The Activation of Phonology During Silent Chinese Word Reading

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The role of phonology in silent Chinese compound-character reading was studied in 2 experiments using a semantic relatedness judgment task. There was significant interference from a homophone of a "target" word that was semantically related to an initially presented cue word whether the homophone was orthographically similar to the target or not. This interference was only observed for exact homophones (i.e., those that had the same tone, consonant, and vowel). In addition, the effect was not significantly modulated by target or distractor frequency, nor was it restricted to cases of associative priming. Substantial interference was also found from orthographically similar nonhomophones of the targets. Together these data are best accounted for by a model that allows for parallel access of semantics via 2 routes, 1 directly from orthography to semantics and the other from orthography to phonology to semantics.

The initial acquisition of most languages (with the important exception of sign language) is through speech. When humans develop secondary verbal skills—reading and writing—it is unclear whether they establish a direct link from orthography to meaning or whether orthography is linked to phonology, with phonology remaining the sole or primary route to meaning. Another possibility is that both pathways exist and that both are used to access meaning during reading. Most of the extensive research on these questions has been conducted with English and other alphabetic writing systems. The first question we address here is whether Chinese, with its nonalphabetic writing system, differs from English in how access to meaning takes place. A second question concerns the nature of the phonological code used during the reading of Chinese.

Reading in English

There are at least three possible routes to meaning during reading in an alphabetic writing system: a direct route from orthography to meaning and two indirect routes to meaning via a phonological representation, one based on spelling-to-sound rules or regularities (a "prelexical" route) and the other based on orthographic identification of a lexical entry that leads to the activation of the word's phonological representation (a "postlexical" route).

To test which routes are used in reading English, Van Orden (1987; Van Orden, Johnston, & Hale, 1988; Van Orden, Pennington, & Stone, 1990) studied participants' performance in a semantic categorization task: A participant was presented with a category name (e.g., FLOWER) followed by a word (e.g., ROSE), which the participant judged as being a member of the category or not. The key trials in these studies were those on which a homophone of a category member (e.g., ROWS) was presented. Participants made many more errors in rejecting these homophones as exemplars of the categories compared with orthographic control words (e.g., ROBS), which were orthographically as similar to the category exemplar as were the homophones. (Typically, for orthographically similar homophones, the error rates were 10% to 15% higher than the error rates for the controls.) This effect was only modulated by the frequency of the category exemplar, not the frequency of the homophone distractor. These results were interpreted as showing that, in accessing the meaning of a printed word in English, there is an initial stage in which the orthography of a word activates a phonological representation, which then activates its associated meaning or meanings, followed by a verification or "spelling check" stage in which the orthographic processing proceeds further and the "wrong" meaning of the homophone is inhibited (the phonology-first verification model). The fact that there were more errors to the homophones than to the spelling controls suggests that in those cases the verification process was aborted. Crucially, pseudohomophones (nonwords whose pronunciation is the same as a target word, such as *sute*) were found to produce

as large an effect as homophones, such as *hare* (Van Orden, 1991; Van Orden et al., 1988), which supports the claim that the prelexical phonological route is used in reading English. Similar results have been obtained when participants are asked to judge whether two simultaneously presented words are semantically related, in that there are many errors to pairs like *MAIL–FEMALE* (Lesch & Pollatsek, 1998). In addition, Lesch and Pollatsek observed a smaller interference effect for "false homophones," such as *BEAD–PILLOW* (for which *BEAD* could be pronounced /bed/ to rhyme with *HEAD*), indicating that prelexical phonology is also involved when the stimuli are words.

These studies indicate that the phonological code accesses meaning quite early; if not, people would not make any more errors on homophones than on controls matched on orthographic similarity. However, the studies do not necessarily indicate (as Van Orden first argued) that prelexical phonological access is always the first route to meaning, followed by an orthographic verification stage. Instead, the above data could also be accommodated by a parallel access model, in which the orthography of a word accesses phonological and semantic codes in parallel but the phonological route (presumably prelexical) is faster in many cases (Van Orden et al., 1990).

Jared and Seidenberg (1991) questioned the phonology-first model, arguing instead for a parallel access model in which the phonological route was not likely to be faster than the direct orthographic route, except for low-frequency words. With the same paradigm and under similar conditions, they replicated Van Orden's results: Homophone distractors produced more errors than did matched controls. However, they hypothesized that the category names primed the phonological codes of the words being presented, amplifying the homophone interference effect (e.g., *flower* primed *rose*, including the phonology of *rows*). To test this hypothesis, they used broad category names that would be unlikely to activate specific targets (e.g., *living thing* and *object*) and found that only low-frequency homophone distractors of low-frequency targets showed substantial interference effects. Jared and Seidenberg concluded that the degree of phonological activation is strongly influenced by the context in which the word is encountered; without priming, phonological information contributes to the activation of word meaning only for low-frequency words. Low-frequency words are presumably affected because phonological activation has already occurred by the time their meanings have been activated by the direct orthographic route.

We think it is unlikely, however, that early phonological access to meaning is restricted to such semantically primed cases. A different explanation of Jared and Seidenberg's (1991) result is that the use of "broad" categories slows down participants' reaction times (RTs) by over 100 ms. As much of this extra time is probably not taken up in looking up the literal meaning of a word, but instead in deciding whether that meaning is consistent with *living thing* or not, any orthographic process (whether it is a parallel orthographic activation of meaning or a verification process) would have more time to reject a wrong spelling of the

target. (Even the strongest phonology-first model has to predict that readers will successfully disambiguate homophones if given enough time.) Moreover, Jared and Seidenberg did not observe any orthographic similarity effects for nonhomophones, so there is no positive evidence in their experiments that orthography accessed meaning prior to phonology. In a verification model, low-frequency homophone distractors of low-frequency targets would have the most difficult spelling patterns to access and thus would require the longest time to pass the verification process and would be the hardest to reject. Thus, when the overall RT is slowed down by 100 ms (by the use of broader categories), a verification model could predict that interference effects would be largely restricted to low-frequency homophone distractors of low-frequency targets. Second, there is evidence from experiments using parafoveal preview and "fast priming" techniques that phonology enters early enough to affect fixation time on a homophone in silent reading of text (Pollatsek, Lesch, Morris, & Rayner, 1992; Rayner, Sereno, Lesch, & Pollatsek, 1995; but see Daneman & Reingold, 1993; Daneman, Reingold, & Davidson, 1995).[1] Thus, it seems most plausible that phonological access to meaning is often quite rapid.

To summarize, most of the work in English using either a category membership judgment (i.e., the standard Van Orden paradigm) or a semantic relatedness judgment shows that participants make large numbers of "false alarms" when homophones of positive instances are presented. This finding shows that English readers frequently activate the phonology of words early in processing, and the phonology may in turn activate word meanings, including meanings that are incompatible with the word's orthography. However, it is not clear whether phonology is the initial route to meaning or whether a direct route from orthography to meaning is activated in parallel with the phonology-to-meaning route. Moreover, although English readers clearly can activate a phonological code prelexically, it is not clear that this is the primary route to phonology in the case of high-frequency words.

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[1] Daneman and Reingold (1993) and Daneman et al. (1995) used a technique in which "errors" (which were either homophonic or orthographically similar to the correct word) were sprinkled throughout a text. They had participants read the text and try their best to ignore these errors. They found as large an early interference effect (i.e., longer gaze durations on the target word) for nonhomophones as for homophones, although the later interference effect (i.e., longer second-pass reading time) for nonhomophones was much greater, leading them to conclude that phonology enters into reading only after initial access. However, Rayner, Pollatsek, and Binder (1998) obtained somewhat different data (with larger immediate interference effects for nonhomophones) that were consistent with a verification model. A problem with this paradigm is that it mixes normal reading with a problem-solving task, thereby making it difficult to interpret lengthening of fixation times. In contrast, Pollatsek et al. (1992) and Rayner et al. (1995) used preview and fast priming manipulations in which the participants were unaware of the primes and previews, creating a situation that was much closer to normal reading.

Why Study Chinese?

In English, and in other languages using an alphabetic writing system, the mapping between orthography and phonology is relatively transparent. That is, grapheme-to-phoneme rules allow a reader to generate or "assemble" the correct pronunciation for most words. In contrast, in a logographic writing system such as Chinese, the pronunciation of a character is largely opaque. Although there are clues to pronunciation in most characters, these clues are unreliable. Thus, the pronunciation of each character must be learned individually, making an assembled route from orthography to phonology unavailable in Chinese. If the absence of such a route prevents access of phonology prior to identification of the character, then it is possible that access of the meaning of words in Chinese dispenses with phonology altogether and goes directly from orthography to meaning or, alternatively, that both orthography and postlexical phonology have access to meaning but differ in their speed.

The orthography of Chinese characters falls into two main classes: integrated characters (18%) and compound characters (82%; Zhou, 1978, as cited by Chen, Flores d'Arcais, & Cheung, 1995). The integrated characters consist of crossed strokes that are inseparable, whereas compound characters usually consist of two separable subcomponents (called *radicals*) that are sometimes themselves integrated characters. One radical, the semantic radical, sometimes provides a categorical cue to the meaning of the whole character, whereas the other radical, the phonetic radical, sometimes provides the correct pronunciation of the whole character. Of all the compound characters, only 39% have a phonetic radical that correctly predicts the sound of the character (Zhou, 1978, as cited by Chen et al., 1995). The proportion is even less (no more than 35%) for compound characters with high and medium word frequencies. Therefore, in most cases, the whole character needs to be recognized before the correct pronunciation can be retrieved, and the use of the phonetic radical to guess the pronunciation would result in the wrong pronunciation of about two thirds of the characters. The pronunciation of each character is monosyllabic, consisting of an initial consonant, a vowel, sometimes a final consonant, and a tone (one of four major tones). Tone is the linguistic abstraction of phonetic pitch carried by the vocalic part (mainly the vowel) of a syllable (Gandour, 1978). If tone is included as part of the syllable (tone will be explained in more detail later), then there are only about 1,300 different syllables used in Mandarin Chinese. Given that there are about 5,000 commonly used characters, each syllable usually corresponds, on average, to 4 different characters, with some syllables representing as many as 40 different characters (Yin, 1984, as cited by Zhou & Marslen-Wilson, 1994), resulting in huge numbers of homophone pairs in Chinese orthography.

Several studies of written word identification in Chinese using lexical decision, priming, or judgment paradigms have suggested that a Chinese printed word activates its phonology automatically (e.g., Hue, 1992; Perfetti & Zhang, 1991; Tan, Hoosain, & Peng, 1995; Tan, Hoosain, & Siok, 1996).

For example, in a backward-masking task, Tan et al. (1995) observed that homophonic masks, but not semantically similar masks, facilitated Chinese character identification under a very brief exposure duration. These findings suggest that phonological codes are processed very rapidly, but they do not necessarily imply that the phonological code of a word is crucial in activating its semantic code.

Perfetti and Zhang (1995) explored the role of phonology in semantic activation more directly. In their study (using a mixture of compound and integrated Chinese characters), two successive words were presented, to which one group of participants made synonymy judgments and another group made homophony judgments. Synonym pairs and homophone pairs, as well as pairs that were neither synonyms nor homophones, were used. Perfetti and Zhang found that participants were slower and were likely to make errors in rejecting homophones (compared with controls) as not being synonyms and in rejecting synonyms as not being homophones, suggesting that phonology is automatically activated when only semantic information is needed, and vice versa.

