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The Relative Time Course of Semantic and Phonological Activation in Reading Chinese

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The relative time course of semantic and phonological activation was investigated in the context of whether phonology mediates access to lexical representations in reading Chinese. Compound words (Experiment 1) and single-character words (Experiments 2 and 3) were preceded by semantic and phonological primes. Strong semantic priming effects were found at both short (57 ms) and long (200 ms) stimulus onset asynchrony (SOA), but phonological effects were either absent in lexical decision (Experiment 1), were present only at the longer SOA in character decision (Experiment 2) or were equally strong as semantic effects in naming (Experiment 3). Experiment 4 revealed facilitatory or inhibitory effects, depending on SOA, in phonological judgments to character pairs that were not phonologically but semantically related. It was concluded that, in reading Chinese, semantic information in the lexicon is activated at least as early and just as strongly as phonological information.

The main question: when reading something written, how do you recognize a word? Do you use sound to "look up" a word from your "mental dictionary", or do you use meaning?

Phonology: language sounds
Semantics: language meaning

A crucial issue in the study of visual word recognition concerns the relations between phonology and meaning (e.g., Carr & Pollatsek, 1985; Frost, 1998; McCusker, Hillinger, & Bias, 1981; Seidenberg & McClelland, 1989; Taft & van Graan, 1998): To what extent does phonology play a role in access to lexical semantics? There have been a number of ways to approach this issue. One approach that has been extensively used in the study of Chinese lexical processing, although not so much in the study of alphabetic languages, is to directly compare the relative time course of phonological and semantic activation in reading. The rationale behind this approach is as follows: It is generally assumed that there are two pathways to lexical semantics from orthographic input, one being the direct mapping between orthography and semantics, and the other being indirect mapping via phonological mediation. It follows that if phonology plays a predominant role in constraining access to semantics, then the one-step computation from orthography to phonology must be faster and more efficient than the one-step computation from orthography to semantics. Only in this way can the two-step indirect access to semantics via phonology have an overall advantage over the direct route from orthography, so that the phonologically mediated route to semantics can dominate over the direct computation from orthography to meaning.

For alphabetic scripts, it is likely that phonological activation from orthography is indeed more efficient than semantic activation from orthography. This is because there is in general a systematic mapping between orthography and phonology, whereas the relations between orthography and semantics are mostly arbitrary. The transformation of activation between different domains is constrained by their regularity of mapping (e.g., Plaut, McClelland, Seidenberg, & Patterson, 1996). The *resonance* theory of lexical processing (e.g., Van Orden & Goldinger, 1994; Van Orden, Jansen op de Haar, & Bosman, 1997; Van Orden, Pennington, & Stone, 1990) goes further to argue that the visual–phonological correlation in English is strengthened as learning progresses and reaches coherence before visual–semantic correlation. The self-consistency between visual and phonological properties rapidly organizes the lexical processing system and dominates over the less self-consistent, less efficient visual–semantics relations. Direct visual access, if it exists at all on this view, plays a minor role in constraining semantic activation (see also Lesch & Pollatsek, 1993; Lukatela & Turvey, 1991, 1994).

"Systematic mapping between orthography and phonology" means that, in alphabetic writing (like English), things are pronounced similar to how they're spelled.

Compared with alphabetic languages, the relations between orthography and phonology in logographic Chinese are much more arbitrary, with essentially no systematic sublexical (subcharacter) correspondence (D. Li, 1993; Yin & Rohsenow, 1994; Zhou, Shu, Bi, & Shi, 1999). This makes the answer to the question of the relative time course of semantic and phonological activation in reading Chinese much less predictable and more interesting. Is phonological activation, on the basis of computation from orthography to phonology, faster and more efficient than semantic activation in Chinese as well? Is there a uniform answer to this question regardless of the linguistic and statistical properties of

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The big question: Does Chinese character reading use phonology? *AND* how fast is phonology activated (as opposed to semantics)?

Those experiments: people had to read two words, one after another. If the two words are related, then you can read the second word faster if you read it when the first word is "activated" in your mind. So they tried showing the words quickly or slowly, to see if the phonology of the first word would get activated right away, or only a while later.

Chinese characters and Chinese words? If the activation of phonological information in reading Chinese occurs very early and always precedes the activation of semantic information, it is reasonable to assume that phonology could play an important role in constraining access to semantics, perhaps as important as the role of phonology in reading alphabetic scripts.

