Automatic activation of phonological information in reading: Evidence from the semantic relatedness decision task

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A semantic relatedness decision task was used to investigate whether phonological recoding occurs automatically and whether it mediates lexical access in visual word recognition and reading. In this task, subjects read a pair of words and decided whether they were related or unrelated in meaning. In Experiment 1, unrelated word-homophone pairs (e.g., LION-BARE) and their visual controls (e.g., LION-BEAN) as well as related word pairs (e.g., FISH-NET) were presented. Homophone pairs were more likely to be judged as related or more slowly rejected as unrelated than their control pairs, suggesting phonological access of word meanings. In Experiment 2, word-pseudohomophone pairs (e.g., TABLE-CHARE) and their visual controls (e.g., TABLE-CHARK) as well as related and unrelated word pairs were presented. Pseudohomophone pairs were more likely to be judged as related or more slowly rejected as unrelated than their control pairs, again suggesting automatic phonological recoding in reading.

In visual word recognition and reading, is word meaning accessed directly from spelling (orthography) or indirectly from sound (phonology) after phonological recoding? This question is of considerable importance and interest. Theoretically, it is related to the question of how the mental lexicon is organized and what the form of mental representations in reading and cognitive processing in general is. Practically, it has implications for formulating methods and techniques aimed at teaching children to read and at remedying various reading deficits.

Given the fact that children learn to speak before they learn to read, early theories of reading asserted that learning to read is simply learning how to translate the printed words into their phonological forms so that the extant lexicon can be accessed (e.g., Gibson, 1970; Gough, 1972; Klapp, 1971; Rubenstein, Lewis, & Rubenstein, 1971). According to this view, proficient adult reading is achieved by converting print to phonology. The hypothesis that word meaning is accessed phonologically and that phonological recoding mediates lexical access of visually presented words is called the *prelexical phonological recoding hypothesis*. Note that we use the term *lexical access* to refer to the process of locating an entry for a word in the mental lexicon.

In contrast, a competing hypothesis about word recognition and reading asserted that an independent orthographic route to the lexicon is established when children learn to read printed words and that phonology plays no direct role in skilled adult reading (e.g., Becker, 1976, 1980; Paap, Newsome, McDonald, & Schvaneveldt, 1982; Rumelhart & Siple, 1974; Smith, 1971). The hypothesis that reading does not involve phonological recoding and that word meaning is accessed orthographically is called the *direct visual access hypothesis*. One interesting fact to note is that the arguments for the direct visual access hypothesis were based almost entirely on a lack of evidence for the phonological recoding hypothesis and that there has been basically no effort to seek evidence for the direct visual access hypothesis.

Indeed, until recently, evidence for prelexical phonological recoding in reading was weak. For example, using a lexical decision task, Rubenstein et al. (1971) showed that homophones (e.g., YOLK) and pseudohomophones (e.g., BRANE) yielded slower lexical decision times than did their controls, suggesting that visually presented letter strings were phonologically recoded prior to lexical access and that the phonological code activates all possible meanings of the sound. However, Coltheart, Davelaar, Jonasson, and Besner (1977) failed to replicate the homophone effect with the use of a different set of stimuli. Although the pseudohomophone effect was replicated in a number of other studies (e.g., Coltheart et al., 1977; Patterson & Marcel, 1977; Seidenberg, Petersen, MacDonald, & Plaut, 1996), the effect was subjected to alternative explanations. For example, Meyer, Schvaneveldt, and Ruddy (1974) argued that pseudohomophone nonwords may look like English words more than nonhomophone nonwords and thus lead to a slower response latency. Consistent with this argument, Martin (1982) and Taft (1982,

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1991) found no pseudohomophone effect when the visual similarity between pseudohomophones and control nonwords was equated. Therefore, Rubenstein et al.'s findings cannot be taken as strong evidence for prelexical phonological recoding in reading.

To further investigate whether prelexical phonological recoding occurs in reading, a number of investigators (e.g., Baron, 1973; Coltheart, Laxon, Rickard, & Elton, 1988; Doctor & Coltheart, 1980; Treiman, Freyd, & Baron, 1983) asked subjects to decide whether a sentence was acceptable or not. The unacceptable sentences were constructed by replacing a word in the originally acceptable sentence with its homophone (e.g., SHE HAS BLOND HARE) or with a control word (e.g., SHE HAS BLOND HARM). The sentences with homophone replacements took longer to reject or to be wrongly judged as acceptable more often than the control sentences. However, whether this finding indicated prelexical or simply postlexical phonological recoding was disputed by other investigators (e.g., Banks, Oka, & Shugarman, 1981; Coltheart et al., 1988).

More recently, a number of investigators used the priming paradigm to show that phonological information is activated very early in visual word recognition. For example, Humphreys, Evett, and Taylor (1982) showed a priming effect for target identification when primes were homophones of targets, although no effect was obtained with pseudohomophones. Perfetti and his colleagues (Perfetti & Bell, 1991; Perfetti, Bell, & Delaney, 1988) used a backward masking procedure in which subjects were asked to identify a target word that was shown briefly and then masked. They found that pseudohomophone masks (e.g., MAYD) facilitated target identification (e.g., MAID) relative to control ones (e.g., MARD). They also demonstrated pseudohomophone priming at a slightly longer stimulus onset asynchrony than that used by Humphreys et al. Although these studies indicate that phonological information is activated early in visual word identification, none of them indicates that phonology actually mediates the access of word meaning.