Two other studies in Chinese have used the Van Orden paradigm to address the role of phonology during Chinese word reading. Leck, Weekes, and Chen (1995) studied both compound and integrated Chinese characters in a categorical decision task. For the compound characters, there were four different types of distractors relevant to our present purposes: homophones of category exemplars with the same phonetic radical as the target words, nonhomophones with the same phonetic radical, orthographically dissimilar homophones, and unrelated control words. Leck et al. found that the false-positive error rates for the different types of distractors did not differ significantly from each other, although both homophone conditions had higher error rates (5.0%) than the nonhomophone conditions (1.4%). However, the RTs of the correctly rejected distractors (correct "no" RTs) differed from each other significantly. Overall, both orthographic similarity (sharing the same phonetic radical) and phonological identity significantly slowed responses compared with the unrelated controls. Although there was no significant interaction between orthographic similarity and homophony, the homophone effect was not significant for the orthographically dissimilar homophone distractors, and the significance of the homophone effect was not reported for the orthographically similar homophone distractors. For the integrated characters, there were three types of distractors: orthographically similar nonhomophones, orthographically dissimilar homophones, and unrelated controls. Leck et al. found that error rate for the orthographically similar nonhomophone distractors (25.7%) was higher than that for the orthographically dissimilar homophone distractors (2.8%) and the unrelated controls (0.7%). The RT pattern was similar. Leck et al. concluded that in the process of retrieving meaning, integrated characters rely primarily on orthographic information, whereas the compound characters rely on both orthographic and phonological information.

Chen et al. (1995) conducted a similar study that used orthographically dissimilar homophone distractors, ortho-

graphically similar nonhomophone distractors, and two types of unrelated controls (there were no orthographically similar homophone distractors). They found interference (in both error rates and correct "no" RTs) due to orthographic similarity but not due to homophones, from which they concluded that phonological information may not be automatically activated during the processing of the meanings of Chinese characters. However, because the Chen et al. study used a mixture of compound and integrated characters (about 23% integrated characters), and because Leck et al.'s (1995) finding suggested that integrated characters show only an orthographic similarity interference effect, the mixing of these two classes of characters might have reduced the likelihood of obtaining a homophone effect. Moreover, although the effect was not significant, their data did show that participants made more errors in response to the homophone distractors than in response to the controls in the two experiments.

A third study using the Van Orden categorical judgment task (Wydell, Patterson, & Humphreys, 1993) examined the processing of Japanese kanji characters (morphographic or logographic characters of Chinese origin) and found interference effects (in errors and correct "no" RTs) due to both orthographic similarity and homophony. However, whereas both Chen et al. (1995) and Leck et al. (1995) used single-character words as targets and distractors, Wydell et al. used two-character words. Although the orthographically dissimilar distractors and targets shared neither character, the orthographically similar distractors were constructed by allowing the target and the distractor to share one character, which made the orthographically similar distractors either phonologically similar (in the orthographically similar nonhomophone case) or identical (in the orthographically similar homophone case) to the target words. Moreover, by letting the target and distractor share a character, many orthographically similar distractors were semantically similar to their targets; thus, the orthographic similarity effect observed in this study was seriously confounded with phonological and semantic similarity. In addition, the authors did not report whether the homophone effect was still significant under the orthographically dissimilar conditions. Recently, Sakuma, Sasanuma, Tatsumi, and Masaki (1998) replicated the findings of Wydell et al. and showed that the homophone effect was only found in the orthographically similar condition. Unfortunately, most of the confounds in the Wydell et al. study were not resolved in the Sakuma et al. study.

All the studies mentioned above (Chen et al., 1995; Leck et al., 1995; Perfetti & Zhang, 1995; Sakuma et al., 1998; Wydell et al., 1993) have used correct "no" RTs as a way to measure orthographic and phonological interference. However, as M. Coltheart, Davelaar, Jonasson, and Besner (1977) pointed out, to make a "no" response, participants need to reject all possible matches; therefore, "no" latencies are usually longer than "yes" latencies, which provides time for additional processing that may not occur during a "yes" response. As such, M. Coltheart et al. argued that the evidence from correct "no" RTs is much less important and informative than evidence from false-positive errors. If we exclude the studies by Sakuma et al. and Wydell et al. for the methodological reasons already mentioned and consider only results from error rates as reliable, then we can say that Chen et al. (with a mixture of compound and integrated characters) and Leck et al. (for integrated characters only) found that only orthographic similarity (but not homophony) produced significant interference and that Perfetti and Zhang (with a mixture of compound and integrated orthographically dissimilar characters) found that homophones produced a significant interference effect. In other words, for compound characters (which include 82% of all Chinese characters), the results were mixed among the different studies. Moreover, none of the studies reported above have found both orthographic similarity and homophony effects to be significant.

Given this state of affairs, we wanted to determine, for compound characters, whether reliable orthographic similarity and homophony effects could be observed in a semantic judgment task in Chinese, and if so, what the interaction between these effects would be. To do so, we used a semantic relatedness judgment task rather than a categorical judgment task. Our primary motivation for this change was that a much wider variety of target words can be used in a relatedness task (there are many words that do not easily fit into standard semantic categories), which allowed us to use a much larger number of targets, thereby greatly increasing the power of our experiment. Whereas Leck et al. (1995) and Chen et al. (1995) each used only 20 target words and Perfetti and Zhang (1995) used 34 different core words, we used 121 target words in Experiment 1 and 180 target words in Experiment 2. We used only compound characters in our experiments not only because they represent the majority of Chinese characters but also because the manipulation of orthographic similarity is more straightforward with compound characters. Compound characters can share an orthographic component (a radical), whereas a manipulation of orthographic similarity for integrated characters must rely on subjective judgments. In Experiment 1, all of our orthographically similar characters shared a phonetic radical; as already noted, two characters sharing a phonetic radical need not be pronounced identically or similarly.

As mentioned earlier, although we do not think the homophone effect found in English is restricted to semantically primed cases, none of the Chinese studies using the semantic judgment paradigm have directly addressed the priming issue raised by Jared and Seidenberg (1991). By collecting associative norms for the cue words used in the experiments, we were able to look into the effect of priming more directly.

Experiment 1

The purpose of this study was to investigate the role of orthography and phonology in semantic retrieval in reading Chinese characters. We used a semantic judgment task (i.e., "Are the two words on the screen semantically related?") rather than the semantic categorization task of Van Orden (1987). A major motivation for this change is that there are many words that are hard to fit in a semantic category.

Table 1
An Example of Items Used in Experiment 1

Cue word	Target	Orthographically similar distractor		Orthographically dissimilar distractor	
		Homophone	Nonhomophone	Homophone	Nonhomophone
边 界	埂	银	很	淫	嘉
/bian1[a] jie4/	/yin2/	/yin2/	/hen3/	/yin2/	/jia1/
border	edge	silver	very	obscene	good

[a]The pronunciation of the character is labeled according to the Chinese phonetic labeling system pinyin. The number at the end denotes the tone (first, second, third, or fourth).

Moreover, there are experiments in English (e.g., Lesch & Pollatsek, 1998) that have used this task and obtained results virtually identical to those of Van Orden.

Method

Participants. For the main experiment, 15 native Chinese speakers from the University of Massachusetts at Amherst were recruited (7 men, 8 women). Their mean age was 30.5 years (SD = 2.7 years). All participants were volunteers and were paid for their participation. These participants all had at least a high school level of education in mainland China and were either university students or relatives of those students (mainly spouses).

Although people from different areas of mainland China (including 5 of the 15 participants in the present study) may speak dialects at home that are completely different from Mandarin, the official dialect in mainland China, only Mandarin is used in school. Children are taught Mandarin at the same time they are taught to read and write.[2] Mandarin is also used on national TV, in radio, in movies, and in all public transportation and is encouraged on many other occasions as well. Therefore, most people from mainland China speak Mandarin fluently and have learned to read aloud almost exclusively in Mandarin. To the extent that Chinese readers may not activate Mandarin phonology, it would work against finding a homophone effect. On average, participants in this experiment had been away from China for 20.7 months (SE = 5.39 months) and used Mandarin 70% of the time (SE = 5.0%) when talking with other people in the United States at the time of testing (self-rated).

Materials and design. The experimental trials used 121 sets of words. Each set consisted of a two-character cue word and five single-character test words—a target word and four distractors.[3] The target word, to which the correct response was "yes," was semantically related to the cue word: It was a synonym of the cue word or an exemplar of the category specified by the cue word. An additional group of 12 native Chinese speakers (who did not participate in either Experiment 1 or 2) rated the semantic relatedness of the cue words and targets on a scale ranging from 1 (*no relation*) to 5 (*highly related*); the average rating was 4.24 (SE = 0.05). None of the distractors were related to the cue word semantically, so the correct response to all of them was "no." There were four types of distractors: (a) a homophone of the target that was also orthographically similar to it, (b) a word that was orthographically similar to the target but pronounced differently from it, (c) a homophone of the target that was orthographically dissimilar, and (d) a nonhomophone of the target that was orthographically and phonologically dissimilar to the target. Orthographic similarity was defined as sharing the same phonetic radical. For the distractors in the nonhomophone conditions, we made sure that no corresponding homophones were semantically related to the

cue word in any way to avoid unintended phonological interference. An example of the materials with English translations is shown in Table 1; all the materials are given in the Appendix.

The test word that was paired with a given cue word was counterbalanced over participants through the use of five experimental lists. Each participant saw only one of the lists, and each list had only one test word (the target or one of the four distractors) paired with a given cue word. There were 34 filler trials similar to the experimental trials, in which each trial consisted of a cue word and a related target or one of the four distractors.[4] Because only one fifth of the 121 experimental trials and the 34 filler trials required a "yes" response, 93 "yes" filler trials were added in which each trial consisted of a cue word and a target. As a result, half of the 248 trials in the experiment were "yes" trials and the other half were "no" trials. The "yes" filler trials were the same in each list; none of the fillers were included in the analyses. The order of the filler and test trials was randomized with the constraint that no more than 4 consecutive trials required the same response.

It was not possible to match the word frequency for each test word within a given trial; therefore, the distribution of word frequency[5] was matched between each category of test words in both experimental and filler trials. On average, in each condition, about 37% of the characters had frequencies between 0 and 10 (per million), with the means for targets, orthographically similar homophone distractors, orthographically similar nonhomophone distractors, orthographically dissimilar homophone distractors, and unrelated controls being 4.2, 3.6, 3.6, 4.0, and 4.5, respectively. About 44% had frequencies between 11 and 100 (per million), with the means for the conditions being 39.8, 35.5, 39.5, 40.8, and 41.3, respectively. About 19% had frequencies greater than 100 (per

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[2] In mainland China, all elementary and secondary schools use the same standard textbooks nationwide. Therefore, on graduation from high school, people from different areas of China are expected to know the same set and number of Chinese characters.

[3] Although each Chinese character has a meaning, the meaning is often loosely defined. Most words in Chinese consist of two or more characters; for an analogy in English, consider *ball game* (see Wang, 1973, for a more detailed description of the Chinese language).

[4] These 34 trials were originally treated as experiment trials. However, it was later discovered that the unrelated controls in these trials shared the semantic radical with the target. As such, the unrelated controls became orthographically similar to the target; consequently, these 34 trials were treated as fillers.