In recent years, Perfetti and his colleagues (e.g., Perfetti & Tan, 1998; Perfetti & Zhang, 1991, 1995; Tan, Hoosain, & Peng, 1995; Tan, Hoosain, & Siok, 1996) have used various techniques to demonstrate mandatory phonological activation in reading Chinese and to compare the relative time course of semantic and phonological activation. These techniques include backward masking, synonym and homophone judgment, and primed naming. Typically, two sets of target words are used in these studies, one set preceded (or followed) by semantically related words and one set by phonologically related words. If the phonological or semantic representations of the first presented words are activated within a given time period, this activation should influence the processing of the second sets of words or characters. By varying stimulus onset asynchrony (SOA) between the first and the second characters, the authors were able to examine which effects, semantic or phonological, emerged first in various experimental tasks. It was concluded that, in reading Chinese, the activation of phonology begins very early and precedes semantic activation (Perfetti & Tan, 1998; Perfetti, Tan, Zhang, & Georgi, 1995; Perfetti & Zhang, 1995), presumably because the correspondence between orthography and phonology is more reliable and precise than the correspondence between orthography and meaning (Perfetti et al., 1995). It was further argued that this early phonological activation has strong effects on access to lexical semantics (Tan & Perfetti, 1997). These conclusions, if correct, may have some important implications for possible universals of lexical processing across different orthographies.

We agree with Perfetti and his colleagues that phonological information is mandatorily activated in reading Chinese (see Zhou, 2000; Zhou & Marslen-Wilson, 1997, 1999a, 2000b; Zhou, Shu, et al., 1999). This claim is not at issue here. There are, however, a number of reasons (see below) for us to question whether phonological activation is indeed generally earlier than semantic activation. The importance of this time course issue is with respect to the further claim, as we noted earlier, that phonology is not only obligatorily activated but also mediates access to lexical and semantic representations. Accordingly, in this research, we use various techniques to compare the relative time course of phonological and semantic activation in visual recognition of Chinese words and characters. Before we move on to these experiments, we first summarize major experimental evidence provided by Perfetti and his colleagues, and evidence from other researchers consistent or inconsistent with their conclusions. Then we report four sets of experiments, which consistently show that semantic activation in reading Chinese is at least as early if not earlier than phonological activation.

Previous Studies

Perfetti and his colleagues used three experimental paradigms to investigate the relative time course of semantic and phonological activation in reading Chinese. The first paradigm was backward masking, in which a briefly exposed target was followed immediately by a second character (i.e., a mask) and then by a pattern mask. Participants were asked to report the characters they saw. The target and the masking character could be semantically, phonologically, or orthographically related. Perfetti and Zhang (1991) varied the exposure times of targets (from 30 ms to 70 ms) while keeping constant the exposure time of the masking characters (30 ms). Although they found strong facilitatory effects for orthographic masks (e.g., 现 xian[4], *now*)[1] in the identification of targets (e.g., 视 shi[4], *watch*), they did not observe any significant effects for semantically related masks (e.g., 看 kan[4], *see*) or for orthographically different homophone masks (e.g., 事 shi[4], *matter*). In addition, the authors found facilitatory priming effects for semantic and homophone masks in forward masking, in which primes were presented first for 50 ms and the targets were then presented for 35 ms, but there was no difference between the facilitatory effects for the two types of masks. Subsequent studies by Tan et al. (1995), however, found a significant phonological facilitatory effect but no semantic priming effect when the exposure times for targets and masks were longer (60 ms and 40 ms, respectively). Moreover, a post hoc analysis showed that a semantic priming effect was present when target characters had "precise" meanings but not when targets had "vague" meanings. Tan et al. (1996) extended these findings by showing that phonological priming effects appeared approximately 14 ms earlier than semantic effects when the meanings of target characters were precise and 28 ms when the meanings of target characters were vague. The general conclusion from these studies is that phonological information is not only automatically activated but activated earlier than semantic information in reading Chinese.

The second approach used by Perfetti and his colleagues was based on phonological and semantic judgment tasks. In the phonological judgment task, participants were asked to judge whether successively presented pairs of characters were homophones, whereas in the semantic judgment task, participants had to decide whether the paired characters were synonyms. Three questions were addressed: First, do semantically but not phonologically related characters show interference effects in homophone judgment? Second, do phonologically but not semantically related characters show interference effects in semantic judgment? Finally, which of the interference effects, semantic or phonological, appear earlier in the time course of activation? Perfetti and Zhang (1995) varied SOAs between the first and second characters and found that phonological interference with synonym judgments appeared at the SOA of 90 ms or longer, but that semantic interference effect with homophone judgments did not appear until the SOA was 140 ms. The magnitude of the phonological interference effect was also larger than the semantic interference effect. These data appear to be consistent with the backward masking studies.