Because there was no clear evidence for the prelexical phonological recoding hypothesis or the direct visual access hypothesis, most theories of reading assumed that direct access through the orthographic code and indirect access through phonological recoding coexist and operate in parallel in reading (e.g., Carr & Pollatsek, 1985; Coltheart, 1978, 1980; Seidenberg, 1985). However, the dual-route hypothesis does not assume that the two access routes are used equally in reading. In fact, access to a lexical entry via phonological recoding is believed to be too slow to support reading in skilled readers. Rather, it is assumed that in normal reading, word meaning is accessed predominantly via the orthographic route and that phonological access of meaning occurs only for nonwords or unfamiliar low-frequency words (see, e.g., Coltheart, 1978, 1980; Jared & Seidenberg, 1991).

The dual-route hypothesis has been challenged by more recent studies demonstrating phonologically medi-

ated associative priming. In the associative priming paradigm, subjects are first shown a prime (e.g., DOE) and then a target (e.g., BREAD) that is the semantic associate of the prime's homophone (e.g., DOUGH). The subjects' task is either to name the target word as quickly as they can or to make a lexical decision. Lesch and Pollatsek (1993) found significant associative phonological priming in naming when the prime was shown for 50 msec but not when it was shown for 200 msec. They interpreted their finding as indicating that inappropriate lexical entries are initially activated by homophone primes but are suppressed later on. The suppression of inappropriate phonological activation at long exposure durations seems to be consistent with the work of Fleming (1993), who found no priming either in naming or in lexical decision when the prime exposure duration was 200 msec. Lukatela and Turvey (1991, 1994) demonstrated similar phonologically mediated associative priming for pseudohomophones. They showed that a word prime (e.g., TABLE) can facilitate naming of a nonword target (e.g., CHARE) if the nonword has the same phonology as that of the associate of the prime (e.g., CHAIR). Similarly, a nonword prime (e.g., TAYBLE) can facilitate naming of a word target (e.g., CHAIR), if its phonology is the same as that of the associate of the target (e.g., TABLE). They interpreted their finding as indicating that lexical representations are coded and accessed phonologically.

More direct evidence indicating that phonology mediates lexical access of visually presented words comes from the semantic categorization task that does not require subjects to use phonology but definitely requires them to consult the meaning of the target words (see, e.g., Van Orden, 1987; Van Orden, Johnston, & Hale, 1988; see also Meyer & Gutschera, 1975). In this task, subjects are first given a category name (e.g., FLOWER) and then are given a word to decide whether it belongs to this category or not. Homophones (e.g., ROWS/ROSE) and pseudohomophones were found to be wrongly judged as the category members or rejected significantly more slowly than control items. This finding provided strong evidence indicating prelexical phonological recoding.

Most recently, Luo (1996) provided additional evidence in support of the prelexical phonological recoding hypothesis. He used a semantic discrimination task in which subjects read a pair of words (e.g., homophone pairs, LION-BARE; control pairs, LION-BEAN) and decided which member of the word pair was related in meaning to a third word (e.g., WOLF). Subjects made significantly more errors and responded more slowly in the homophone condition than in the orthographic control condition, indicating that inappropriate lexical entries were accessed by homophone words via the phonological route, which interfered with the subjects' choice of correct response. The study also showed that when a delay was imposed between the word pair and the third word, the phonologically mediated interference effect diminished, indicating that the wrongly activated lexical entries via the phonological route were later inhibited, apparently via the ortho-

graphic route. These findings provided strong evidence that phonological information is activated automatically in visual word recognition and that it perhaps mediates lexical access in reading. In addition, Luo showed that word frequency had no significant influence on the phonologically mediated interference effect, suggesting that phonological recoding occurs for all words.

Finally, several recent studies of Chinese reading (e.g., Perfetti & Zhang, 1991, 1995; Tan, Hoosain, & Siok, 1996) have indicated that phonological information is activated automatically even in a writing system once believed to have a negligible role for phonology. For example, Perfetti and Zhang (1995) asked subjects to decide whether two Chinese characters had the same meaning (in a semantic decision task) or the same pronunciation (in a phonological decision task). In semantic decision, phonological interference occurred on critical negative trials that involved two characters having the same pronunciation (i.e., homophones). Similarly, in phonological decision, semantic interference occurred on critical negative trials that involved two characters having the same meaning. Perfetti and Zhang (1995) argue that these findings suggest that phonological information is activated automatically and that phonological activation is an intrinsic constituent of word identification in Chinese and English.

The purpose of the present study was to seek converging evidence for the phonological recoding hypothesis by using a *semantic relatedness decision* task in which subjects read a pair of words and decided whether the two words were related or unrelated in meaning. The semantic relatedness decision task is similar to Perfetti and Zhang's (1995) semantic decision task and Van Orden's (1987) semantic categorization task. All require subjects to make a decision on the basis of word meanings. There are, however, some differences among these tasks too. In the present task, subjects decided whether two words were *related* in meaning, whereas Perfetti and Zhang (1995) asked subjects to decide whether two characters had the *same* meaning and Van Orden asked subjects to decide whether a word *belonged to* (was a member of) a given category. In addition, two words were shown simultaneously in the present task, whereas they were presented sequentially in the other two tasks.