[5] The word count (single-character count) of the frequency dictionary (*Xiandai Hanyu Pinlu Cidian*, 1986) included 1.8 million single characters and was based on articles published between the 1930s and the 1980s. To our knowledge, this is the only available frequency dictionary published in mainland China.

million), with the means for the conditions being 353.8, 379.0, 447.3, 466.7, and 471.1, respectively. Some of the characters appeared more than once in the cue and filler conditions. However, no experimental test word was seen more than once by a given participant.

Procedure. Participants were seated in front of an IBM PC 386 in a quiet room. Chinese characters (in font style JSong and 28 pixels high) generated by Chinese word-processing software (TwinBridge Multi-Lingual System for Windows 3.1—Chinese Standard Version 3.3) were displayed as pictures. Participants responded through a response switch box connected to the PC. The switch box had three switches, two on the right and one on the left. Participants were instructed to rest their right thumb and right index fingers on the two right switches, respectively, and the left index finger on the left switch. As soon as the switch was pulled, a signal was sent to the computer (with millisecond accuracy) and recorded.

Participants initiated a trial with the right thumb. Each trial began with a fixation "+" at the center of the screen for 500 ms. The "+" was then replaced by the cue word for 500 ms. Immediately following the offset of the cue word, the test word (target or distractor) appeared in the center of the screen for 500 ms. The participants were instructed to judge, both quickly and accurately, whether the cue and test words were semantically related by pulling the right index switch for a "yes" response and the left index switch for a "no" response, as soon as the test word appeared. RT was measured from the onset of the test word to the participant's response. Both RT and response accuracy were recorded. No feedback was given. Ten practice trials were given; after the practice trials, the experimenter left the testing room. The experiment lasted about 30 min.

Post hoc tests and scoring. After the semantic judgment trials, participants were given two tests. The first was designed to make sure that the homophones seen by the participant had functioned as homophones (it is not uncommon for Chinese readers to mispronounce certain low-frequency characters). Participants were instructed to pronounce aloud all homophone distractors they had seen and the targets corresponding to those homophones (which they did not see). Homophone distractors and targets were intermixed randomly. When a participant did not pronounce the two words in a pair the same way (i.e., correctly), that trial was excluded from later analyses.

The purpose of the second test was to make sure that participants could correctly distinguish the three orthographically similar characters (V. Coltheart, Patterson, & Leahy, 1994; Jared & Seidenberg, 1991). For each of the 121 experimental sets of words, the cue word and the three test words (the target and the two orthographically similar distractors) were printed in a horizontal row, with the target and distractors in a random order. The participant's task was to circle the test word that was semantically related to the cue. If a participant chose the wrong character in this test and had also made the same error on the corresponding experimental trial, it was assumed that the error represented a lack of familiarity with the character and not a momentary orthographic confusion. These trials were also removed from the analyses.

Among the 121 experimental trials, three cue–distractor combinations were deleted for which the semantic relationship between the cue word and distractor was not unambiguously negative. Additional data points were deleted on the basis of one or the other of the postexperiment tests. Trials for which the participant's RT was above 3,000 ms were also removed. In sum, 6.2% of the data points were excluded from the analyses. To control for possible differences among the counterbalanced lists, we used list as a between-subjects variable in the subject analyses (Pollatsek & Well, 1995).

Associative norms. Eighteen Chinese volunteers (who had not been involved in any other part of the study reported in this article) participated in this part of the study. Participants were presented cue words used in Experiment 1 printed out on paper for each of which they had to write down the first two Chinese characters that came to mind. They were instructed to leave the line blank if they could not think of anything in 5 s. These participants also performed the same task with the cue words of Experiment 2. The order of the cue words within experiments, as well as between experiments, was counterbalanced over participants through the use of four lists.

Results and Discussion

In the analyses below, *homophone interference effect* refers to the difference between the average of the two homophone distractor conditions and the two nonhomophone distractor conditions and *orthographic similarity interference effect* refers to the difference between the average of the two orthographically similar conditions and the average of the two orthographically different conditions. We set $p < .05$ as our significance level: All reported F values were significant unless otherwise stated. F values are reported by subjects (F_1) and by items (F_2).

Error rates for the distractors. When the correct response was "no," participants made more errors when the distractor was either orthographically similar to or homophonic with a possible target (see Table 2). Both the 9.4% main effect of homophony and the 12.2% main effect of orthographic similarity were highly significant, $F_1(1, 10) = 57.10$, and $F_2(1, 120) = 20.30$, and $F_1(1, 10) = 101.49$, and $F_2(1, 120) = 28.93$, respectively. The interaction between the two was also significant, $F_1(1, 10) = 9.51$, and $F_2(1, 120) = 6.39$, indicating that orthographic similarity effects were greater for homophones and/or that homophone effects were greater when the words were orthographically similar.

In pairwise comparisons, the 13.7% interference effect of homophony when the stimuli were both orthographically similar was significant, $F_1(1, 10) = 35.12$, and $F_2(1, 120) = 6.91$, and the 5.1% interference effect of homophony when neither stimulus was orthographically similar to the target was significant over subjects and marginally significant over items, $F_1(1, 10) = 15.80$, and $F_2(1, 120) = 3.39$. The 16.5% interference effect of orthographic similarity to the target when the stimuli were both homophones of the target and the 7.9% effect when neither stimulus was a homophone of the target were both significant, $F_1(1, 10) = 131.48$, and $F_2(1, 120) = 22.95$, and $F_1(1, 10) = 13.24$, and $F_2(1, 120) = 9.17$, respectively.

RTs for correct "no" responses. The RT results are also shown in Table 2. Participants were 69 ms slower in making a correct judgment when the distractors were homophones of the target compared with unrelated distractors, $F_1(1, 10) = 8.72$, and $F_2(1, 120) = 7.14$, and were 92 ms slower in rejecting orthographically similar distractors, $F_1(1, 10) = 9.41$, and $F_2(1, 120) = 9.09$. The interaction between the two was not significant, $F_1(1, 10) = 1.69$, and $F_2(1, 120) = 1.13$.

In pairwise comparisons, the 42-ms homophone interference effect when the stimuli were orthographically similar to

Table 2

Means of Percentage of Errors and Correct Reaction Times (in Milliseconds) in Experiment 1 for Distractors as a Function of Experimental Condition

Condition	Homophone		Nonhomophone		Difference
	M	SE	M	SE	
Percentage of errors					
Orthographically similar	26.0	2.6	12.3	2.7	13.7
Orthographically dissimilar	9.5	1.8	4.4	0.9	5.1
Difference	16.5		7.9		
Correct reaction times					
Orthographically similar	1,184	57	1,142	56	42
Orthographically dissimilar	1,119	53	1,023	45	96
Difference	65		119		

Note. For targets, the mean percentage of errors was 7.1 ($SE = 1.4$) and the mean correct reaction time was 947 ($SE = 21$).

the target was not significant, $F_1(1, 10) = 2.97$, and $F_2(1, 120) = 0.86$, whereas the 96-ms homophone interference effect when neither the control nor the homophone distractor was orthographically similar to the target was significant, $F_1(1, 10) = 6.93$, and $F_2(1, 120) = 7.54$. The 65-ms interference due to orthographic similarity when both distractors were homophones was not significant, $F_1(1, 10) = 2.37$, and $F_2(1, 120) = 1.51$, but the 119-ms orthographic similarity interference effect when neither distractor was a homophone of the target was significant, $F_1(1, 10) = 17.11$, and $F_2(1, 120) = 9.56$.

Overall, although weaker and less consistent, the orthographic similarity and homophone interference effects on correct "no" RTs mimicked those on the error rates. Obviously, neither the homophone interference effect nor the orthographic similarity effect is the result of a speed–accuracy trade-off. It is less clear, however, whether homophony interfered more for the orthographically similar homophones than for the orthographically dissimilar ones. There was a significant interaction in the error data between orthographic similarity and homophony, which suggests that there was more interference for the orthographically similar

homophones. However, this interaction is a comparison of the absolute sizes of the effects (a difference of two differences). Such a measure is suspect when there are large differences in the error base rates (as in this case). Moreover, the homophone interference effect in the RT data was larger for the orthographically dissimilar homophones than for the orthographically similar homophones. Thus, although the interaction in the error data suggests that there is a larger interference effect for orthographically similar homophones, it is difficult to draw strong conclusions from it. The important point is that there are significant interference effects for both orthographically similar and orthographically dissimilar homophones.

RT for correct and false "yes" responses. In the original Van Orden studies, one piece of evidence for the phonology-first model came from RTs of false "yes" responses (Van Orden et al., 1988). Therefore, we analyzed the false "yes" response data from the present experiment and found that false "yes" RTs were substantially longer than true "yes" RTs (see Table 3). In particular, this is so for the orthographically similar homophones, for which the false "yes" responses were 300 ms slower than those for the true "yes"

Table 3

Means of Reaction Times (in Milliseconds) for Correct and False "Yes" Responses in Experiment 1

Reaction time truncation	Target ("yes")		Distractor (false "yes")							
			Orthographically similar homophone		Orthographically similar nonhomophone		Orthographically dissimilar homophone		Orthographically dissimilar nonhomophone	
	M	SE	M	SE	M	SE	M	SE	M	SE
3,000 ms	947	21	1,251	101	1,132	75	1,354	117	1,224	160
No. of data points	330		83		43		31		16	
2,000 ms	910	17	1,126	79	1,059	58	1,226	94	1,010	81
% trials removed[a]	3		13		9		10		19	
1,500 ms	853	14	962	40	988	48	981	39	921	58
% trials removed[a]	9		28		23		32		25	

[a] Relative to the 3,000-ms truncation point.

responses and were still over 100 ms slower than those for the true "yes" responses, even when all responses over 1,500 ms were removed from the analysis (see Table 3). This is in contrast to the results of Van Orden (1987), who found that, for English-speaking participants, RTs for false "yes" responses to homophones were only a little slower than those for true "yes" responses and that the differences were virtually all due to the upper tail of the distribution, suggesting that phonology normally is activated early in English word reading.

Effects of associative priming. One concern we had was whether the homophone interference effect was restricted to instances in which the cue stimulus primed the target word, as Jared and Seidenberg (1991) claimed. "Priming" is an elusive concept, however, as the 30 years of research on priming has indicated. In this literature, two types of priming have been differentiated: associative and semantic priming (e.g., Fischler, 1977; see McRae & Boisvert, 1998, for a recent summary). Obviously, if the concept of "priming" extends to all semantically related pairs of words, then one could claim that the meaning and/or lexical entry of the target is primed on all trials on which a distractor stimulus is presented. Thus, from the present data, it would be possible to argue that involvement of phonological coding is restricted to situations in which a semantically related word or context preceded a Chinese one-character word. Even if this were true, however, the present finding would be of general interest, because in the ecological situation that one presumably wants to extrapolate to—silent reading of text—it would be unusual for words to appear in contexts in which there was not some semantic support.

