simply the time spent fixating the target word when first encountered; for the reader who saw the vain version in Figure 1, first pass reading time was 266 msec; for the reader who saw vein it was 334 msec; and for the reader who saw vine it was 334 msec as well. Total time on the target word included the first pass time plus any subsequent time spent in regressive fixations to it; for the reader of vain, total time was still 266 msec because vain was not refixated; for the reader of vein it was 584 msec (the sum of fixations 1 and 3); and for the reader of vine it was 1051 msec (the sum of fixations 1, 3, 5, and 7). Total

5 The duration of consecutive fixations on a word have been summed together; see Carpenter & Daneman, 1981; Just & Carpenter, 1980.
CORRECT WORD

... a vain little man...

1  
(256)

2  
(217)

3  
(283)

HOMOPHONE ERROR

... a vein little man...

1  
(334)

2  
(217)

3  
(250)

4  
(317)

NONHOMOPHONE ERROR

... a vine little man...

1  
(334)

2  
(384)

3  
(250)

4  
(183)

5  
(217)

6  
(183)

7  
(250)

8  
(367)

Fig. 1 Three readers' eye fixations while reading the phrase containing the target words vain, vein, and vine, respectively. In each case, the sequence of fixations is denoted by successive numbers below the fixated word, with the duration of each fixation (in msec) indicated in parentheses below the associated fixation. Note that readers paused longer on the errors vein and vine than on the contextually consistent vain. Note also that the first pass reading time for the same-length homophone error vein was no shorter than that for the nonhomophone control error vine; however, total repair time for vein was much shorter than for vine, indicating the typical homophone facilitation effect for same-length homophones.

*repair time* included all consecutive fixations, forward and regressive, from the first fixation on the target word up to but not including any fixations in advance of the target word once the reader proceeded in a forward direction (that is, did not regress back to the target word or to any word preceding the
CORRECT WORD

... only four feet high...

1  2  3  4
(150) (150) (183) (217)

HOMOPHONE ERROR

... only for feet high...

1  2  3
(150) (300) (150)
4  5
(334) (183)
6  7  8  9
(350) (233) (167) (217)

NONHOMOPHONE ERROR

... only fir feet high...

1  2  3
(167) (300) (367)
4  5
(183) (433)
6  7
(257) (283)

Fig. 2 Three readers' eye fixations while reading the phrase containing the target words four, for, and fir, respectively. Note that readers paused longer on the errors for and fir than on the contextually correct four. Note also that the first pass reading times showed that the different-length homophone error for was initially as disruptive as the nonhomophone error fir; moreover, the total repair times for for and fir were equivalent, indicating the typical lack of a homophone facilitation effect for the different-length homophone errors.

target); for the reader of vain total repair time included only the 266 msec fixation on the target word because no regressions were initiated; for the reader of vein, total repair time was 801 msec (the sum of fixations 1–3); for the reader of vine, it was 1801 msec (the sum of fixations 1–7). For

6 Note that fixations 2, 4, and 6 were included in the computation of total repair time even
additional illustrations of how the three dependent measures were computed, see Figure 2, which depicts the eye fixation protocols of three subjects reading the continuing phrase ...only four/four/four feet high... 7 The individual eye fixation protocols in Figures 1 and 2 also serve as prototypical examples of the results to be presented next; Figure 1 shows the typical pattern for same-length homophones (e.g., vein/vain); Figure 2 shows the pattern for different-length homophones (e.g., for/four).

Results and Discussion  

EXPERIMENT 1  

Table 1 demonstrates the effect of same-length and different-length homophone errors on the reader's eye fixation behaviour. The data have been averaged across the two familiarization conditions (familiarized and unfamiliarized) because preliminary analyses showed that familiarization did not influence eye fixation patterns or interact with any of the experimental manipulations (all Fs < 1). As seen in Table 1, all three dependent measures showed that readers took more time to process a homophone if it was inconsistent with the context, thereby providing strong evidence for the spontaneous detection of homophone errors during normal reading. The first dependent measure, first pass time on the target word, provided evidence that the detection was immediate, that is, that it occurred when the reader first encountered the error, rather than later on, say at the end of a clause or sentence (see also Carpenter & Daneman, 1981; Just & Carpenter, 1980). As seen in Table 1, readers spent on average 347 msec when first encountering a homophone error, as compared to only 299 msec fixating the correct word, a 48 msec difference that was significant across subjects, $F_1(1,19) = 18.13$, $MS_e = 2554$, $p < .001$, and across items, $F_2(1,46) = 8.46$, $MS_e = 6319$, $p < .01$, and presumably reflected the difficulty readers were experiencing integrating the inconsistent word (e.g., board) with the prior text (Alone at his teller's cage, idle and board,...). 8 There was no difference in the additional processing though they were fixations in advance of the target word vis á vis; this is because regressions to the target word were initiated after them; however, fixation 8 was not included in the calculation because the reader did not initiate a regression back to the target word or to any word(s) preceding it, but resumed reading in a forward direction.