We conducted two experiments with the semantic relatedness decision task. In Experiment 1, we used homophones: Unrelated word-homophone pairs that sounded related (e.g., LION-BARE) and their visual controls (e.g., LION-BEAN) as well as truly related word pairs (e.g., FISH-NET) were presented. In Experiment 2, we used pseudohomophones: Word-pseudohomophone pairs (e.g., TABLE-CHARE) and their visual controls (e.g., TABLE-CHARK) were embedded in truly related and unrelated word pairs. The subjects were instructed to respond as quickly and accurately as they could. To anticipate, we showed that subjects made more errors and responded more slowly on homophone and pseudohomophone pairs than on their respective control pairs. The homophone and pseudohomophone

effects provide further evidence that phonological information is activated automatically in visual word recognition and that phonology perhaps mediates lexical access in reading.

EXPERIMENT 1

The main purpose of this experiment was to use the semantic relatedness decision task to determine (1) whether a pair of words, a homophone (e.g., BARE) and a semantic associate (e.g., WOLF) of the homophone's counterpart (e.g., BEAR), would more likely be mistakenly judged as semantically related than their visual control pairs (e.g., BEAN-WOLF) and (2) whether the homophone pairs would be more slowly rejected as unrelated than their visual controls. If it is the case that subjects' performance is worse on the homophone pairs than on the visual control pairs, it would indicate that inappropriate lexical entries have been accessed by homophone words via the phonological route, in support of the phonological recoding hypothesis. If no such homophone effect was obtained, that would indicate that phonological recoding does not mediate lexical access in reading for meaning, in support of the direct visual access hypothesis or the dual-route hypothesis.

On the other hand, if phonological information is indeed activated early and automatically in visual word recognition, one might expect that not only should the homophone effect be demonstrated in the semantic relatedness decision task, it should remain even when the homophone and its semantic foil are shown for a relatively brief duration. Accordingly, another purpose of this experiment was to investigate whether the homophone effect, if it exists, would also be obtained when the duration of stimulus presentation was relatively short.

Method

Subjects. Fifty-six undergraduates at Wesleyan University served as paid subjects. They were randomly assigned to two groups. One group of 28 was tested in a short stimulus duration condition and the other group of 28 was tested in an unlimited stimulus duration condition. All subjects were native English speakers and had normal or corrected-to-normal vision.

Materials and Design. Three sets of word pairs were constructed. They included (1) semantically related word pairs, such as DESERT-BARREN and FISH-NET; (2) unrelated word homophone pairs that sounded related, such as WOLF-BARE and SAND-BEECH; and (3) unrelated word pairs that were the controls of the homophone pairs, such as WOLF-BEAN and SAND-BENCH. Each set consisted of 40 word pairs.

The homophones and their visual controls used in this experiment were the same as those in Experiment 3 of Luo (1996); they are shown in Appendix A. These words were selected from the word sets used by Fleming (1993), Humphreys et al. (1982), and Lesch and Polatsek (1993). The homophones and their visual controls were approximately equated in terms of word length and frequency. Homophones had a mean length of 4.32 letters ($SD = .75$), whereas visual controls had a mean length of 4.36 letters ($SD = .81$). Homophones had a mean frequency of 46.6 per million words ($SD = 122.9$), whereas visual controls had a mean frequency of 44.6 per million words ($SD = 77.4$). Measures of word frequency were derived from Francis and Kučera (1982).

There were two independent variables: type of unrelated word pairs (homophone pairs vs. visual control pairs) and presentation duration (unlimited vs. short duration). A mixed design was used. Presentation duration of word pairs was manipulated between subjects. A first group of 28 subjects was tested in the short stimulus duration condition, in which word pairs were shown for 250 msec. A second group of 28 subjects was tested in the unlimited stimulus duration condition, in which word pairs remained visible until subjects responded. Type of unrelated word pairs was manipulated within subjects.

The experiment consisted of 80 trials: 40 related trials and 40 unrelated trials. For each subject, half of the unrelated trials were homophone trials and the other half were visual control trials. All 40 homophones and 40 visual controls were used equally often and they were counterbalanced across subjects.

Apparatus and Procedure. The Experiment was run on an Apple Macintosh microcomputer (Performa 578). Each word was printed in uppercase Geneva typeface in 12-point size. On each trial, two words were presented side by side. They were black on a white background. The horizontal distance between the centers of the two words was approximately 20 mm, one to the left and one to the right of the center of the computer screen. The relative position of the two words was randomized so that each word had approximately the same probability of appearing on the left or on the right. The subjects sat at a distance of about 60 cm in front of the computer screen. The laboratory was dimly lit to minimize screen reflections.

At the beginning of the experiment, subjects were shown written instructions on the computer screen. They were told that their task in the experiment was to decide whether the two words in each pair were related or unrelated in meaning. They were also told that when the two words were related, they would be obviously and directly related. Each trial consisted of a fixation cross shown for 1 sec and a pair of words that was shown for 250 msec in the short duration condition or remained visible until subjects responded by pressing a key in the unlimited duration condition.