Instead, we take the force of the Jared and Seidenberg (1991) argument to apply to associative priming. That is, if the homophone interference effect were limited to situations in which the target word was a strong associate of the cue word, then the homophone interference effect (and by implication, activation of phonological codes) would have a fairly restricted domain. Among other things, if the homophone interference effect were restricted to these cases, it might be a result of conscious prediction of the target from the prime (Neely, 1991). As described above, we collected associative norms from a separate group of 18 participants to determine whether this was the case. The mean number of participants ($n = 18$) who spontaneously generated the target word given the cue word for all 121 items was 1.7 ($SD = 2.6$, range $= 0–11$). Thus, it seems quite clear that few of the targets were in fact strong associates of the cue word.

To further determine whether associative priming may have modulated the homophone effect, we sorted the items into two groups: zero-associate items ($n = 64$), for which no participant came up with the target word, and associate items ($n = 57$), for which at least 1 participant generated the target word. Because this analysis was post hoc, we only investigated the reliability of effects across items. For trials on which the target was presented, participants made fewer errors and were significantly faster in accepting targets when they were associated, with errors of 4.7% and 9.1%, $F(1, 119) = 2.46$, and RTs of 900 ms and 1,013 ms, $F(1, 119) = 5.29$, for associate and zero-associate targets, respectively,

suggesting that associative priming was affecting acceptance of the targets.

For the distractors, in error rates, the main effect of priming was nonsignificant but was in the opposite direction from that predicted by the priming hypothesis (overall errors of 14.7% and 11.7% for zero-associate and associate items, respectively), $F(1, 119) = 1.46$. The homophone interference effects were 8.5% and 10.3% for the zero-associate and associate words, respectively. The orthographic similarity effects were 10.0% and 14.4% for the zero-associate and associate words, respectively. However, despite the indication of a small modulation of the orthographic and phonological interference effects with priming, neither interaction was significant ($Fs < 1$). Similar results were observed in the RTs. The main effect of priming was not significant, $F(1, 119) = 2.98$. The homophone interference effects were 57 ms and 82 ms for the zero-associate and associate words, respectively, and the orthographic similarity effects were 86 ms and 80 ms for the zero-associate and associate words, respectively. Neither orthographic nor phonological similarity interacted with priming significantly ($Fs < 1$).

Therefore, although there were indications of associative priming of the target word, the main effects of orthographic and phonological similarity observed in Experiment 1 in the distractor error rates cannot be accounted for mainly as the result of priming of the targets by their cue words, contrary to Jared and Seidenberg's (1991) hypothesis for English readers.

Word-frequency effects. Another question is whether the interference effects are modulated by the frequency of the target or distractor words. One reason this is of interest is that a phonology-first verification model predicts that the size of the interference effect in English for a homophone distractor should depend on the frequency of the target item, because the lower the frequency of the target, the harder it is to access the orthographic code of the target to decide that the distractor does not match it. A second reason is that Jared and Seidenberg (1991) claimed that the homophone interference effect is largely restricted to low-frequency distractor words, which is consistent with the view that the phonological route is largely a back-up path to meaning. In this analysis, both targets and distractors were sorted into three frequency categories: low, for which the word-frequency count was lower than 10 per million; medium, for which the count was between 10 and 100 per million; and high, for which the count was above 100 per million. However, a factorial analysis was not possible as the two variables were correlated. For the targets, in item analyses of errors and RTs, participants made fewer errors and were significantly faster in accepting higher frequency targets, with error rates of 8.9%, 6.5%, and 5.1% ($F < 1$) and RTs of 1,051 ms, 933 ms, and 872 ms, $F(2, 118) = 4.03$, for target words of low, medium, and high frequency, respectively.

In the error analyses for rejecting distractor words, the effect of the *corresponding target* frequency resulted in significantly more errors for distractors with low-frequency targets (17.8%) than for those with medium- or high-frequency targets (10.9% and 11.1%, respectively), $F(2, 118) = 3.68$. However, there was no clear effect of target

frequency on the homophone interference effect ($F < 1$). The size of the homophone interference effect for distractors with low-, medium-, and high-frequency targets was 6.7%, 12.2%, and 7.4%, respectively, indicating little in the way of any frequency trend and certainly not a bigger effect for distractors with low-frequency targets. The interaction of target frequency and orthographic similarity was not significant either, $F(2, 118) = 2.07$, with the size of the orthographic similarity effect being 18.9%, 8.2%, and 11.9% for distractors of low, medium, and high target frequency, respectively. In the analysis of distractor frequency, the overall effect of the distractor frequency was not significant ($F < 1$) and its influence on the homophone interference effect was inconsistent ($F < 1$): 8.6%, 11.1%, and 4.2%, respectively, for the low-, medium-, and high-frequency distractors. However, there appeared to be some significant distractor frequency effect on the size of the orthographic similarity effect: 15.2%, 14.9%, and 0.8%, respectively, for the low-, medium-, and high-frequency distractors, $F(2, 118) = 3.68$. That is, there was virtually no similarity effect for the high-frequency distractors, although the size of the effect was about the same for low- and medium-frequency distractors.

In the RTs for correct distractor responses, there was little overall effect of target frequency on distractor RTs ($F < 1$). There was a slight hint of a target frequency effect on the homophone interference effect and orthographic similarity effect, with homophone interference effects of 111 ms, 48 ms, and 46 ms and orthographic similarity effects of 101 ms, 80 ms, and 62 ms for low-, medium-, and high-frequency targets, respectively (but $F < 1$ for both interactions). In the analysis of distractor frequency, the overall effect was not significant ($F < 1$). There appeared to be some interactions between distractor frequency and the size of the homophone and orthographic similarity effects: 40 ms, 59 ms, and 132 ms for the homophone effect and 4 ms, 107 ms, and 36 ms for the orthographic similarity effect for low-, medium-, and high-frequency distractors ($F < 1$ for both interactions). However, these interactions were in a direction opposite to what one would expect from the Jared and Seidenberg (1991) hypothesis.

In sum, neither the frequency of the target nor the frequency of the distractor modulated the homophone interference effect in any consistent way. In particular, the homophone interference effect was definitely not always the greatest for homophones of low-frequency targets, nor was it restricted to low-frequency homophone distractors. The interference effect in the RT data was actually greatest for the high-frequency homophone distractors. The only frequency effect of any note was that the orthographic similarity interference effect seemed to disappear for high-frequency orthographically similar distractors.

The role of the phonetic radical in the orthographic similarity effect. It could be argued that because orthographically similar distractors shared the phonetic radical with the target character, the orthographic similarity effect we observed was a phonological effect in disguise. That is, because most phonetic radicals can stand alone and have their own pronunciation, which can be congruent or incon-

gruent with the pronunciation of the character in which they appear, it is possible that the orthographic similarity interference effect was actually caused by activation of the target phonology by phonetic radicals in distractor characters. Studies in Chinese character naming have shown that congruent characters are named faster than incongruent ones (Fang, Horng, & Tzeng, 1986; Hue, 1992; Pollatsek, Tan, & Rayner, in press; Seidenberg, 1985). In the present study, if the orthographic similarity effect observed was indeed a phonological effect in disguise, we would expect participants to make more errors and take longer to reject orthographically similar distractors whose phonetic radicals were congruent with targets, resulting in an apparent orthographic similarity effect.

We selected a subset of trials used in the experiment to perform further analyses. These trials either contained a congruent target, in which the phonetic radical shared the same vowel, consonant, and tone with the target character ($n = 32$), or an incongruent target, in which the phonetic radical shared neither the vowel nor the consonant (but possibly shared the same tone) with the target character ($n = 24$). Other trials were not included in the analyses, either because the phonetic radical of the target did not fit the above two criteria or because the phonetic radical could not stand alone and thus did not have its own pronunciation. Note that if the pronunciation of a phonetic radical is congruent with the pronunciation of a target, it is also congruent when it appears in the orthographically similar homophone distractor but incongruent when it appears in the orthographically similar nonhomophone distractor. In any case, if the pronunciation of a phonetic radical congruent with the target is independently activated, it will facilitate the retrieval of the target phonology. Likewise, if a phonetic radical is incongruent with the target, it is also incongruent with the orthographically similar homophone distractor; however, it could be either congruent or incongruent with the orthographically similar nonhomophone distractor. In any case, the activation of the pronunciation of that phonetic radical will not facilitate the retrieval of the target phonology.

For targets, the difference between the congruent and incongruent targets was not significant. The raw scores for congruence and incongruence were, respectively, 8.3% and 8.3% for errors ($F = 1$) and 923 ms and 1,019 ms for RTs, $F(1, 54) = 1.69$. This RT result is consistent with that of Pollatsek et al. (in press), who found a significant congruence effect in a naming task.

For distractor responses in this subset of trials, the overall effects of orthographic similarity and homophony were still significant in the error rates, $F(1, 54) = 4.68$, and $F(1, 54) = 7.93$, respectively. Moreover, the orthographic similarity effect for congruent targets (5.0%) was less than that for incongruent targets (11.5%), which is in the opposite direction from that predicted by the phonetic radical having an independent role; however, the interaction of orthographic similarity and radical congruence was not significant ($F < 1$). For the RTs of this subset of trials, the overall effect of orthographic similarity was significant, $F(1, 54) = 9.15$, but not that of homophony ($F < 1$). The orthographic

similarity effects for the congruent and incongruent cases were similar: 117 ms for congruent cases and 122 ms for incongruent cases. The interaction of congruence with orthographic similarity was not close to significant ($F < 1$).

Although there was some indication with the targets that the pronunciation of the phonetic radical might have been retrieved, slowing identification of the target if incongruent, the orthographic similarity effect observed in the distractor responses did not seem to be modified by the congruence of the phonetic radical with the target's pronunciation and is therefore unlikely to have been a disguised phonetic effect.

Summary. The data from Experiment 1 showed that, with orthographic similarity held constant, homophony can interfere with participants' performance in a semantic judgment task, indicating that phonology is activated in reading Chinese characters. We also found that orthographically similar nonhomophone distractors generated substantially more errors (12.3%) than the orthographically dissimilar homophone distractors (9.5%). Moreover, the homophone interference observed could not be accounted for by associative priming (as Jared & Seidenberg, 1991, had argued) because cue and target items that were not associated at all (in our normative study) produced almost as big a homophone interference effect as items that had some associative priming. In addition, post hoc tests showed that target frequency modulated RTs to targets and that high distractor frequency reduced or eliminated the orthographic similarity interference effect. There was no indication, however, that the frequency of the target affected the homophone interference effect (as had been reported by Van Orden, 1987) or that the interference effect was limited to low-frequency homophones, as claimed by Jared and Seidenberg. We defer further discussion of the implications of Experiment 1 to the General Discussion.

Experiment 2

There were two principal questions addressed in Experiment 2. The first was whether the phonological code used while reading Chinese included the tone of the syllable, and the second was whether the phonological interference effect observed in Experiment 1 was an artifact of the presence of many orthographically confusable characters.

In Mandarin, the pronunciation of a character is a single syllable defined by a consonant, a vowel, and a tone, which is superimposed on the vowel. Consonants, vowels, and tones are all crucial in determining which word is intended. It is possible, however, that the phonological representation of a character during silent reading does not represent all of these properties of the speech code. For example, Berent and Perfetti (1995) found evidence suggesting that the phonological representation in reading English may not initially have a full representation of vowel information. By analogy, some part of the representation of speech may be omitted from the phonological code or only imperfectly represented. We attempted to assess the nature of the phonological representation used in processing written Chinese by varying the phonological similarity between the target and distractors on these three dimensions (i.e., consonant, vowel, and tone).