7 For the four reader, first pass reading time, total time on the target word, and total repair time were all 150 msec, the duration of fixation 2. For the for reader, first pass reading time was 300 msec, the duration of fixation 2; total time on the target word was 716 msec, the sum of fixations 2, 5 and 7; total repair time was 1550 msec, the sum of fixations 2 – 7. For the fir reader, first pass reading time was 300 msec, the duration of fixation 2; total time on the target word was 750 msec, the sum of fixations 2, 4, and 6; total repair time was 1550 msec, the sum of fixations 2 – 6.

8 There was already evidence for inconsistency detection on the first fixation. An analysis that
time for homophone errors that were the same length as their homophone mates (e.g., \textit{board} substituted for \textit{bored}; \textit{vein} substituted for \textit{vain}) or a different length than their homophone mates (e.g., \textit{none} substituted for \textit{nun}; \textit{for} substituted for \textit{four}), (subject and item interaction $F_{1} < 1$), a finding which suggests that both error types were equally likely to be detected. However, there were differences across the two kinds of homophone errors for the dependent measures that included regressive fixations, a finding which suggests that the more similarly spelled same-length homophone errors may have been easier to repair. As seen in Table 1, \textit{total time spent on the target word} was much greater for incorrect homophones ($M = 554$ msec) than for correct ones ($M = 351$ msec), $F_{1}(1,19) = 30.31$, $MS_{s} = 27264$, $p < .001$, and $F_{1}(1,46) = 65.43$, $MS_{s} = 14901$, $p < .001$; and \textit{total repair time} was also much greater for incorrect homophones ($M = 789$ msec) than for correct homophones ($M = 449$ msec), $F_{1}(1,19) = 25.35$, $MS_{s} = 91263$, $p < .001$, and $F_{1}(1,46) = 65.56$, $MS_{s} = 42435$, $p < .001$. However, for both dependent measures the processing cost of an inconsistent word was significantly less for the same-length homophones than for the different-length homophones. As Table 1 shows, readers only spent an additional 148 msec processing a same-length homophone error than its contextually consistent homophone mate; in contrast, they spent an additional 258 msec processing a different-length homophone than its contextually consistent homophone mate, interaction $F_{1}(1,19) = 6.45$, $MS_{s} = 9471$, $p < .03$, and interaction $F_{1}(1,46) = 4.60$, $MS_{s} = 14910$, $p < .04$. Similarly, the processing cost associated with an incorrect homophone that was the same length as its correct homophone mate was 236 extra msec in total repair time; the processing cost associated with an incorrect homophone that was a different length than its correct mate was 443 extra msec of repair time, interaction $F_{1}(1,19) = 7.62$, $MS_{s} = 28077$, $p < .02$, and interaction $F_{1}(1,46) = 5.66$, $MS_{s} = 42435$, $p < .03$. Although we have no overt measure of whether or not readers successfully repaired the inconsistency, the shorter time spent reading and rereading phrases containing same-length homophone errors strongly suggests that readers could recover from these errors more easily.