The third approach used by Perfetti and his colleagues was primed naming, in which target characters were preceded by semantic or phonological primes and participants were asked to pronounce the targets as quickly as possible. Perfetti and Zhang (1991) found that the homophone priming effect was larger than

[1] Throughout the article, we give the pronunciations of Chinese characters in pinyin—the Chinese alphabetic system. Numbers in brackets represent the lexical tones of syllables.

The rest of this introduction is very long and detailed; you don't need to worry about every detail. The most important thing is that you can understand the design and results of Experiment 1 (starting on page 1248); you don't need to worry as much about this "Previous Studies" section.

the semantic priming effect. A recent study by Perfetti and Tan (1998) suggested that although homophone priming effects could be obtained when the SOA was 57 ms, a semantic priming effect was not detected until the SOA was about 85 ms. Moreover, the homophone priming effects were much larger than the semantic effects (though, see Chen & Shu, 1997, which did not replicate this study using the same stimuli and similar experimental procedures).

The data from the three approaches used by Perfetti and his colleagues all seem to point to the same conclusion: Not only is phonology automatically activated in reading Chinese, but it is also activated earlier than semantics. Although the authors have been duly cautious about whether task demands may have influenced the patterns of priming effects (Perfetti & Tan, 1998), they nonetheless generally accept that phonological activation occurs earlier, and provide a theoretical account in terms of the relative reliability of the link between orthography and phonology and between orthography and meaning (e.g., Perfetti et al., 1995). Phonological activation is viewed as bound more reliably to printed symbols than to semantic information, and this is seen as universal across different orthographies, reflecting the fundamental role of phonology in word recognition.

One possible problem for this view is that the relative arbitrariness of the relation between orthography and phonology in Chinese (see, e.g., D. Li, 1993; Yin & Rohsenow, 1994; Shen & Forster, 1999; Zhou, Shu, et al., 1999) may not allow the same rapid computation from orthography to phonology as is seen in alphabetic systems. Orthographically similar simple characters are mostly pronounced in different ways, whereas orthographically different (simple and complex) characters may have the same pronunciations. Even for complex or compound characters containing phonetic radicals, which may have the function of indicating the pronunciation of whole characters, less than a third of them have the same pronunciation as their phonetic radicals (e.g., Fan, Gao, & Ao, 1984; Y. Li & Kang, 1993; Shu, Wu, Zheng, & Zhou, 1998). About one third of complex characters ("irregular" characters) bear no phonological relations with their phonetic radicals at all. Although the sublexical phonological processing of phonetic radicals can support the phonological activation of complex characters (Fang, Horng, & Tzeng, 1986; Hue, 1992; Peng, Yang, & Chen, 1994; Seidenberg, 1985; Zhou & Marslen-Wilson, 1999b), this function is mainly restricted to low frequency "regular" complex characters that contain homophonic phonetic radicals. For most characters, this sublexical phonological processing may even interfere with the phonological activation of the whole characters. Moreover, there is little "feedback consistency" (Stone, Vanhoy, & Van Orden, 1997; Ziegler, Montant, & Jacobs, 1997) between phonology and orthography in Chinese, as one phonological form (i.e., a syllable) usually corresponds to several characters. Such feedback and feedforward consistency are thought to be crucial in determining the primary role of phonology in organizing the lexicon and in access to semantics (Van Orden & Goldinger, 1994; Van Orden et al., 1990, 1997). Thus, even the resonance theory of lexical processing does not necessarily predict a central role for phonology in reading Chinese.

However, the relations between orthography and meaning are arguably less arbitrary in Chinese than in alphabetic languages. This is because semantic radicals in complex characters may have the function of indicating the semantic category of the whole characters, although this function has been obscured for many characters (D. Li, 1993; Yin & Rohsenow, 1994). There is evidence that this function helps the semantic activation of the whole characters (e.g., Feldman & Siok, 1999; Zhou & Marslen-Wilson, 1999b). Moreover, the fact that some characters have multiple, usually related, meanings does not necessarily imply that semantic activation of these characters is more difficult (see, e.g., Azuma & van Orden, 1997). Therefore, it can be argued that functional analyses of the Chinese writing system do not necessarily point to an earlier phonological than semantic activation in reading Chinese.