The subjects pressed the "Z" key on the computer keyboard to indicate that the two presented words were related and the "/" key to indicate that they were unrelated. Both error rates and reaction times were measured. The subjects were instructed to respond as quickly and accurately as possible. At the end of each trial, the subjects received feedback about their response from the computer. A message ("Correct" or "Sorry") was shown for 2 sec in a small window near the bottom of the computer screen. The subjects initiated each trial by pressing the space bar.

All types of stimulus trials (40 related trials, 20 unrelated homophone trials, and 20 unrelated visual control trials) were intermixed and the order of their presentation was randomized separately for each subject. Eight practice trials—4 related trials, 2 homophone trials, and 2 visual control trials—preceded 80 experimental ones. The practice trials were not included in the analysis.

Data analysis. The mean error rate and reaction time as a function of stimulus type (homophone pairs vs. visual control pairs) were analyzed. The error rate was the proportion of trials in which subjects mistakenly judged unrelated pairs as related. In addition, trials in which subjects' reaction times were greater than 3,000 msec were counted as incorrect. The reaction time data were based on trials in which the subjects made correct responses. Subject effects were analyzed by computing a mean for each subject across each condition, collapsing across items. Item effects were analyzed by computing a mean for each item across each condition, collapsing across subjects.

In this experiment, truly related word pairs served as fillers. The error rates on these trials were 11% in the unlimited duration condition and 18% in the 250-msec condition. The reaction times were 1,034 msec in the unlimited duration condition and 899 msec in the

Table 1
Mean Error Rate (%E) and Reaction Time
(RT, in Milliseconds), With Standard Deviations,
as a Function of Presentation Duration and Stimulus Type
in the Semantic Relatedness Decision Task in Experiment 1

Stimulus Type	Presentation Duration							
	Unlimited		250 msec		Unlimited		250 msec	
	%E	SD	%E	SD	RT	SD	RT	SD
Homophone	15.4	9.6	33.2	14.1	1,291	302	1,092	216
Visual control	7.5	9.3	29.5	16.0	1,250	293	1,050	212
Difference	7.9		3.7		41		42	

250-msec duration condition. These results were of little interest for the present purpose.

Results and Discussion

The mean error rate and reaction time as a function of stimulus type (homophone vs. visual control) and presentation duration (unlimited vs. 250 msec) are shown in Table 1.

Error rate data. As we can see from Table 1, the subjects made more errors in the homophone trials than in the visual control trials, indicating that incorrect lexical entries were accessed by homophones. Two analyses of variance (ANOVAs) with a mixed design were performed on the error rate data for the subject effect and item effect, respectively. The analyses showed a significant effect of stimulus type (homophone pairs vs. visual control pairs). The effect of stimulus type was significant by subjects [$F(1,54) = 12.89$, $MS_e = .007$, $p < .001$] and by items [$F(1,39) = 4.66$, $MS_e = .018$, $p < .05$], indicating that homophone pairs were more frequently misjudged as related than were visual control pairs. The main effect of presentation duration (unlimited vs. 250 msec) was also significant by subjects [$F(1,54) = 45.59$, $MS_e = .024$, $p < .001$] and by items [$F(1,39) = 131.1$, $MS_e = .015$, $p < .001$], indicating that subjects made more errors when word pairs were shown for a short duration than when they were shown for an unlimited duration. However, there was no significant interaction between stimulus type and presentation duration ($F_s < 1.61$, $p > .05$), indicating that the duration of stimulus presentation had no significant influence on the homophone effect. But further analysis showed that the 3.7% difference in the short duration condition was not reliable ($p < .05$).

Reaction time data. As we can see from Table 1, the subjects responded more slowly in the homophone trials than in the visual control trials, indicating extra effort taken to inhibit incorrect lexical entries accessed by homophones. Two ANOVAs with a mixed design were performed on the reaction time data for the subject effect and item effect, respectively. The analyses showed a significant effect of stimulus type (homophone pairs vs. visual control pairs) by subjects [$F(1,54) = 6.91$, $MS_e = 6,966.1$, $p < .01$] and marginally significant by items [$F(1,39) = 3.75$, $MS_e = 9,473.3$, $p = .06$], indicating that homo-

phone pairs were more slowly rejected as unrelated than were visual control pairs. The main effect of presentation duration (unlimited vs. 250 msec) was also significant by subjects [$F(1,54) = 8.69$, $MS_e = 127,766.8$, $p < .01$] and by items [$F(1,39) = 205.8$, $MS_e = 15,470.9$, $p < .001$]. However, there was no interaction between stimulus type and presentation duration ($F_s < 1$), indicating that the homophone effect was not influenced by the duration of stimulus presentation.

A close inspection of reaction time data and error rate data suggests that there might be a speed/accuracy trade-off between two exposure duration conditions. Specifically, in the short duration condition, subjects appeared to have adopted a strategy that boosted response speed at the expense of response accuracy. This probably explains why a reliable homophone effect was not obtained for error rates in the short duration condition. But, the overall pattern of results appeared to be quite similar in the two exposure duration conditions.