Experiment 1 ruled out the possibility, albeit an unlikely one, that readers would fail to detect \textit{all} "sound-okay" errors during normal silent reading for comprehension. Instead, Experiment 1 provided strong evidence that readers are able to detect at least some substantial proportion of the homophonic errors (e.g., \textit{board} in \textit{Alone at his teller's cage}, \textit{idle} and \textit{board},...), a finding included only the first fixation on the target word showed that readers spent on average 260 msec when first fixating a homophone error, as compared to only 241 msec when first fixating the correct word, a difference that was significant across subjects, $t(19) = 2.42$, $p < .03$, and across items, $t(47) = 2.01$, $p < .05$. Of course, the 19 msec difference is smaller than the 48 msec difference found for first pass reading time, presumably because the latter measure would be more likely to capture the later stages of processing (Inhoff, 1984) that are involved in detecting a semantic inconsistency between the target word and the prior text.
which suggests that readers pay attention to orthographic codes in determining the meanings for words. However, phonological processes would still be implicated if homophonic errors (e.g., board) went unnoticed more frequently than orthographically matched nonhomophonic errors (e.g., beard), or if there was a difference in recovery time for the two kinds of errors. This possibility was tested directly in Experiment 2.

**EXPERIMENT 2**

Table 2 demonstrates the effect of same-length and different-length homophone and nonhomophone errors on the reader's eye fixation behaviour. As in Experiment 1, the data have been averaged across the two familiarization conditions (familiarized and unfamiliarized) because preliminary analyses showed that familiarization did not affect the eye fixation durations or interact with any of the other experimental manipulations (all $p$s < 1).

The first point to note is that the homophone error data closely replicated those found in Experiment 1. All three dependent measures showed that readers spent longer processing homophone errors than their contextually correct homophone mates, and only in the case of the two dependent measures that included regressive fixations was there the additional finding that the processing cost of an inconsistent homophone was smaller if the homophone was the same length as its context correct mate. Not only was this pattern of results identical to that for Experiment 1, but the size of each effect was the same too. This was revealed in a series of across-experiment analyses of variance (ANOVA's) that included the data for homophone errors and correct words from all 20 subjects in Experiment 1 as well as all 30 subjects in Experiment 2; for each of the three dependent measures, the ANOVA's revealed no main effect of experiment, and no interactions between experiment and the
other manipulations (all $p > .18$). Thus, the mere presence of nonhomophonic errors in the Experiment 2 text did not affect the way readers processed the homophone errors.

When the eye fixation data for all three types of target words in Experiment 2 were considered, an interesting pattern emerged. In a nutshell, the data revealed that readers initially experienced as much difficulty when encountering a homophonic error as a nonhomophonic one; however, homophony facilitated the recovery process, at least for homophones that shared the same length as their context correct mates.

**Initial detection:** The **first pass reading times** revealed a significant main effect for type of target word, $F(2,58) = 7.38$, $MS_e = 5167$, $p < .001$, and $F(2,90) = 7.53$, $MS_e = 3611$, $p < .01$. A seen in Table 2, readers spent on average 278 msec when first encountering a contextually consistent word, whereas they spent an additional 45 msec on a homophone error and an additional 43 msec on a nonhomophone error. Pair-wise $t$-tests showed that the main effect could be attributed to the difference between processing a semantically consistent target word versus a semantically inconsistent one. Readers initially took longer to process a homophone error than its contextually correct homophone mate, a finding that was significant across subjects $t(29) = 3.40$, $p < .01$, and items, $t(47) = 3.47$, $p < .001$; similarly, they took longer to process a nonhomophone error than the contextually correct word, subject $t(29) = 3.77$, $p < .001$, and item $t(47) = 3.69$, $p < .001$. However, there was no difference in initial processing time for homophone versus nonhomophone errors, subject $t(29) = 0.02$, $p > .95$, item $t(47) = 0.07$, $p > .90$, a result which shows that homophonic errors were as disruptive as nonhomophonic errors, and suggests that homophonic errors were detected as

<table>
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<th>Correct Word</th>
<th>Homophone Error</th>
<th>Nonhomophone Error</th>
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<td>Mean</td>
<td>385</td>
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</table>
Eye Fixations and Phonological Recoding

The finding was consistent across same-length and different-length homophone errors (subject and item interaction $F_{s} < 1$), thus suggesting that both types of homophone errors were detected as easily as the nonhomophone errors. In contradistinction to the findings from proofreading responses (Daneman & Stainton, 1991), the results from our on-line reading measure provide no evidence for a homophone interference effect. We take this lack of phonological interference in the early detection of homophonic errors as evidence against those models that assume phonological sources of activation invariably precede word identification (Daneman & Stainton, 1991; Van Orden, 1987).