In spoken Chinese, different fundamental frequency (F0) contours indicate different tones for otherwise identical phonemes. Chinese Mandarin dialect has four major tones (four different F0 contours). The same consonant–vowel pairs with different tones specify completely different lexical items. In the case of /ma/, the first tone means *mother,* the second *linen,* the third *horse,* and the fourth *swear.* Characters that share the same consonants and vowels but different tones are mostly semantically unrelated, although sometimes they may share the same phonetic radical. Tone in Chinese has some resemblance to intonation in English, although intonation in English rarely carries lexical information. Moreover, intonation in English has been shown to have some right-hemisphere involvement (Blumstein & Cooper, 1974) and thus could be spared in patients with left-hemisphere damage. In contrast, nonfluent aphasic Chinese speakers with left-hemisphere lesions have been documented to have deficits in tone production, along with deficits in segmental production (e.g., Hughes, Chan, & Su, 1983; Naeser & Chan, 1980; Packard, 1986).

These observations suggest that the retrieval and activation of tone might be a necessary part of phonological activation during reading. In addition, in a study of phonological encoding in short-term memory, Xu (1991) found that lists that contained Chinese characters with the same tone and vowel but different consonants were harder to recall when the vowel's tone was the same than when the tone was different, which suggests that tones are activated during phonological rehearsal in short-term memory. Taft and Chen (1992), on the other hand, suggested that tonal information may not always be retrieved when reading Chinese characters. In a homophony judgment task on Chinese characters, participants had the most trouble making "no" judgments when the two characters agreed in everything but tone. However, no study has directly investigated tonal effects on semantic retrieval in reading. Thus, in Experiment 2, we were especially interested in whether a distractor that shared the consonant and vowel with a target, but not the tone, would interfere as much as a distractor sharing consonant, vowel, and tone—an exact homophone. (In Experiment 1, all homophone distractors shared consonant, vowel, and tone with their targets.)

Another purpose of Experiment 2 was to evaluate phonological effects in the absence of orthographic similarity. In Experiment 1, there were many trials with orthographically similar distractors. The presence of these orthographic confusions may have caused participants to strategically activate phonology. Although we do not know in normal reading how often a reader encounters orthographically similar words, we decided to test the extreme case; that is, we wanted to assess whether phonological activation (and hence interference in the semantic judgment task) still occurs in the absence of any orthographic confusions.

Method

Except as specified, the method was like that of Experiment 1.

Participants. Twenty-four native Chinese speakers, recruited from the Massachusetts Institute of Technology (MIT) campus,

participated in this experiment. Thirteen were men, and 11 were women; the mean age was 30.0 years (SD = 1.4 years). Thirteen of the 24 participants spoke a dialect of Chinese other than Mandarin in addition to Mandarin. All participants were volunteers and were paid for their participation. These participants all had at least a high school level of education in mainland China and were either students at MIT or relatives of those students (mainly spouses). On average, participants had left China for 37.6 months (SE = 8.4 months) and used Mandarin 47% of the time (SE = 4.6%) when talking with other people in the United States at the time of testing (self-rated).

Materials. One hundred eighty sets of words were used in this experiment. Each set consisted of a cue word, a target word, and five distractor words. As in Experiment 1, only the target was semantically related to the cue. The five distractor types were as follows: (a) an exact homophone of the target (i.e., sharing the same vowel, consonant, and tone); (b) a word that shared the same vowel and consonant with the target but not the tone; (c) a word that shared only the consonant with the target; (d) a word that shared only the vowel with the target; and (e) a word that did not share the consonant, vowel, or tone with the target. None of the distractors were orthographically similar to the target. Examples of the materials used in this experiment are shown in Table 4, and all the materials are shown in the Appendix.

There were six different experimental lists, over which the 180 sets of items were counterbalanced across the six experimental conditions. Thus, each list contained 30 trials in each condition. In addition, 120 filler trials were included, all with related targets, so that of the 300 trials in the experiment, half the trials required a "yes" response and the other half a "no" response.

The selection of targets, distractors, and cue words was less constrained here than it was in Experiment 1 (we did not have to match for orthographic similarity between targets and distractors). Thus, we were able to select cue and target word pairs with stronger semantic relationships, which should have facilitated semantic judgments. As in Experiment 1, 8 native Chinese speakers rated the semantic closeness between the cue words and targets on a scale ranging from 1 to 5. The average rating was 4.72 (SE = 0.04) for Experiment 2 as compared with 4.24 (SE = 0.05) for the materials used in Experiment 1.

When we increased the cue word and target word relatedness, the average word frequency of the targets increased because high-frequency words were more familiar and their meanings were clearer to the participants. To keep the frequency distribution balanced across targets and distractors in Experiment 2, we also increased the average frequency of all distractor conditions. Hence, the average word frequency of Experiment 2 was slightly higher than that of Experiment 1. On average, for each condition in Experiment 2, about 16% of the characters were in the frequency range of 0 to 10, with the means for targets; same consonant, vowel, and tone distractors; same consonant and vowel but different tone

distractors; same consonant but different vowel and tone distractors; same vowel but different consonant and tone distractors; and unrelated controls being 4.4, 4.5, 3.9, 4.3, 5.4, and 4.7, respectively; 49% of the characters were in the frequency range of 11 to 100, with the means for the conditions being 42.0, 40.0, 44.3, 40.5, 43.3, and 43.7, respectively; and 35% of the characters were in the frequency range of above 100, with the means for the conditions being 407.9, 677.4, 409.6, 395.7, 392.7, and 353.6, respectively.

Procedure. Participants were seated in front of a Macintosh Quadra 630 in a quiet room. Chinese characters (in font style Song and 36 pixels high) generated by the Apple Chinese Language Kit were displayed as pictures by MacProbe 2.0. Participants responded by pressing keys on the computer keyboard. They were instructed to rest their left and right index fingers on the F and K keys, respectively, and press the F key for a "no" response and the K key for a "yes" response. The keys were labeled in Chinese. In scoring, keys around the F key were also defined as the "no" key (E, R, T, D, G, C, and V); in the same way, keys around the K key were defined as the "yes" key (U, I, O, J, L, M, and comma). Participants pressed the space bar with their thumbs to initiate a trial. The rest of the procedure was the same as in Experiment 1, except that the presentation durations for the fixation cross and for the first and the second words were each 495 ms instead of 500 ms.

Scoring. There were no postexperimental tests of correct pronunciation in this experiment because of the higher frequency of the words. Of the total data points, 1.69% were deleted for the following reasons: 0.21% because the RT was greater than 3,000 ms, 0.83% because participants responded by pressing neither the "yes" nor the "no" key, and 0.65% because there turned out to be semantic ambiguities between certain cue word–target and cue word–distractor pairs. As in Experiment 1, the counterbalancing group was used as a between-subjects variable in the analyses.

Associate norms. The same group of 18 Chinese volunteers who participated in the semantic norms for Experiment 1 also participated in this test. As in Experiment 1, cue words used in Experiment 2 were printed out on paper and participants had to write down the first two Chinese characters that came to mind when they saw each cue word. Participants were instructed to leave a blank if they could not think of anything in 5 s. The order of the cue words within experiments, as well as between experiments, was counterbalanced over participants through the use of the four lists.

Results

Error rates. Homophone distractors produced a significantly higher error rate than any of the nonhomophone distractors, $F_1(4, 72)$ = 4.36, and $F_2(4, 716)$ = 4.13 (see Table 5). The contrast between the homophone distractors and the average of the nonhomophone distractors was significant, $F_1(1, 18)$ = 17.92, and $F_2(1, 179)$ = 10.76, as

Table 4
An Example of Material Used in Experiment 2

Cue word	Target	Distractor				
		Sharing consonant, vowel, and tone	Sharing consonant and vowel	Sharing consonant	Sharing vowel	Unrelated
隐藏	匿	逆	霓	恼	凄	恍
/yin3 cang2/	/ni4/	/ni4/	/ni2/	/nao3/	/qi1/	/huang3/
conceal	hide	against	neon	angry	sad	sudden

Note. The pronunciation of the character is labeled according to the Chinese phonetic labeling system pinyin. The number at the end denotes the tone (first, second, third, or fourth).

Table 5
Means of Percentage of Errors and Correct Reaction Times (in Milliseconds) in Experiment 2 for Target Words and Distractors That Shared All, Some, or No Phonological Characteristics of the Target

| | Target ("yes") | | Distractors ("no") | | | | | | | | | |
| | | | Sharing consonant, vowel, and tone | | Sharing consonant and vowel | | Sharing consonant | | Sharing vowel | | Unrelated | |
Variable	M	SE	M	SE	M	SE	M	SE	M	SE	M	SE
% error	4.7	0.8	11.3	1.7	6.7	1.4	6.0	1.2	7.1	1.4	7.3	1.4
Reaction time	644	24	776	33	756	30	764	32	769	30	754	26

were pairwise comparisons between the homophone condition and each of the nonhomophone distractors: versus the same consonant and vowel but different tone condition, $F_1(1, 18) = 11.77$, and $F_2(1, 179) = 8.44$; versus the same consonant condition, $F_1(1, 18) = 11.86$, and $F_2(1, 179) = 11.61$; versus the same vowel condition, $F_1(1, 18) = 11.41$, and $F_2(1, 179) = 6.05$; and versus the unrelated condition, $F_1(1, 18) = 8.22$, and $F_2(1, 179) = 6.31$. As is clear from Table 5, none of the four nonhomophone distractor conditions differed significantly from each other ($Fs < 1$).

RTs. The RT results for correct "no" responses are also given in Table 5. The overall difference among the five distractor conditions was not significant, $F_1(4, 92) = 1.39$, and $F_2(4, 716) = 1.43$. However, the 22-ms difference between the homophone condition and the unrelated distractor condition was marginally significant over subjects and items, $F_1(1, 18) = 3.72$, and $F_2(1, 179) = 3.67$, and the 20-ms difference between the homophone condition and the same consonant and vowel condition was significant over subjects and marginally significant over items, $F_1(1, 18) = 4.77$, and $F_2(1, 179) = 2.96$ (none of the other comparisons reached significance). The RT differences were in the same direction as the error differences; hence, there was no speed–accuracy trade-off. There were not enough false "yes" responses for a meaningful analysis of those RTs.

Effects of associative priming. As in Experiment 1, we collected associative norms from a separate group of 18 participants. The mean number of participants who spontaneously generated the target was 2.2 ($SD = 3.2$; range = 0–15). The 180 items were sorted into three groups: zero-associate items ($n = 64$), for which no participants had generated the target character; low-associate items ($n = 66$), for which 1 or 2 participants generated the target character; and high-associate items ($n = 50$), for which 3 or more participants had generated the target. For the targets, in item analyses of errors and RTs, participants made somewhat fewer errors and were significantly faster in accepting targets that were more associated, with error rates of 6.5%, 5.4%, and 2.0%, $F(2, 177) = 1.92$, and RTs of 680 ms, 657 ms, and 601 ms, $F(2, 177) = 4.68$, for zero-associate, low-associate, and high-associate items, respectively.