In addition, a wider look at the experimental evidence does not suggest unequivocal support for earlier phonological activation. For example, some of the phonological effects reported by Perfetti and his colleagues may be open to alternative explanations. Given that the relative time course of phonological and semantic activation is inferred from phonological and semantic priming effects, the degree of phonological or semantic overlap between primes and targets (or between the first and second characters) could influence the pattern of phonological or semantic effects and hence the conclusions concerning their relative time course (see Perfetti & Zhang, 1995; Zhou, Shu et al., 1999). The reason the phonological effect occurred earlier in semantic judgment than did the semantic effect in phonological judgment may be partly due to the fact that phonologically related characters were always homophones, sharing all phonological properties, whereas semantically related characters, even synonyms, differed on some semantic properties. Moreover, different task demands may augment or minimize the phonological or semantic effects and hence affect the conclusions about relative time course drawn from these effects.

Several other studies of phonological and semantic priming did not show the same pattern of strong and early phonological effects in reading Chinese. In more than 10 experiments using both visual–visual and masked priming lexical-decision tasks with either the short or long SOAs, Zhou, Marslen-Wilson, Taft, and Shu (1999) did not observe significant priming effects between two-character compound words having homophonic but nonhomographic characters (e.g., 滑翔 hua[2] xiang[2], *glide;* 华贵 hua[2] gui[4], *luxury*), whether the homophonic morphemes were at the first or the second constituent position. Zhou, Shu et al. (1999) used homophonic compound words (e.g., 洁净 jie[2] jing[4], *clean;* 捷径 jie[2] jing[4], *shortcut*) as primes and targets, and they did not observe significant priming effects in lexical decision, although they did find a significant facilitatory effect in naming. The absence of phonological priming effects in lexical decision to compound words contrasted with robust morphological or semantic priming effects in the same experiments. Even in the primed naming task, which taps directly into phonology, phonological effects are not always observed. We observed significant priming effects for homophonic compound words (Zhou, Shu et al., 1999) and single-character words (Zhou, Shu et al., 1999; Zhou, Wu, & Shu, 1998). However, both Zhang, Feng, and He (1994) and Wu and Chen (1997) found no homophone priming effects for low-frequency characters.

Finally, claims for earlier phonological activation in reading Chinese are only inconsistently supported by studies that used semantic tasks, such as semantic categorization or phonologically mediated semantic priming. These are tasks which have played an important part in providing evidence for the role of phonology in access to semantics in alphabetic scripts (e.g., Fleming, 1993;

Jared & Seidenberg, 1991; Lesch & Pollatsek, 1993; Lukatela & Turvey, 1991, 1994; Van Orden, 1987; Van Orden, Johnston, & Hale, 1988). This turns out to be a complex and controversial area in the study of Chinese. Tan and Perfetti (1997), and more recently, Chua (1999) and Xu, Pollatsek, and Potter (1999), for example, did find significant phonological effects. Other studies using these techniques, however, have revealed either nonsignificant or relatively weak phonological effects, independent from orthographic effects (e.g., Chen, Cheung, & Flores d'Arcais, 1995; Leck, Weekes, & Chen, 1995; Sakuma, Sasanuma, Tatsumi, & Masaki, 1998; Wydell, Patterson, & Humphreys, 1993; Zhou, Shu et al., 1999; Zhou & Marslen-Wilson, 2000b; see General Discussion), or have found effects only for special sets of the materials. Thus, although we (Zhou & Marslen-Wilson, 1999a) did observe significant phonologically mediated semantic priming effects in primed naming, these effects were only for a restricted subset of mediated homophone primes, which is inconsistent with the claim for mandatory, across-the-board phonological mediation in access to semantics.

From this review it is clear that there is sufficient uncertainty in the literature to warrant further investigation into the relative time course of semantic and phonological activation in reading Chinese. In the present study, we reexamined this issue by using different tasks to provide converging evidence. The potential influence of task demands on the pattern of semantic and phonological effects is discussed in the different experiment sections and in the General Discussion. Experiment 1 used a lexical-decision task to explore semantic and phonological priming effects in reading Chinese two-character compound words. Experiment 2 examined these priming effects in reading single-character words or morphemes in a character-decision task. The same design and critical characters were also used in Experiment 3, which used a primed naming task. In Experiment 4, the phonological judgment task used by Perfetti and Zhang (1995) was used to examine potential semantic interference effects. In all of these experiments, the SOA between primes and targets was systematically manipulated to track the relative time course of semantic and phonological activation in reading Chinese. The choice of SOAs generally followed the work of Perfetti and his colleagues.