Error Recovery: When the post-detection error-recovery fixations were included in the analysis, a homophone effect finally emerged. In the interests of brevity, only the results for total repair time will be presented in detail because the other measure of recovery time, total time on the target word, produced the identical pattern of results. The ANOVA on total repair time revealed a significant main effect of type of target word, $F_{1}(2.58) = 40.23, MS_{e} = 110444, p < .001$, and $F_{2}(2.90) = 51.21, MS_{e} = 65603, p < .001$. In addition, the target word x length-similarity interaction was significant across subjects, $F_{1}(2.58) = 3.90, MS_{e} = 56947, p < .03$, and marginally significant across items, $F_{2}(2.90) = 2.42, MS_{e} = 65603, p < .10$. As was the case for the first pass data, pair-wise $t$-tests showed that readers took longer to process both kinds of semantically inconsistent target words relative to the semantically consistent ones. Readers took longer in repair time for a homophone error than for its contextually correct homophone mate: 307 msec longer if it was the same length as its mate, subject $t(29) = 5.05, p < .001$, item $t(23) = 6.39, p < .001$, and 512 msec longer if it was a different length, subject $t(29) = 5.60, p < .001$, item $t(23) = 7.38, p < .001$. Similarly, readers took longer in repair time for a nonhomophone error than for the contextually correct word: 520 msec for same-length pairs, subject $t(29) = 5.56, p < .001$, item $t(23) = 7.24, p < .001$, and 510 msec for the different-length pairs, subject $t(29) = 7.57, p < .001$, and item $t(23) = 5.86, p < .001$. However, unlike the first pass data which showed no difference in initial processing time for homophone versus nonhomophone errors, the repair time data revealed that readers spent significantly less time (213 msec) repairing a homophonic error than a nonhomophone error (287 msec).

9 An analysis of the first fixation on the target word produced a similar, albeit smaller effect. There was no difference in first fixation duration for homophone errors ($M = 245$ msec) versus nonhomophone errors ($M = 247$ msec); subject $t(29) = 0.30, p > .75$, item $t(47) = 0.10, p > .90$. However, for both error types, duration of the first fixation was longer than for the correct target word ($M = 231$ msec); pairwise $t$-tests showed that the 14 msec difference between homophone errors and correct words was marginally significant, $t(29) = 1.85, p < .07$, item $t(47) = 1.88, p < .07$, whereas the 16 msec difference between nonhomophone errors and correct words was statistically significant, subject $t(29) = 2.29, p < .03$, item $t(47) = 2.32, p < .03$. 
nonhomophonic one, but only if the homophone error was the same length as
its context correct mate, subject \( t(29) = 3.06, p < .01 \), and item \( t(23) = 2.69, p < .02 \). Of course, we have no overt measure of whether our readers
successfully resolved the inconsistency by recovering the correct word;
however, the shorter time spent reading and rereading phrases containing
same-length homophonic errors (e.g., *idle and board*) relative to phrases
containing the orthographically-matched nonhomophonic errors (e.g., *idle
and beard*), strongly implies that readers were able to recover from the
"sound-okay" errors more easily. Because the two kinds of errors (e.g., *board,
beard*) were equated for their orthographic similarity to the correct word (e.g.,
bored), but only the former (e.g., *board*) shared the same phonological
representation as the correct word (e.g., *bored*), we attribute the facilitation
effect to the availability of the shared phonology /bɔːrd/ and its usefulness in
providing readers with a route to recovering the correct alternative. Daneman
and Stainton (1991) showed that homophony facilitated error recovery when
readers were explicitly asked to repair the errors they encountered while
reading. Our replication of this homophone facilitation effect shows that
readers initiate error recovery heuristics spontaneously during normal reading
for meaning. However, our study also revealed that homophony was not
sufficient to facilitate error recovery; orthographic similarity was necessary
too. As Table 2 shows, readers were no faster to recover from a
different-length homophonic error (e.g., *Russell stopped and wade the
situation*...) than they were to recover from the nonhomophonic control error
(e.g., *Russell stopped and wide the situation*), subject \( t(29) = 0.04, p > .95 \),
item \( t(23) = 0.20, p > .80 \); thus even though the homophonic error (*wade*)
shared the same phonological representation (/wɛld/) as the correct alternative
(*weighed*), the orthographic dissimilarity appeared to prevent readers from
using the shared phonology to facilitate recovery. Because the present
homophone facilitation was limited to the more similarly spelled same-length
homophone errors (e.g., *board/bored* not *wade/weighed*), and because
homophony did not interfere with the initial detection of either kind of
homophonic error (*board* or *wade*), we believe our results call for a more
restricted and delayed involvement of phonological processes than Daneman
and Stainton (1991) have proposed.