For the distractors, in the item analysis of errors, neither the effect of priming nor the interaction between priming and distractor condition was close to being significant, $F(2, 177) = 0.14$, and $F(8, 71) = 0.29$, respectively. The error differences between homophone distractors and the average

of all the other distractors were 3.6%, 5.0%, and 5.2% for the zero-associate, low-associate, and high-associate items, respectively. The pattern of results for RTs was similar. Neither the main effects of priming nor the interaction between priming and distractor condition was close to being significant, $F(2, 177) = 0.59$, and $F(8, 708) = 0.70$, and the differences between the homophone distractors and the average of all the other distractors were 18 ms, 12 ms, and 47 ms for the zero-associate, low-associate, and high-associate distractors, respectively. Thus, although there was some indication that associative relatedness affected the target response, there was no significant effect of associative priming on the homophone interference effect.

In another attempt to increase the likelihood of detecting the effect of priming in the homophone effect observed, we selected from Experiment 1 the orthographically dissimilar homophone distractors (sharing the same consonant, vowel, and tone with the targets) and their unrelated controls and combined them with the homophone distractors and their unrelated controls from Experiment 2 for joint analyses of the priming effect. With a total of 301 items, both the effect of priming and its interaction with homophony were not significant in the error analysis ($Fs < 1$). The same results held true in the RT analysis, $F(1, 299) = 1.92$, for the effect of priming and $F < 1$ for the interaction between priming and homophony. We also calculated the magnitude of the homophone effect in each case (the differences between the homophone distractors and their controls) to see whether it was modulated by associative priming. In error rates and RTs, the 95% confidence interval for zero-associate items was 3.3% ± 3.9% and 54 ms ± 52 ms, respectively; for the associate items, they were 4.6% ± 3.4% and 60 ms ± 45 ms, respectively. None of the differences reached significance ($Fs < 1$). Therefore, with increased power by combining results from Experiments 1 and 2, we still failed to find any significant effect of associative priming.

Word-frequency effects. As in Experiment 1, targets and distractors were sorted into three frequency categories: low, for which word-frequency count was lower than 10 per million; medium, for which the count was between 10 and 100 per million; and high, for which the count was above 100 per million. For the targets, in the item analyses of errors and RTs, participants made significantly fewer errors and were significantly faster in accepting higher frequency targets, with error rates of 10.5%, 3.3%, and 4.1%, $F(2, 177) = 4.49$, and RTs of 718 ms, 633 ms, and 634 ms,

$F(2, 177) = 5.10$, for target words of low, medium, and high frequency, respectively.

However, neither target word frequency nor its interaction with the distractor manipulation significantly affected the rejection rate for the distractors, $F(2, 177) = 0.59$, and $F(8, 708) = 0.47$. The differences in error rate between the homophone distractors and the average of all the other distractors according to the corresponding target frequency were 3.4% (low), -5.1% (medium), and 4.4% (high). The frequency of the distractor items had no clear effect, either, $F(2, 177) = 0.86$. Although the interaction of the distractor frequency and phonological manipulation was significant, $F(8, 708) = 2.94$, the pattern was not easily interpretable. The differences in error rate between the homophone distractors and the average of all the other distractors were 8.2%, 1.0%, and 8.3%, for the low-, medium-, and high-frequency distractors, respectively.

A similar pattern was observed in RTs for the distractors. Neither the effect of the corresponding target word frequency nor its interaction with the phonological manipulation was significant, $F(2, 177) = 0.28$, and $F(8, 708) = 1.39$. The differences in RT between the homophone distractors and the average of all the other distractors according to the corresponding target frequency were 8 ms (low), 22 ms (medium), and 37 ms (high). As for the error rates, the effect of the distractor frequency itself was not significant, $F(2, 177) = 0.20$, and the interaction of the distractor frequency and phonological manipulation was significant, $F(8, 708) = 2.77$, but fairly uninterpretable. The differences between the homophone distractors and the average of all the other distractors were 19 ms, -1 ms, and 68 ms for the low-, medium-, and high-frequency distractors, respectively.

In sum, there were no consistent frequency effects modulating the homophone interference effect. As with Experiment 1, the homophone interference effect was definitely not greatest for homophones of low-frequency targets, nor was it restricted to low-frequency homophone distractors. The uninterpretable pattern observed in the significant interaction of distractor frequency and homophony suggests a complicated interaction between target and distractor frequencies, which were not factorially varied in the present experiment.

Discussion

Even though there were no orthographic confusions between the targets and distractors in Experiment 2, we observed phonological activation. This suggests that the activation of meaning by phonology is an automatic process during reading Chinese and not a result of special strategies induced by the stimulus set of Experiment 1. In fact, the size of the difference in error rates between orthographically different homophones and their controls was almost identical to that found in Experiment 1. Moreover, as in Experiment 1, the homophone interference effect observed in Experiment 2 was not modulated systematically by either the target or the distractor frequency, nor was it the result of target priming by the cue word.

In addition to replicating Experiment 1, Experiment 2

indicated that the tone of a distractor, as well as its vowel and consonant, had to be identical to that of the target to produce any interference. Characters that shared the vowel and consonant with the target, but not the tone, produced no more interference than unrelated distractors. This indicates that tonal information, together with consonant and vowel information, is an essential part of the phonological representation activated in reading Chinese characters. This makes sense because if phonology is activated in order to assist retrieval of a specific lexical item, it would greatly reduce precision if phonologically similar as well as phonologically identical words were also activated. On the other hand, if tonal information, together with consonant and vowel information, is activated, a lexical item could be narrowed down to a relatively few candidates, which could then be further narrowed down by orthography and context.

Taft and Chen (1992) obtained data, however, that can be interpreted as implying that the retrieval of tonal information is not obligatory when reading Chinese. In their studies, native Mandarin and Cantonese speakers were asked to judge whether two characters shared the same pronunciation (consonant, vowel, and tone). They found that participants had the most difficulties (increased error rates and RTs) in saying "no" when the characters shared the same consonant and vowel but had different tones, regardless of whether the task was performed silently or aloud. However, the homophone judgment and homophone generation tasks used by Taft and Chen might not have tapped into the normal process involved in retrieving tonal information. For example, if not too many such foils were used, it could have induced strategies to start to respond before full tonal information was available. In any case, the phonological codes used in their task are not necessarily those involved in semantic retrieval during reading.

The activation of tonal information was also addressed (albeit indirectly) in previous experiments using a backward-masking paradigm. A study by Tan et al. (1995) found that homophonic masks facilitated Chinese character identification at durations slightly above threshold. However, a similar study by Perfetti and Zhang (1991) failed to observe this effect at threshold durations. Tan et al. (1995) tentatively attributed this disagreement to differences in the homophonic masks used in these two experiments. Tan et al. (1995) used phonologically identical target-mask pairings (including identical tones), whereas the tones of about one third of the so-called homophonic masks used by Perfetti and Zhang were different from those of their targets. However, the difference in results may have been due instead to the difference in target durations (see Tan et al., 1996). Thus, whether benefits from the use of homophonic masks are restricted to same-tone homophones remains an open question.

The same-tone homophone effect, however, has been confirmed in a separate study using a different paradigm. Xu, Caramazza, and Potter (1999) found that in a Stroop-like picture–Chinese word interference paradigm, a distractor homophonic with the picture name produced significantly more facilitation in naming the picture than a distractor homophonic (except in tone) with the picture

name. However, the latter also significantly facilitated picture naming compared with a completely unrelated control distractor. (None of these distractors were orthographically similar to the target name.) In this task, because the characters were to be ignored (and most were not homophonic to the name of the picture), the fact that their phonological representation was still activated shows that activation of the tone, as well as other phonemes, is quite automatic during reading.

The RTs in Experiment 2 were much faster than they were in Experiment 1. This could have been due to the higher average word frequency and stronger semantic relationships used, the absence of orthographically confusing distractors in Experiment 2, or the use of a different participant population and apparatus. In any case, a similar homophonic interference effect was found in the two experiments for orthographically dissimilar homophones.

General Discussion

In two experiments using a semantic judgment task, we found an interference effect for homophones of target Chinese characters. Significant homophone interference effects were obtained both when the distractors were orthographically similar to the target words (Experiment 1) and when they were orthographically dissimilar to the target words (Experiments 1 and 2). In addition, in Experiment 2, interference was only observed for exact homophones (i.e., those that shared tone as well as consonants and vowels), indicating that the phonological code subserving silent reading in Chinese contains tonal information and thus is likely to be quite close to the spoken language. Moreover, the activation of phonology is unlikely to be a strategic response to the presence of orthographic confusions, as it was observed in Experiment 2, when no orthographically confusing characters were included as distractors.

Jared and Seidenberg (1991) argued that the use of a semantic judgment paradigm causes targets (and hence their phonology) to be primed by cue words, amplifying any homophone effect observed. For priming to occur, however, during the 500-ms presentation of the cue words before the onset of the distractors, participants had not only to finish processing the cue word but also to fully activate the orthography and phonology of several likely targets. We collected norms for associations for all the cue words used in each experiment (allowing participants to take several seconds to write down whichever two words first came to mind after they saw each cue word). With a sample of 18 participants, we expected that any rapidly primed associates would be written down by at least 2 or 3 participants. Taking these norms as an operational definition of priming, we found that primed targets did not produce significantly larger homophone effects than unprimed targets in either experiment.

As indicated in the introduction, the data from the prior studies using the closely related Van Orden paradigm were mixed, and none of those studies found reliable orthographic similarity and homophone effects at the same time. The present experiments established a clear-cut homophone

effect in errors and a reasonably robust homophone effect in RTs, for both orthographically similar and dissimilar distractors, as well as an orthographic similarity effect for both homophone and nonhomophone distractors. In addition, as indicated above, the results of Experiment 2 demonstrate that phonological effects occur even in the absence of orthographic confusions (see also Perfetti & Zhang, 1995). Although the word frequencies in the present experiments were somewhat lower than those in the previous studies, we think it is unlikely that this difference alone could account for the differences in our findings and those of the previous studies in Chinese because post hoc tests of frequency showed no interaction with either interference effect. Moreover, in Experiment 2, the overall word frequency was similar to the frequency distribution for compound characters in the Leck et al. (1995) study, and we still found consistent and significant effects. The difference between the present results and those of prior studies is probably due to use of the semantic relatedness task, which allows larger stimulus sets to be constructed and hence increases power.

The homophone interference effects of the present experiments are similar to those in English using a similar paradigm (e.g., Van Orden, 1987; Van Orden et al., 1988). First, when homophones were orthographically similar to the true associates, the error rate was substantially higher than for the matched control words. Although the size of the effect in the present study (13.7%) is smaller than that reported in the original Van Orden study (24%), it is in the range of the 10% to 15% difference that has typically been found in follow-up studies in English, although different criteria were used for calculating orthographic similarity and there are differences between Chinese and English. The size of our effect for orthographically dissimilar homophones (5.1% in Experiment 1 and about 5% in Experiment 2) is roughly comparable with that observed by Van Orden, but other studies (V. Coltheart et al., 1994; Jared & Seidenberg, 1991) found no significant effect for orthographically less similar homophone distractors in English. We think it is implausible that this phonological interference effect is larger in Chinese than in English and suspect that the lack of reliability of the interference effect for orthographically less similar homophones in English is due to a power problem.