Experiment 1

The purpose of Experiment 1 was to examine the relative time course of semantic and phonological activation in reading two-character compound words, which is the most common type of word in Chinese (over 70% by type; Institute of Language Teaching and Research, 1986). This experiment, using a visual–visual priming lexical-decision task, was based on two of our earlier studies (Zhou, 2000; Zhou, Shu et al., 1999) but with a more systematic manipulation of the phonological and semantic relations between primes and targets and the SOA between primes and targets. A target word (e.g., 洁净 jie[2] jing[4], *clean*) was preceded either by its semantic associate (e.g., 卫生 wei[4] sheng[1], *hygienic*) or by a word phonologically related to the target (e.g., 捷径 jie[2] jing[4], *shortcut*). The SOA between primes and targets was either relatively short (57 ms) or long (200 ms). The crucial question here was which priming effect, semantic or phonological, appeared earlier and/or had a larger magnitude.

"semantic associate" means a word with a similar meaning (e.g., 洁净 and 卫生 have related meanigs)

In this and the following experiments, we used two types of phonological primes: homophones and semihomophones. *Semihomophones* are defined as words which share the same segmental template with the targets, but which differ on lexical tone. Comparing the phonological priming effects for homophones and semihomophones provides us with additional information as to whether suprasegmental (tonal) information plays a significant role in lexical decision to compound words, which, as we argue later, taps mainly into semantic activation of compounds. More important, by including both homophones and semihomophones, we can go some way toward balancing the degree of phonological and semantic overlap between primes and targets, allowing both semantic and phonological pairs to have nonoverlapping properties. This balance is particularly important for some tasks, such as semantic and phonological judgment, because the relative time course of semantic and phonological activation is inferred from the comparison of the strength of the effects in these tasks. The between-task comparison is likely to be influenced by the relative easiness of these tasks, which, in turn, is influenced by the extent of semantic or phonological overlap between primes and targets (Perfetti & Zhang, 1995; Zhou, Shu et al., 1999).

Method

"Method" sections are often very complicated. Refer to the Chow & Lewis (2011) handout (from the readings for Week 2) for some tips about how to read this section.

Design and stimuli. The design and sample stimuli are presented in Table 1. The complete list of critical stimuli can be found in Appendix A. Two groups of target words were used. In one group (the homophone group), 44 target words (e.g., 洁净 jie[2] jing[4], *clean*) were preceded by their semantic associates (e.g., 卫生 wei[4] sheng[1], *hygienic*) and by words homophonic to the targets (e.g., 捷径 jie[2] jing[4], *shortcut*). In another group (the semihomophone group), 80 targets (e.g., 跳跃 tiao[4] yue[4], *jump*) were preceded by semantic associates (e.g., 飞翔 fei[1] xiang[2], *fly*) and by semihomophones that shared the same segmental templates with the targets but differed on the tones of both constituent syllables (e.g., 条约 tiao[2] yue[1], *treaty*). Note that none of the homophone or semihomophone primes bore any orthographic relation to their targets. The comparison between semantic and phonological priming effects here was within item, rather than between items as in Perfetti and Tan (1998), Tan et al. (1995), and Tan et al. (1996). The unequal number of targets for the two groups of stimuli was due to practical restrictions in selecting stimuli and to our desire to have as many critical stimuli as possible. As we show later, this imbalance between the number of homophone pairs and semihomophone pairs does not influence the pattern of priming effects.

To assess semantic and phonological priming effects, we used target words that were also preceded by unrelated control primes. Because semantic and phonological primes could differ on a number of properties, such as frequency and visual complexity, we created separate control primes for the two types of critical primes. This was done by re-pairing semantic or phonological primes with targets. That is, a semantic (or phonological) prime for one target in the homophone or semihomophone group was used as an unrelated semantic (or phonological) control prime for another target in the same group. Thus, the same set of words were used as semantic and control primes and another set of words were used as phonological primes and their controls. The only difference between control primes and semantic or phonological primes was that the former had no systematic relations with the corresponding targets, whereas the latter shared either semantic or phonological properties with their targets.

There were 60 pairs of word–word fillers and 168 pairs of word–nonword fillers, in which primes and targets had neither semantic, orthographic, nor phonological relations at either the whole-word or character level. There were also 16 word–nonword filler pairs that shared one syllable with either the same or different tones at either the first or the

Visual-visual means people in the experiment read characters (rather than hearing sounds). Priming is the kind of study used: where people read one word and then right after that they read another word, which is either related or unrelated. If the two words are related, then you are supposed to be able to read the second word more easily because the first word helps you "activate" it.
Lexical decision means that the participants' task in the experiment was to decide whether each word she reads is a real word or not a real word.