The demonstration of the homophone effect in the semantic relatedness decision task provides strong evidence indicating automatic activation of phonological information in visual word recognition and reading. It also suggests that inappropriate lexical entries are accessed by homophones via the phonological route and perhaps prior to the access of word meaning via the visual route. If word meaning is accessed in visual form only as claimed by the direct visual access hypothesis, or the direct visual access route is on the average faster than phonological access as claimed by the dual-route hypothesis, then there should be no significant difference in performance between the homophone pairs and their visual controls. The fact that homophone pairs are more frequently judged as semantically related and that they are more slowly rejected as unrelated than their orthographic control pairs suggests that phonological information is used to access word meanings in reading. The fact that the homophone effect also occurs for relatively short exposure durations further supports the notion that phonological information is activated automatically in visual word recognition and that it perhaps mediates the access of word meanings in reading.

We prefer to interpret our findings as indicating *pre-lexical* phonological mediation. However, other explanations based on *postlexical* activation of phonology are possible. For example, suppose that lexical entries for the homophone (BARE) and its semantic foil (LION) are accessed via a visual route, as proposed by the direct visual access hypothesis or the dual-route hypothesis, and that lexical access is followed by the automatic retrieval of both addressed phonology and semantics. It may be the case that when the semantics of the two words are compared, which takes some time, the addressed or assembled phonology of BARE could activate the entry for BEAR, thus introducing interference in the semantic relatedness decision task.

Although we cannot conclude with certainty that phonological mediation occurs before lexical access, the homophone effect demonstrated in Experiment 1 does show

that the activation of phonological information is automatic or obligatory. Note that it is unlikely that the homophone effect can be attributed to some strategic factors in information processing. The semantic relatedness decision task requires subjects to make a decision based solely on the meanings of words. Phonological information is neither required nor useful for performing the task. As a matter of fact, the activation of phonological information in this task is detrimental to performance. Subjects should have tried to prevent it from being computed, if they could do so. The fact that the phonological effect is demonstrated even when phonological information is detrimental to performance indicates that phonological recoding occurs automatically and that it is not under subjects' strategic control.

EXPERIMENT 2

Experiment 1 provided strong evidence indicating that phonological information is activated automatically in reading printed words. What is less clear is whether phonology precedes and mediates lexical access of word meaning. If phonological information is used to access meaning, then a nonword (e.g., CHARE) that shares the same phonology as a real word's (e.g., CHAIR) might also be mistakenly judged as semantically related to the real word's semantic associate (e.g., TABLE). Similarly, such nonword should also take longer to be rejected as unrelated than an orthographic control nonword. There are several implications if such a pseudohomophone effect can be demonstrated. First, it would confirm the point that phonological recoding does occur routinely and automatically in visual word recognition. Second, it would show that phonological information is indeed used to access word meanings. And if this is true for nonwords, it may also be true for real words. Finally, if phonological information is activated only postlexically, pseudohomophones are not expected to produce interference in the semantic relatedness decision task, because nonwords do not have lexical entries that can be accessed visually and thus should be dismissed as unrelated rather quickly.

Accordingly, the purpose of Experiment 2 was to test whether a pseudohomophone effect could be demonstrated with the semantic relatedness decision task—namely, whether word–pseudohomophone pairs (e.g., TABLE–CHARE) would more likely be judged as related in meaning and more slowly rejected as unrelated than their visual control pairs (e.g., TABLE–CHARK).

Method

Subjects. The subjects were 26 paid undergraduates from the same pool as in Experiment 1. They were native English speakers and had normal or corrected-to-normal vision.

Materials and Design. Four sets of stimuli were constructed. They included (1) 90 semantically related word–word pairs such as DESERT–BARREN and FISH–NET; (2) 60 unrelated word–pseudohomophone pairs such as TABLE–CHARE and DOCTOR–NERSE; (3) 60 unrelated word–nonword pairs that were the controls of the homophone pairs, such as TABLE–CHARK and DOCTOR–DERSE; and (4) 30

unrelated word–word pairs such as DAYS–FURY and GROWN–ETHIC. The pseudohomophones and their visual controls were selected from the word and nonword sets used by Lukatela and Turvey (1991) and are shown in Appendix B. Truly unrelated word–word pairs were included to discourage subjects from turning the semantic relatedness decision task into a lexical decision task (i.e., say RELATED if two items are both words and say UNRELATED if there is a nonword in the pair).

A within-subjects design was used. There was only one independent variable: the type of word–nonword pairs (word–pseudohomophone pairs vs. word–nonword pairs). The experiment consisted of 180 trials: 90 related trials and 90 unrelated trials. For each subject, 30 of the unrelated trials consisted of word–pseudohomophone pairs, another 30 trials consisted of visual control pairs, and the remaining 30 trials contained unrelated word–word pairs. All 60 pseudohomophones and 60 visual controls were used equally often, and they were counterbalanced across subjects.

Apparatus and Procedure. The apparatus and procedure were almost the same as in Experiment 1. At the beginning of the experiment, the subjects were shown written instructions on the computer screen. They were told that their task was to decide whether the two words in a pair were related or unrelated in meaning. They were warned that some trials might contain a nonword that looked or sounded like a real word. In that case, they, of course, should say the stimulus pairs were unrelated.

In this experiment, the stimulus remained visible until the subjects responded by pressing a key. The subjects pressed the “Z” key on the computer keyboard to indicate that the stimulus pairs were semantically related and the “/” key to indicate that they were unrelated. Both error rates and reaction times were measured. The subjects were instructed to respond as quickly and as accurately as possible. They received feedback about their response from the computer. A message (“Correct” or “Sorry”) was shown for 2 sec in a small window near the bottom of the computer screen. The subjects initiated each trial by pressing the space bar.