Phonology-First Verification Model

In general, the homophone interference effect is consistent with a verification model, in which the first encoding process to access meaning is the phonological code (Van Orden, 1987). In this model, the phonological code activates the semantic representation of all homophones, but further processing of the orthographic form ("verification") causes inhibition of the "wrong" homophones. To accommodate the finding that orthographic similarity between homophones modulates the size of the interference effect, the verification model makes the plausible assumption that the orthographic verification process occurs more quickly the more dissimilar the "right" and "wrong" homophones are. In this task, the assumption seems to be that one responds "yes" if a mismatch in spelling between the target word and

the word actually presented is not found prior to some deadline to respond. In Van Orden's data on English, participants were about as quick in falsely responding "yes" to orthographically similar homophones of true associates as in responding "yes" to true associates. Such a finding is strong evidence for the phonology-first model because the meanings of both the target and distractor would be only activated by the sound of the letter string (whether the target or the distractor) and because the time taken to make a "yes" response should be largely independent of whether it is correct; all that matters is that the response beats the verification process.

Our data, however, are different from Van Orden's. In Experiment 1, the false "yes" responses to orthographically similar homophones were substantially slower than the true "yes" responses and the false "yes" responses to orthographically dissimilar homophones were even slower than those to the orthographically similar homophones. This pattern of data, however, could be accommodated by an orthographic verification stage, which operates more slowly to indicate a (false) match the more different the stimulus is from the orthography of the true associate stored in memory. Perhaps the difference in the pattern obtained for English and Chinese is that the orthographically similar homophones in English are more similar (differing by a single letter) than in Chinese (for which they differ in one of the two radicals that compose the character).

One way to explain the pattern of RTs for the true "no" responses discussed in the preceding paragraph and the pattern of RTs for the false and true "yes" responses displayed in Table 3 is to assume that the verification process is a "random walk" between two thresholds: one for making a "match" decision and one for making a "mismatch" decision (i.e., match or mismatch on orthographic properties). If one assumes that true associates start out nearest to the orthographic match threshold and orthographically dissimilar homophones start out farthest from this match threshold (with orthographically similar homophones intermediate), then one can easily accommodate the pattern of data observed. The random-walk process to reach the match threshold should be fastest for true associates, slowest for orthographically dissimilar homophones, and intermediate for orthographically similar homophones. Analogously, to explain the correct "no" RTs, the random-walk process to reach the mismatch threshold should be faster for the orthographically dissimilar homophones than for the orthographically similar homophones.

One result that seems problematic for the phonology-first verification model is that the orthographically similar nonhomophone distractors generated substantially more errors (12.3%) than the unrelated controls (4.4%) and even more errors than the orthographically dissimilar homophone distractors (9.5%). A phonology-first model might try to explain an orthographic similarity effect from nonhomophone distractors by positing that each lexical item activates not only its phonological code but also the phonological codes of all other orthographically similar lexical entries. Thus, given an orthographic input, many phonological codes would be activated and the effects of the phonological code associated with the word semantically related to the cue word should be diluted by all the other phonological codes not semantically related to the cue word. As a result, it would seem that such a model would predict substantially weaker effects of orthographic similarity than those we observed. (The verification process, given such an assumption, would also be complex enough so that the model would lose most of its heuristic value.) Another explanation of the orthographic similarity effect for nonhomophone distractors is that given the context provided by the cue word, participants simply misread the distractor as the target in some occasions (see Potter, Moryadas, Abrams, & Noel, 1993), resulting in false "yes" responses. However, this theory does not explain why false "yes" responses were slower than true "yes" responses.

Another problem for the verification model is that we did not find the homophone effect to be modulated by the frequency of the target word (Van Orden, 1987). Although we did not factorially manipulate target and distractor frequencies in our design (thus, the frequency analysis was post hoc), if only target frequency determines the size of the homophone effect as predicted by the verification model, we should still be able to observe such an effect in our post hoc test.

Parallel Access Model

In this model, both the orthography and phonology of a character activate meanings in parallel. In the case of an orthographically similar distractor, the orthography has some probability of activating the target's orthography and hence its meaning (especially in conjunction with the cue); a homophone distractor activates its phonology and in turn activates all the meanings associated with that phonology, including that of the target. For orthographically similar homophone distractors, this potentially dual activation of the target meaning makes them harder to reject than any other type of distractor. However, in a parallel access model, there would be significant activation of the target word meaning through similar orthography or through identical phonology alone. This explains why one can obtain significant interference from homophony or orthographic similarity without support from the other. It can also explain why "false" yes responses are slower than true "yes" responses if we assume a "horse-race" type of model. That is, for homophone and/or orthographically similar distractors, there is a race to activate the true meaning of the distractor and the meanings associated with the similar-looking or identical-sounding target. Because the activation of the true meaning is (on average) stronger, it usually wins the race and a correct "no" response is made. Moreover, on those trials in which the usually slower horse wins (i.e., the meaning of the target, resulting in a false "yes" response), the response should be, on average, slower than the trials in which the usually faster horse wins the race (i.e., the true "yes" responses to the target words). We think the finding by Van Orden et al. (1988)—that false "yes" responses were as fast as true "yes" responses—is probably due to the fact that phonology

in an alphabetic writing system such as English can be activated relatively rapidly using a nonlexical route.

On the other hand, it is not clear that the parallel access model handles the frequency effect any more gracefully than the phonology-first model. Because the parallel access model is an intrinsically more "powerful" and less constrained model, it does not make any particular prediction of the frequency effect, unless more specific assumptions on the relative strength of the two routes to meaning (one via orthography and the other via phonology) are made. In the present experiments, the target and distractor frequencies were not systematically manipulated. It will take another experiment that does so to better understand how target and distractor frequencies affect the homophone and the orthographic similarity effect and to better constrain the parallel access model.

Other Models

Another logical possibility in Chinese is that orthography directly looks up semantics before phonology. In fact, Taft and van Graan (1998) have recently proposed such a model for printed word identification in all languages. They argue that in silent reading only orthography has access to semantics and that the observed homophone effects in semantic tasks could be explain by orthography–phonology–orthography (OPO) rebound. That is, the orthography of the homophone distractor would first activate its phonology, which, in turn, proceeds through a feedback loop to active the orthography of the target. From the activation of the target orthography, the target semantics would then be retrieved to create interference in the semantic task, resulting in the homophone effect observed. Although the OPO rebound can explain the present results without postulating any link between phonology and semantics when reading, there must exist connections between phonology and semantics for speech comprehension (e.g. Frost, 1998), and it is not clear why this phonology-to-semantics route would not be used in silent reading. In an attempt to resolve this, Taft and van Graan proposed two forms of phonological representation, a surface phonology that connects to speech and the semantic system and a separate phonology that connects to orthography and surface phonology but not to semantics. Although this model seems like a disguised version of the parallel access model, it needs more processors and processing stages than does the parallel access model, and its main virtue is that it appears to deny phonology any direct access to semantics. Further research will be needed to discover whether this more complex model is necessary to account for the present results.

The present results could also be explained by the "triangle" interactive network now popular in parallel distributive models, in which there are three nodes—one representing orthography, another representing phonology, and the third representing semantics—that continuously interact with each other. In this model, the orthographic stimulus activates orthography, phonology, and semantics continuously. These activations then feed excitation to each other to converge on solutions for the orthographic, phono-

logical, and semantic representations of the stimuli. In such a model, the excitation from phonology to the semantics of all homophones would cause some activation of target semantic features for a homophone distractor. Similarly, the connections from orthography to semantics would mean that a character that was orthographically similar to a target character would activate the target character's semantic representation to some extent, giving the orthographic similarity effect. Thus, the model is quite similar to the parallel access model above, but it posits fairly massive "feedback" between semantics and the other two representations. Whether these complications are necessary to explain our data, however, is an open question.

This leaves open the question of whether Chinese is processed in a fundamentally different way than English. We think it is more parsimonious to posit that the same process applies to both languages. This is perhaps most gracefully accommodated within the parallel access framework. One would merely posit that the relative speed of the two routes ("horses") differs between the two languages because phonology in English can be more quickly activated through its alphabetic orthography and thus phonological access of meaning is likely to be faster in English (relative to orthographic access of meaning) than in Chinese.

Conclusions

The present experiments indicate that (a) phonological coding occurs automatically in semantic processing of Chinese characters and it is not restricted to low-frequency words; (b) this coding is quite precise, as no phonological interference was observed with phonologically similar characters (including those identical to targets in everything but tone); and (c) the activation of meaning during silent reading in Chinese is most readily explained by a model in which orthographic and phonological representations contact semantic representations in parallel.

References

Berent, I., & Perfetti, C. A. (1995). A rose is a reez: The two-cycles model of phonology assembly in reading English. Psychological Review, 102, 146–184.

Blumstein, S., & Cooper, W. E. (1974). Hemispheric processing of intonation contours. Cortex, 10, 146–158.

Chen, H. -C., Flores d'Arcais, G. B., & Cheung, S. -L. (1995). Orthographic and phonological activation in recognizing Chinese characters. Psychological Research, 58, 144–153.

Coltheart, M., Davelaar, E., Jonasson, J. T., & Besner, D. (1977). Access to the internal lexicon. In S. Dornic (Ed.), Attention and performance (Vol. 6, pp. 535–555). Hillsdale, NJ: Erlbaum.

Coltheart, V., Patterson, K., & Leahy, J. (1994). When a ROWS is a ROSE: Phonological effects in written word comprehension. Quarterly Journal of Experimental Psychology: Human Experimental Psychology, 47A, 917–955.

Daneman, M., & Reingold, E. (1993). What eye fixations tell us about phonological recoding during reading. Canadian Journal of Experimental Psychology, 47, 153–178.

Daneman, M., Reingold, E. M., & Davidson, M. (1995). Time course of phonological activation during reading: Evidence from

eye fixations. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 21,* 884–898.

Fang, S. P., Horng, R. Y., & Tzeng, O. J. L. (1986). Consistency effects in the Chinese character and pseudo-character naming tasks. In H. S. R. Kao & R. Hoosain (Eds.), *Linguistics, psychology, and the Chinese language* (pp. 1–21). Hong Kong, China: University of Hong Kong.

Fischler, I. (1977). Semantic facilitation without association in a lexical decision task. *Memory & Cognition, 5,* 335–339.

Frost, R. (1998). Toward a strong phonological and orthography in visual word recognition: True issues and false trails. *Psychological Bulletin, 123,* 71–99.

Gandour, J. T. (1978). The perception of tone. In V. A. Fromkin (Ed.), *Tone: A linguistic survey* (pp. 41–60). New York: Academic Press.

Hue, C. W. (1992). Recognition processes in character naming. In H. C. Chen & O. J. L. Tzeng (Eds.), *Language processing in Chinese* (pp. 93–107). Amsterdam: North-Holland.

Hughes, C. P., Chan, J. L., & Su, M. S. (1983). Aprosodia in Chinese patients with right cerebral hemisphere lesions. *Archives of Neurology, 40,* 732–736.

Jared, D., & Seidenberg, M. S. (1991). Does word identification proceed from spelling to sound to meaning? *Journal of Experimental Psychology: General, 120,* 358–394.

Leck, K. J., Weekes, B. S., & Chen, M. J. (1995). Orthographic and phonological pathways to the lexicon: Evidence from Chinese readers. *Memory & Cognition, 23,* 468–476.

Lesch, M. F., & Pollatsek, A. (1998). Evidence for the use of assembled phonology in accessing the meaning of printed words. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 24,* 573–592.