SOA ("stimulus onset asynchrony") means how much time there was between reading the first word and reading the second word.

Table 1
Design and Sample Stimuli in Experiment 1

Stimulus group	Prime: Semantic	Prime: Semantic control	Prime: Phonological	Prime: Phonological control	Target
Homophone	卫生	义务	捷径	遗弃	洁净
Pinyin	wei(4) sheng(1)	yi(4) wu(4)	jie(2) jing(4)	yi(2) qi(4)	jie(2) jing(4)
Gloss	*hygienic*	*duty*	*shortcut*	*abandon*	*clean*
Frequency	1192	1192	256	256	448
Semihomophone	飞翔	聪明	条约	现实	跳跃
Pinyin	fei(1) xiang(2)	cong(1) ming(2)	tiao(2) yue(1)	xian(4) shi(2)	tiao(4) yue(4)
Gloss	*fly*	*clever*	*treaty*	*reality*	*jump*
Frequency	843	843	1068	1068	835

Note. The phonological prime in the upper part of the table is homophonic to its target, whereas the phonological prime in the lower part of table shares its segmental templates but not its lexical tones with its target.

The most important thing about the "Method" section to understand is this table. If you understand the table (don't worry about "Frequency"), then you basically understand what they did in this experiment.

second constituent position. The phonologically related characters in these pairs were orthographically different. The reason for including these related prime–target pairs was to reduce the possibility of participants using strategies based on phonological overlap between critical prime–target pairs, in responding to critical targets (but see Zhou, Shu et al., 1999). Nonword targets were created by combining real characters (morphemes) in a pseudorandom way. None of the nonwords were pseudohomophones that had the same phonological forms as real words. Characters that had been used in critical stimuli were not used again in filler items. There were also 20 pairs of practice items, which had a similar composition to the test items.

The two groups of critical targets and their primes were split, in a Latin square design, into four test versions. In each version, 31 targets, 11 from the homophone group and 20 from the semihomophone group, were preceded by semantic primes. Another 11 targets were preceded by homophone primes and 20 targets by semihomophones. There were also 62 critical targets preceded by the unrelated control primes. The same targets and the same primes appeared only once in a particular test version. The 184 word–nonword and 60 word–word filler items were added to each test version, which thus contained 184 word targets and 184 nonword targets.

A pseudorandom sequence was used to arrange the stimuli in each version in such a way that, across the four test versions, the same target appeared at the same position. The only difference between versions was that the primes for a particular critical target were different. There were never more than 4 consecutive targets requiring the same responses. Prime–target pairs with the same relations were roughly evenly distributed across a test sequence. Thus in each version, 17% (64/368) of the primes shared either semantic properties or segmental templates with their targets. There was a break after practice and two breaks in the main test session. The first three prime-target pairs after each break were always fillers.

Procedure. All stimuli were generated using a computer word-processing program and captured as pictures on the screen by a snapshot program. Each word was excised and stored as an image file on a computer hard disk. Both primes and targets were created in 48-point songti font. A word was about 2.4 × 3.8 cm in size, and participants were seated about 60 cm from the screen.

The presentation of stimuli to participants and the recording of reaction times were controlled by the experimental software DMASTR (Forster & Forster, 1990). In each trial, an eye fixation signal ("+") was first presented at the center of the screen for 300 ms, followed by a blank screen for another 300 ms. A prime was then presented for either 57 ms or 200 ms depending on the SOA conditions. The corresponding target was presented immediately after the prime at the same location for 400 ms. There was an interval of about 3 s between the disappearance of the target and the eye fixation signal of the next trial. Participants were tested in groups of 3 or less in a quiet room.

Because the notion of wordhood can be ambiguous for some Chinese compound words, participants were explicitly instructed that real words were those used in the language and have relatively fixed meanings, whereas nonwords were those not used in the language and had no fixed or commonly accepted meanings. This may bias participants toward the use of semantic information in their decision. Participants were asked to make their decisions as quickly and as accurately as possible.

Participants. A total of 88 native speakers of Mandarin Chinese were tested, 44 at the SOA of 57 ms and 44 at the SOA of 200 ms. They were all undergraduate students at Beijing Normal University and were paid for their participation.

Results

Mean reaction times, based on correct responses and without trimming, were computed separately for participants and items.[2] Response error rates were also computed for each participant and each item. Mean reaction times and error percentages in different priming conditions are reported in Table 2. Semantic and phonological priming effects, as assessed against their respective baselines, are plotted in Figure 1.