The experiment consisted of 180 trials. They were intermixed, and the order of their presentation was randomized separately for each subject. Eighteen practice trials preceded 180 experimental ones. The data from the practice trials were not included in the analysis. All other aspects of the experiment were the same as those of Experiment 1.

Data analysis. The mean error rate and reaction time as a function of stimulus type (pseudohomophone trials vs. visual control trials) were analyzed. The error rate was the proportion of trials in which subjects mistakenly judged unrelated pairs as related. In addition, trials in which subjects’ reaction times were greater than 3,000 msec were counted as incorrect. The reaction time data were based on trials in which the subjects made correct responses. Subject effects were analyzed by computing a mean for each subject across each condition, collapsing across items. Item effects were analyzed by computing a mean for each item across each condition, collapsing across subjects.

Results and Discussion

The mean error rate and reaction time as a function of stimulus type (word–pseudohomophone pairs vs. control

word–nonword pairs) are shown in Table 2. Four within-subjects repeated measures ANOVAs on the error rate data and the reaction time data were conducted, for the subject effect and the item effect, respectively.

Error rate data. The ANOVA showed a significant effect of stimulus type by subjects [$F(1,25) = 21.11$, $MS_e = .004$, $p < .001$] and by items [$F(1,59) = 18.18$, $MS_e = .011$, $p < .001$], indicating that subjects made significantly more errors in the pseudohomophone trials than in the visual control trials. This result suggests that lexical entries were accessed by pseudohomophone nonwords, resulting in the word–pseudohomophone pairs’ being sometimes mistakenly judged as related in meaning.

Reaction time data. The subjects in Experiment 2 responded much faster than those in Experiment 1. This was most likely due to differences in stimulus materials and to the fact that two thirds of the unrelated trials in Experiment 2 contained nonwords.

The ANOVA revealed a significant effect of stimulus type by subjects [$F(1,25) = 14.44$, $MS_e = 1,119.9$, $p < .001$] and by items [$F(1,59) = 5.19$, $MS_e = 10,433.9$, $p < .03$], indicating that word–pseudohomophone pairs were more slowly rejected as unrelated than were control word–nonword pairs. This result suggests that lexical entries were initially accessed by pseudohomophone nonwords and were later inhibited.

These results are consistent with those of Experiment 1. Taken together, the fact that subjects made more errors and responded more slowly in the homophone or pseudohomophone trials than in the visual control trials indicates that phonological mediation does occur routinely and automatically and that phonological information is probably used to access word meaning in visual word recognition and reading.

It is also interesting that the error rate for pseudohomophones in Experiment 2 did not differ much from the error rate for homophones in Experiment 1 in the comparable unlimited duration condition (16.3% vs. 15.4%). This suggests that subjects had just as much of a problem with word–homophone pairs such as SAND–BEECH as with word–pseudohomophone pairs such as DOCTOR–NERSE. One could argue that this suggests that there is indeed much phonological lexical access. Note that the equivalence of homophone and pseudohomophone effects in the categorization task led Van Orden et al. (1988) to argue that lexical access in reading for meaning is solely phonological. However, Coltheart, Patterson, and Leahy (1994) failed to replicate the equivalence of homophone and pseudohomophone effects in their study.

GENERAL DISCUSSION

In the present study, a semantic relatedness decision task was used to investigate whether phonology is activated automatically and whether it mediates lexical access in visual word recognition and reading. In this task, subjects read a pair of words and decided whether they were related or unrelated in meaning. Experiment 1 demonstrated a homophone effect in which subjects’ decisions

Table 2
Mean Error Rate (%E) and Reaction Time
(RT, in Milliseconds), With Standard Deviations,
as a Function of Stimulus Type in the Semantic
Relatedness Decision Task in Experiment 2

Stimulus Type	(%) E	SD	RT	SD
Pseudohomophone	16.3	9.5	876	184
Visual control	7.9	8.2	841	154
Difference	8.4		35	

were less accurate and slower when the word pairs consisted of a homophone (e.g., BARE) and a semantic associate (e.g., WOLF) of the homophone's counterpart (e.g., BEAR) than when they consisted of their visual controls (e.g., BEAN-WOLF). The homophone effect suggests that phonological information is activated automatically in visual word recognition and reading. The finding is consistent with the phonologically mediated interference effect demonstrated in the semantic discrimination task (Luo, 1996), in which a homophone distractor (e.g., BARE) interfered with subjects' correct response in matching two semantically related words (e.g., LION-WOLF) more than a visual control distractor (e.g., BEAN).

Experiment 2 in the present study demonstrated a pseudohomophone effect in which pseudohomophone nonwords (e.g., CHARE) were more often mistakenly judged as related or more slowly rejected as unrelated to a semantic associate (e.g., TABLE) of the pseudohomophone's real-word counterpart (e.g., CHAIR) than were control nonwords. The pseudohomophone effect again indicates that the activation of phonological information is part of the word identification process and that word meaning is probably accessed via the phonological route.