McRae, K., & Boisvert, S. (1998). Automatic semantic similarity priming. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 24,* 558–572.

Naeser, M., & Chan, S. (1980). Case study of a Chinese aphasic with the Boston Diagnostic Aphasia Exam. *Neuropsychologia, 18,* 389–399.

Neely, J. H. (1991). Semantic priming effects in orthographic word recognition: A selective review of current findings and theories. In D. Besner & G. Humphreys (Eds.), *Basic processes in reading: Orthographic word recognition* (pp. 264–336). Hillsdale, NJ: Erlbaum.

Packard, J. L. (1986). Tone production deficits in nonfluent aphasic Chinese speech. *Brain and Language, 29,* 212–223.

Perfetti, C. A., & Zhang, S. (1991). Phonological processes in reading Chinese characters. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 17,* 633–643.

Perfetti, C. A., & Zhang, S. (1995). Very early phonological activation in Chinese reading. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 21,* 24–33.

Pollatsek, A., Lesch, M. F., Morris, R. M., & Rayner, K. (1992). Phonological codes are used in integrating information across saccades in word identification and reading. *Journal of Experimental Psychology: Human Perception and Performance, 18,* 148–162.

Pollatsek, A., Tan, L. -H., & Rayner, K. (in press). The role of phonological codes in integrating information across saccadic eye movements in Chinese character identification. *Journal of Experimental Psychology: Human Perception and Performance.*

Pollatsek, A., & Well, A. D. (1995). On the use of counterbalanced designs in cognitive research: A suggestion for a better and more powerful analysis. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 21,* 785–794.

Potter, M. C., Moryadas, A., Abrams, I., & Noel, A. (1993). Word selection in reading sentences: Preceding versus following contexts. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 19,* 3–22.

Rayner, K., Pollatsek, A., & Binder, K. S. (1998). Phonological codes and eye movements in reading. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 24,* 476–497.

Rayner, K., Sereno, S. C., Lesch, M. F., & Pollatsek, A. (1995). Phonological codes are automatically activated during reading: Evidence from an eye movement priming paradigm. *Psychological Science, 6,* 26–30.

Sakuma, N., Sasanuma, S., Tatsumi, I. F., & Masaki, S. (1998). Orthography and phonology in reading Japanese kanji words: Evidence from the semantic decision task with homophones. *Memory & Cognition, 26,* 75–87.

Seidenberg, M. S. (1985). The time course of phonological code activation in two writing systems. *Cognition, 19,* 1–30.

Taft, M., & Chen, H. C. (1992). Judging homophony in Chinese: The influence of tones. In H. C. Chen & O. J. L. Tzeng (Eds.), *Language processing in Chinese* (pp. 151–172). Amsterdam: North-Holland.

Taft, M., & van Graan, F. (1998). Lack of phonological mediation in a semantic categorization task. *Journal of Memory and Language, 38,* 203–224.

Tan, L. H., Hoosain, R., & Peng, D. -L. (1995). Role of early presemantic phonological code in Chinese character identification. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 21,* 43–54.

Tan, L. H., Hoosain, R., & Siok, W. W. T. (1996). Activation of phonological codes before access to character meaning in written Chinese. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 22,* 865–882.

Van Orden, G. C. (1987). A *ROWS* is a *ROSE:* Spelling, sound, and reading. *Memory & Cognition, 15,* 181–198.

Van Orden, G. C. (1991). Phonologic mediation is fundamental to reading. In D. Besner & G. W. Humphreys (Eds.), *Basic processes in reading* (pp. 77–103). Hillsdale, NJ: Erlbaum.

Van Orden, G. C., Johnston, J. C., & Hale, B. L. (1988). Word identification in reading proceeds from spelling to sound to meaning. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 14,* 371–386.

Van Orden, G. C., Pennington, B. F., & Stone, G. O. (1990). Word identification in reading and the promise of subsymbolic psycholinguistics. *Psychological Review, 97,* 488–522.

Wang, W. S. -Y. (1973). The Chinese language. *Scientific American, 228,* 50–60.

Wydell, T. N., Patterson, K. E., & Humphreys, G. W. (1993). Phonologically mediated access to meaning for kanji: Is a *rows* still a *rose* in Japanese kanji? *Journal of Experimental Psychology: Learning, Memory, and Cognition, 19,* 491–514.

Xiandai hanyu pinlu cidian [Modern Chinese frequency dictionary]. (1986). Beijing, China: Beijing Language Institute Press.

Xu, Y. (1991). Depth of phonological recoding in short-term memory. *Memory & Cognition, 19,* 263–273.

Xu, Y., Caramazza, A., & Potter, M. C. (1999). *Lexical access in Chinese picture naming.* Manuscript in preparation.

Yin, B. (1984). A quantitative research of Chinese morphemes. *Zhongguo Yuwen, 5,* 338–347.

Zhou, X., & Marslen-Wilson, W. (1994). Words, morphemes and syllables in the Chinese mental lexicon. *Language and Cognitive Processes, 9,* 393–422.

Appendix

Table A1
Materials Used in Experiment 1

Cue	T1	T2	T3	T4	T5	Cue	T1	T2	T3	T4	T5	Cue	T1	T2	T3	T4	T5
写下	记	纪	妃	鲫	鳃	野面	兽	豚	狈	钡	坝	夸发	耀	愁	耘	地	承
午餐	饭	贩	阪	泛	逗	比条	食	狱	饨	钝	豚	耕支	稼	论	耜	争	知
伟顶	极	功	巧	蚣	螺	方理	燕	谕	喻	偷	狱	货自	了	对	币	满	不
年化	龄	汲	怜	泄	温	恶艳	闻	净	狰	偷	闻	阻肥	塞	肉	罐	茫	暗
催地	酶	铃	侮	蛉	奴	画兽	捂	蚊	纹	妩	拘	水光	炭	布	昏	觉	台
草舞	坪	梅	抨	萧	领	测品	居	抚	护	绘	枯	卖视	大	怪	明	星	带
飞体	期	评	斯	舆	否	口性	辜	沪	绘	驹	蟆	烛大	焦	明	栖	省	声
肉展	蜻	斯	猜	咤	律	飘假	磨	烩	驹	估	馍	焦粗	粗	星	章	亮	散
舒售	躯	讴	坤	童	郎	夹圆	墨	拘	估	馍	株	鬼点	鬼	带	弱	丽	豫
出兴	伸	坤	艄	游	盆	依真	徉	枯	馍	株	侍	流携	点	栖	密	谢	掉
高骗	销	艄	偷	务	叹	多尾	阳	蟆	株	侍	缔	两节	悄	省	谢	掉	酒
洪撑	愉	偷	杼	茎	抓	献共	涅	扬	侍	缔	缤	悄明	胸	声	掉	酒	生
支电	诈	杼	柱	缴	胆	旋不	潴	佯	缔	缤	蚪	稀瘦	明	章	酒	生	废
导肪	柱	桐	铜	飞	填	炒暴	柿	蹀	缤	蚪	牺	瘦美	稀	亮	生	废	猛
脂见	铜	铀	油	订	宇	鲜宽	递	株	蚪	牺	陀	美犹	美	散	废	猛	
会唬	油	悟	晒	统	湾	斟量	濑	待	牺	陀	淒	犹浓	犹	弱	猛		
吓计	晒	悟	惊	宛	栏	猛多	陡	蹄	陀	淒	锅	浓花	浓	丽			
诡色	惊	狡	绯	匣	斩	卑断	锡	滨	淒	锅	祖	花去	花	豫			
红臀	狡	绞	腚	杏	绿	悬房	邪	抖	锅	祖	栩	去白	去	谢			
臀刺	绯	绞	捅	淹	雷	干厅	驮	硒	祖	栩	酌	白卫	白	掉			
黄昏	腚	绰	侠	移	饼	只有	独	诸	栩	酌	裸	卫生	卫	酒			
闯荡	捅	晚	烟	崎	澎		郭	驼	酌	裸	砍	废猛	荒	生			
名字	侠	姓	怡	很	泰		毵	犊	裸	砍	博	凶	凶	废			
弥漫	烟	胭	椅	哦	佩		许	绫	砍	博	贱						
快乐	怡	饴	垠	瓷	茅		辆	担	博	贱	决						
边凳	椅	倚	蛾	披	涂		蝌	徇	贱	决	峻						
凤子	垠	银	资	孤	嘉		侃	翎	决	峻	梁						
财界	蛾	峨	玻	纯	佐		勃	狳	峻	梁	噪						
窗物	资	婆	狐	帕	诅		荞	钓	梁	噪	燥						
皮毛	玻	弧	沌	拍	傀		绝	裸	噪	燥	堂						
混乱	狐	炖	舶	枕	胚		郡	炊	燥	堂	惟						
航行	沌	铂	珀	轻	奔		粮	栈	堂	惟							
褐色	舶	粕	耽	褐	苑		皂	快	惟								
拖延	珀	眈	径	靖	杏		糖	嗅									
小路	耽	胚	竭	捷	淹		党	涩									
尽力	径	碣	雉	窒	移		锥	操									
野鸡	竭	稚			虐													

Note. The two trials that were completely deleted are not included in the table. An asterisk indicates a particular condition that was deleted from a particular trial in the analyses. T1 = target; T2 = orthographically similar homophone distractor; T3 = orthographically similar nonhomophone distractor; T4 = orthographically dissimilar homophone distractor; T5 = orthographically dissimilar nonhomophone distractor.

Table A2
Materials Used in Experiment 2

Cue	T1	T2	T3	T4	T5	T6	Cue	T1	T2	T3	T4	T5	T6	Cue	T1	T2	T3	T4	T5	T6

Note. T1 = target; T2 = same consonant, vowel, and tone distractor; T3 = same consonant and vowel but different tone distractor; T4 = same consonant but different vowel and tone distractor; T5 = same vowel but different consonant and tone distractor; T6 = different consonant, vowel, and tone distractor.

Call for Nominations

The Publications and Communications Board has opened nominations for the editorships of *Behavioral Neuroscience, JEP: Applied, JEP: General, Psychological Methods,* and *Neuropsychology* for the years 2002–2007. Michela Gallagher, PhD; Raymond S. Nickerson, PhD; Nora S. Newcombe, PhD; Mark I. Appelbaum, PhD; and Laird S. Cermak, PhD, respectively, are the incumbent editors.

Candidates should be members of APA and should be available to start receiving manuscripts in early 2001 to prepare for issues published in 2002. Please note that the P&C Board encourages participation by members of underrepresented groups in the publication process and would particularly welcome such nominees. Self-nominations are also encouraged.

To nominate candidates, prepare a statement of one page or less in support of each candidate. The search chairs are as follows:

- Joe L. Martinez, Jr., PhD, for *Behavioral Neuroscience*
- Lauren B. Resnick, PhD, and Margaret B. Spencer, PhD, for *JEP: Applied*
- Sara B. Kiesler, PhD, for *JEP: General*
- Lyle E. Bourne, Jr., PhD, for *Psychological Methods*
- Michael F. Enright, PhD, and [cochair] for *Neuropsychology*

Address all nominations to the appropriate search committee at the following address:

> [Name of journal] Search Committee
> c/o Karen Sellman, P&C Board Search Liaison
> Room 2004
> American Psychological Association
> 750 First Street, NE
> Washington, DC 20002-4242

The first review of nominations will begin December 6, 1999.