Conclusions
The results from our on-line eye fixation data support a theory of word
identification in which phonological sources of activation and influence are
delayed relative to orthographic sources (see also, Coltheart, 1978; McCusker,
et al., 1981), rather than a theory in which phonological codes play an early
and/or dominant role (e.g., Daneman & Stainton, 1991; Pollatsek, Lesch,
Morris, & Rayner, 1992; Van Orden, 1987; Van Orden, Pennington & Stone,
1990). Two aspects of our eye fixation data are inconsistent with theories that
Eye Fixations and Phonological Recoding

give phonological codes an early, important role in word identification and lexical access: the eye fixations that reflect the initial detection of homophonic errors, and the eye fixations that reflect subsequent attempts to repair the errors.

Contrary to Daneman and Stainton’s (1991) results from their secondary proofreading task, we found no differences in the initial detection of homophonic errors (e.g., board) relative to nonhomophonic orthographic controls (e.g., beard), whether readers had been previously exposed to an error-free version of the text (e.g., Alone at his teller’s cage, idle and bored...) or not. The complete lack of a homophone confusion effect is inconsistent with a model that assumes phonologically-mediated lexical access. If phonological sources of activation preceded lexical access, then readers should have had more difficulty detecting inconsistencies arising from homophonic errors (e.g., board) than from nonhomophonic ones (e.g., beard). The tendency would have been for board’s phonological representation, /bɔːrd/, to have activated the false lexical entry bored, meaning “disinterested”; because bored’s meaning is compatible with the semantic and syntactic constraints of the sentence context, Alone at his teller’s cage, idle and..., the inconsistency would have remained unnoticed. By contrast, the error word beard’s phonological representation /bɜːrd/ would have activated the lexical entry beard whose meaning “facial hair” contradicts the semantic and syntactic constraints of the sentence, making the nonhomophonic inconsistency much easier to detect. By showing that homophony did not interfere with inconsistency detection, the present results strongly suggest that readers bypassed phonology, using the orthographic representations for board and beard as a direct route to their contextually inconsistent meanings, “plank” and “facial hair.”

Whereas our initial detection data did not provide evidence for the early engagement of phonological processes in word identification, our post-detection data provided some evidence for the delayed involvement of phonology in the error recovery processes. Consistent with Daneman and Stainton’s (1991) findings from the problem-solving version of their proofreading task, we found evidence for a homophone facilitation effect in the error recovery processes that are initiated after an inconsistency is detected. When explicitly instructed to repair the errors that they identified, Daneman and Stainton’s (1991) subjects were better able to repair homophonic errors (e.g., board) than nonhomophonic controls (e.g., beard), presumably because they could use the shared phonology of homophonic pairs (e.g., /bɔːrd/) to recover the correct alternative (e.g., bored). Our readers were not explicitly instructed to repair the errors; however, regressive eye fixations initiated spontaneously after detecting an inconsistency revealed that error recovery processes are an integral part of normal reading for understanding, and that readers can exploit shared phonological codes to repair inconsist-
encies arising from homophonic words. However, whether these phonological codes are activated automatically as a by-product of lexical access (McCutchen & Perfetti, 1982), or whether they are deliberately and consciously computed as part of a reader's repertoire of error-recovery heuristics (Carpenter & Daneman, 1981), we cannot say. All we can conclude from the present data is that the ability to exploit these phonological codes appears to be somewhat limited because the orthographic dissimilarity between our different-length homophone pairs (e.g., wade/weighed; none/nun) eliminated the homophone facilitation effect. Thus, even when it comes to post-inconsistency-detection recovery processes, readers appear to pay considerable attention to orthographic sources of information as they attempt to interpret and reinterpret inconsistent words.

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References


**Appendix**

**TARGET WORDS USED IN EXPERIMENTS 1 AND 2**

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<th>Correct Word</th>
<th>Homophone Error</th>
<th>Nonhomophone Error</th>
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