The findings from the present study, therefore, provide evidence against the direct visual access hypothesis. According to this hypothesis, phonology plays no direct role in the reading of printed words (see, e.g., Glushko, 1979; Green & Shallice, 1976; Humphreys & Evett, 1985; Humphreys et al., 1982; Kay & Marcel, 1981). The notion of visual direct access as the only route to the mental lexicon can also be disputed on other grounds. One argument is that from the developmental perspective, children have already established a phonologically accessible lexicon before they start to learn how to read and it would be unwise not to use the extant, fully functional system for lexical access. A related argument is that in the English language, phonology is encrypted into orthography. Therefore, from the perspective of cognitive economy, it makes sense to convert orthography into phonology and then access the lexicon phonologically, rather than to have to establish a completely new access route to the lexicon.

The present findings are also inconsistent with the dual-route hypothesis. According to this hypothesis, the phonological route, although it exists, is too slow to be of use in lexical access (Coltheart, 1978, 1980; Henderson, 1982; McCusker, Hillinger, & Bias, 1981). To the contrary, the demonstration of the homophone effect and the pseudohomophone effect indicates that phonological information is activated automatically and that lexical access involving phonological recoding is at least as fast as direct visual access.

A variant of the dual-route hypothesis claims that phonological recoding may occur, but that it is an intentional, strategic process (see, e.g., Carr, Davidson, & Hawkins, 1978; Davelaar, Coltheart, Besner, & Jonasson, 1978; Hawkins, Reicher, Rogers, & Peterson, 1976). The findings from the present study do not support this notion. Because lexical access via the phonological route leads

to the activation of inappropriate lexical entries and is thus detrimental to performance in the semantic relatedness decision task, subjects should have tried to shut down this mode of lexical access. The demonstration of the homophone and pseudohomophone effects in the semantic relatedness decision task indicates that they were apparently unable to do so.

Therefore, the findings from the present study add to a growing body of evidence for the phonological recoding hypothesis, indicating that phonology is activated automatically in visual word recognition and that phonological information perhaps mediates lexical access in reading for meaning.

However, the present study does not rule out the possibility that there is an independent visual route to the mental lexicon. Indeed, it is probably impossible to prove that the direct visual access route does not exist at all. The fact that subjects performed reasonably well on the homophone and pseudohomophone trials, although bothered by their presence, also suggests that there must be a way of inhibiting incorrect lexical entries accessed via the phonological route as in the case of homophones and pseudohomophones. The direct visual access route probably provides a way of double checking to make sure that correct lexical entries are accessed in visual word recognition and reading.

Therefore, one possible compromise is to assume that (1) there are two independent routes to the mental lexicon, a slow visual route and a fast phonological route; (2) the phonological route is a predominant route, used universally for lexical access in visual word recognition and reading; and (3) the visual route serves as a backup system that double checks and reinforces the activation of correctly accessed lexical entries.

Note that Van Orden and colleagues (Van Orden, 1987; Van Orden et al., 1988) have proposed a mechanism called *spelling check* as a way of inhibiting wrongly accessed lexical entries. Theoretically, spelling check is performed within the mode of phonological lexical access. First, the visual form of a word activates its corresponding phonology, which in turn activates the meaning of this word in the mental lexicon. Then the feedback from meaning specifies what the word should look like and whether or not it matches stimulus input. This is thus quite different from the assumption that there are two independent routes to the mental lexicon and that the convergence of their activations eliminates ambiguities in accessing lexical entries.

The findings from the present study can also be elucidated with the resonance/coherence framework proposed by Van Orden and Goldinger (1994) and Stone and Van Orden (1994). The framework is derived from dynamic systems theory. According to this framework, a word recognition system involves three interconnected components (subsymbols): visual subsymbols, phonological subsymbols, and semantic subsymbols. Presentation of a printed word initiates a massive spread of activation from visual features to linguistic features. After the initial spread

of activation, cooperative-competitive dynamics begin among all subsymbols, and coherent structures emerge as relatively stable feedback loops. Eventually, visual-phonologic-semantic dynamics will all settle into a coherent global resonance. However, according to Van Orden and his colleagues, visual-phonologic resonances will precede visual-semantic resonances because the visual forms of words are more strongly correlated with their names than with their meanings. In addition, phonologic-semantic relations will cohere before visual-semantic relations because there is a greater correspondence between phonological and semantic patterns than between visual and semantic patterns and because speech is much more common than reading. Given these assumptions, the homophone effect and the pseudohomophone effect shown in the present study arise from the dominance of visual-phonologic resonances and phonologic-semantic resonances over visual-semantic resonances.

In the present study, we focused on the question of whether phonological information is activated automatically and whether prelexical phonological recoding takes place in the reading of printed words. However, we have not discussed the question of how phonology can be assembled prelexically. If it is the case that we cannot convert all printed words to their phonological representations without lexical access, then there is no basis to suggest that phonological recoding can mediate lexical access of all words.

According to some researchers (e.g., Coltheart, 1978; Coltheart, Curtis, Atkins, & Haller, 1993), phonology is assembled in two distinct ways: a prelexical (or nonlexical) route and a (post)lexical route. More specifically, it is proposed that prelexical phonology can be assembled for regular words only, by "grapheme-phoneme" conversion rules. For irregular or exception words (e.g., PINT), however, phonology is generated postlexically, because there is no explicit rule for pronouncing irregular words. However, recent work from connectionist modeling has shown that several models can learn to compute phonological codes for irregular as well as regular words by a single nonlexical mechanism (e.g., Plaut, McClelland, Seidenberg, & Patterson, 1996; Seidenberg & McClelland, 1989; Van Orden, 1987). Thus there is the possibility that phonology is generated prelexically for all words.