Analyses of variance (ANOVAs) were conducted separately for reaction times and error rates, with SOA as a between-participants factor (57 ms vs. 200 ms), and stimulus group (homophone vs. semihomophone), relation type (semantic vs. phonological), and prime type (prime vs. control) as three within-participant factors. In the reaction time analyses, the main effect of prime type was highly significant, $F_1(1, 86) = 61.343$, $p < .001$, $MSE = 1{,}440$, and $F_2(1, 122) = 88.558$, $p < .001$, $MSE = 1{,}364$, indicating that targets were responded to faster when they were preceded by related (semantic and phonological) primes (540 ms) than by unrelated control primes (562 ms). The main effect of relation type was also significant, $F_1(1, 86) = 53.437$, $p < .001$, $MSE = 786$,

[2] Trimming data in different ways, such as discarding reaction times longer than 3 standard deviations from these means, did not change the pattern of priming effects.

Table 2
Mean Reaction Times (in Milliseconds) and Error Percentages in Experiment 1

		Semantic		Semantic control		Phonological		Phonological control	
Stimulus group	SOA	*M*	%	*M*	%	*M*	%	*M*	%
Homophone	57 ms	530	1.7	572	6.4	565	7.9	576	7.2
	200 ms	523	4.8	575	7.0	558	4.8	560	5.2
Semihomophone	57 ms	518	1.9	558	5.5	557	7.0	551	6.5
	200 ms	516	3.0	560	6.3	558	6.1	556	6.4

Note. SOA = stimulus onset asynchrony.

This table is the most important part of the "Results" section. You don't need to worry so much about the detailed statistics in the writing; if you understand this table and the first sentence of the "Discussion" section, then you understand what the findings of this experiment were.

and $F_2(1, 122) = 51.044$, $p < .001$, $MSE = 1{,}631$, indicating that targets were responded to faster when they were preceded by semantic primes and their controls (543 ms) than by phonological primes and their controls (560 ms). More important, the interaction between prime type and relation type was significant, $F_1(1, 86) = 93.753$, $p < .001$, $MSE = 800$, and $F_2(1, 122) = 91.987$, $p < .001$, $MSE = 1{,}495$, suggesting that the patterns of priming effects for semantic primes and for phonological primes were different and that further analyses separating semantic and phonological priming were needed. The interaction between prime type and stimulus group was significant by participants, $F_1(1, 86) = 4.228$, $p < .05$, $MSE = 677$, but not by items, $F_2(1, 122) = 2.163$, $p > .1$, $MSE = 1{,}364$. No other effects or interactions involving prime type or relation type reached significance.

Separate analyses were conducted for semantic and phonological priming effects, as assessed against their respective controls. The main effect of semantic priming was highly significant, $F_1(1, 86) = 147.222$, $p < .001$, $MSE = 1{,}108$, and $F_2(1, 122) = 231.574$, $p < .001$, $MSE = 1{,}114$. This effect did not interact with stimulus group or SOA. In contrast, the main effect of phonological priming was not significant ($F_1 < 1$, $F_2 < 1$), nor was its interaction with stimulus group, $F_1(1, 86) = 3.566$, $.05 < p < .1$, $MSE = 769$; and $F_2(1, 122) = 1.896$, $p > .1$, $MSE = 1{,}745$, or with SOA ($F_1 < 1$, $F_2 < 1$). Thus, whereas semantic primes showed strong facilitatory effects across stimulus group and across SOA, phonological primes, whether homophones or semihomophones, did not show significant priming effects on lexical decision to targets.

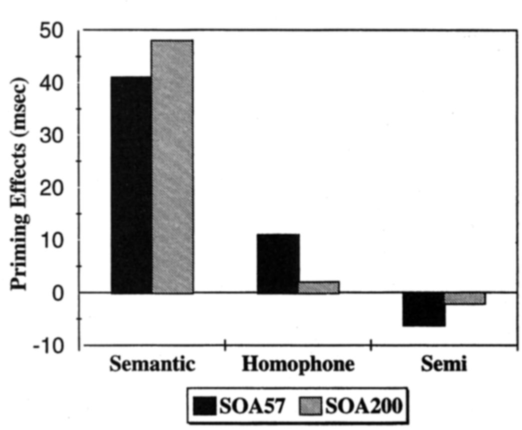

Figure 1. Experiment 1: Priming effects for semantic and phonological primes across SOAs. Semantic effects are averaged across homophone and semihomophone groups. Phonological effects are broken down into homophone and semihomophone groups. SOA = stimulus onset asynchrony.