Finally, if there are indeed two routes to the mental lexicon: a direct visual route and an indirect phonological route, one can ask the question of how an indirect route can be faster than a direct route. This question is related to the question of how the mental lexicon is organized and what the predominant mode of access to the lexicon is. One possibility is that the mental lexicon is organized phonologically (Lukatela & Turvey, 1991, 1994). Although there is no direct evidence for this proposal, the fact that children initially acquire language as a purely phonetic system suggests this possibility. Another possibility is that the mental lexicon is organized in some abstract forms but the phonological access to the lexicon is more

rapid than the visual access because of developmental priority and the dominance of spoken language over visual symbols in everyday communication. It is to be hoped that researchers will be able to address and resolve these issues in the future.

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APPENDIX A
Words Used to Construct Unrelated Word Pairs
in Experiment 1

Source Word	Homophone	Orthographic Control
JAIL	BALE	BALL
SAND	BEECH	BENCH
SKY	BLEW	BLED
RIVER	CREAK	CREED
DEER	DOUGH	DOOM
TAXI	FAIR	FEAR
COAT	FIR	FAR
ROSE	FLOUR	FLOOR
GAME	FOWL	FOAL
DOOR	GAIT	GASP
BALD	HARE	HARM
RIDING	HOARSE	HOUSE
MONEY	LUTE	LIST
FEMALE	MAIL	MILE
HORSE	MAIN	MEAN
MAJOR	MINER	MIRROR
TISSUE	MUSSEL	MISSILE
ALL	NUN	NOON
ACHE	PANE	PANS
STOP	PAWS	PEAS
COUPLE	PEAR	PIER
WAR	PIECE	PEACH
VOTE	POLE	POOL
WATER	REIN	RUIN
MODEL	ROLL	RULE
PRICE	SAIL	SEAL
QUOTE	SIGHT	FIGHT
HEART	SOLE	SOIL
MOON	SON	SIN
GAZE	STAIR	START
BEEF	STAKE	STARK
THEFT	STEEL	STEAD
SUGAR	SUITE	SWEAT
HEAD	TALE	TILE
BLOOD	VANE	VINE
OCEAN	WAIL	WHEEL
TRASH	WAIST	WARTS
STRONG	WEEK	WEAR
TWO	WON	GONE
LEFT	RITE	ROTE

Note—Each unrelated word pair consisted of a source word and a homophone or its orthographic control.

APPENDIX B
Words and Nonwords Used to Construct Unrelated
Word–Nonword Pairs in Experiment 2

Source Word	Pseudohomophone	Orthographic Control
GONE	AWEIGH	AWELTH
ROAST	BEAF	BELF
HAWK	BURD	BORD
BREAD	BUDDER	BUSHER
BAKE	CAIK	CAWK
TABLE	CHARE	CHARK
OPEN	CLOZED	CLOOED
WEAR	CLOZE	CLOME
SNEEZE	COPH	COCH
WEEP	CRIE	CRIT

APPENDIX B (Continued)

Source Word	Pseudohomophone	Orthographic Control
WET	DRIE	DROE
NEAR	PHARR	PHAER
SMOKE	FYER	FLER
FOUR	FYVE	FOVE
FAKE	FRAWD	FRAID
GRAPE	FRUTE	FRUST
BIBLE	GAHD	GERD
MOAN	GRONE	GRONT
DOCTOR	NERSE	DERSE
HOUSE	HOAM	HORM
COLD	HAHT	MAHT
CIDER	JOOCE	JORCE
BLADE	NYFE	NOFE
ROAD	LAIN	LARN
EARLY	LAIT	LART
MOST	LEEST	LERST
TRUTH	LIZE	LIDE
GREEN	LITE	LITH
TIGHT	LUSE	LESE
HATE	LUV	LIV
YOUR	MYNE	MENE
DEAF	MEWT	MERT
HAMMER	NALE	NARL
FLEET	NAYVY	NARVY
EIGHT	NYNE	NUNE
FILE	PAYPER	PARPER
WAR	PEECE	PERCE
GROUP	PEEPL	PERPLE
PIECE	PYE	POE
STOVE	PYPE	PUPE
CLOUD	RANE	RAND
LION	RORE	ROTR
DEEP	RUTED	RETED
OATS	RIE	REE
BOY	GURL	SURL
OBEY	SURVE	SARVE
HERD	SHEAP	SHEMP
SOLE	SHOOH	SHORN
DREAM	SLEAP	SLEMP
SUDS	SOPE	SORP
EAT	SUPE	SUPL
BITE	TEATH	TERTH
FLOOR	TIAL	TIRL
GRAVE	TOOM	TORM
TRAIN	TRAX	TRAW
PINE	TREA	TREM
ONE	TWOO	TWOK
SPIDER	WHEB	WERB
TON	WATE	WRAT
FLOUR	WHEET	WHEST

Note—Each pair consisted of a source word and a pseudohomophone or its orthographic control.

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