Analyses of error rates revealed a significant main effect of prime type, $F_1(1, 86) = 8.588$, $p < .005$, $MSE = 0.0052$, and $F_2(1, 122) = 10.230$, $p < .005$, $MSE = 0.0058$, indicating that there were fewer errors when targets were preceded by related primes (4.7%) than by unrelated control primes (6.2%). However, the interaction between prime type and relation type was significant, $F_1(1, 86) = 17.378$, $p < .001$, $MSE = 0.0037$, and $F_2(1, 122) = 11.631$, $p < .001$, $MSE = 0.0075$, suggesting that the patterns of priming effects were different for semantic primes and phonological primes. The main effect of relation type was also significant, $F_1(1, 86) = 18.365$, $p < .001$, $MSE = 0.0039$, and $F_2(1, 122) = 14.874$, $p < .001$, $MSE = 0.0063$, indicating that fewer errors were committed when targets were preceded by semantic primes and their controls (4.5%) than by phonological primes and their controls (6.5%). The interaction between relation type and SOA was significant, $F_1(1, 86) = 12.409$, $p < .001$, $MSE = 0.0039$, and $F_2(1, 122) = 10.230$, $p < .005$, $MSE = 0.0036$. No other main effects or interactions reached significance.

Separate analyses of error rate were then conducted for semantic and phonological priming effects, as assessed against their respective controls. For semantic priming, the main effect of SOA was significant, $F_1(1, 86) = 3.364$, $.05 < p < .1$, $MSE = 0.0056$, and $F_2(1, 122) = 5.865$, $p < .05$, $MSE = 0.0031$. More important, the main effect of prime type was highly significant, $F_1(1, 86) = 25.783$, $p < .001$, $MSE = 0.0042$, and $F_2(1, 122) = 21.758$, $MSE = 0.0066$, suggesting that there were fewer errors when targets were preceded by semantic primes than by control primes. For phonological priming, although there was a significant main effect of SOA, $F_1(1, 86) = 4.528$, $.05 < p < .1$, and $F_2(1, 122) = 4.921$, $p < .05$, $MSE = 0.0037$, we found that the main effect of prime type was not significant ($F_1 < 1$, $F_2 < 1$), indicating that targets were responded to equally as accurately when they were preceded by phonological primes and by unrelated control primes. No other effects or interactions were significant.

Discussion

The data from both SOAs demonstrated that whereas semantic primes had strong effects on lexical decision to compound words, the phonological primes, whether homophones or semihomophones, did not have significant facilitatory or inhibitory effects on the targets. This null effect of phonological priming was striking because it was obtained in the context that there were no word–nonword pairs that had the same segmental elements with the same or different tones. Participants could, in theory, make "yes" responses to critical word targets preceded by homophone or semihomophone primes as soon as they detected that the targets shared the same segmental templates with primes. Note also that the mixture of homophone and semihomophone primes in the same experiment was not responsible for the pattern of priming effects observed here. Zhou, Shu et al. (1999) used only homophone compounds as primes and targets and observed the same strong semantic effect and the nonsignificant phonological effect in lexical decision, although a significant homophone priming effect was observed in naming. Zhou (2000) used only semihomophone compounds as primes and targets and found no significant phonological effect at a short SOA (100 ms), although there were significant inhibitory effects between semihomophones at a longer SOA (357 ms) or when primes were presented auditorily.

The finding of a strong semantic priming effect for compound words at short SOA is consistent with earlier results in lexical decision to compound words, reported by Zhou, Shu et al. (1999), indicating that semantic activation in reading Chinese compound words occurs very early. The absence of phonological priming at the two SOA conditions that we tested is also consistent with the data from a number of other experiments on Chinese compound words (e.g., Zhou, Shu et al., 1999) and clearly contrasts with the significant homophone priming effects typically found in alphabetic scripts (e.g., Grainger & Ferrand, 1994). The presence of semantic effects and the absence of phonological effects are certainly suggestive evidence that information about the phonological properties of compound words is not activated earlier or more strongly than semantic information. Nonetheless, the absence of significant phonological priming effects does not mean that phonology is not automatically activated in reading Chinese (see Zhou, Shu et al., 1999). What remains to be explained is why phonology, obligatorily activated, had such marginal effects in this experiment.

One possibility is that the lack of phonological effect is related to the use of bisyllabic compounds as stimuli. It may be, for example, that lexical decisions about compounds have to be made on higher level lexical or semantic grounds, so that phonological factors are backgrounded (see Zhou, Marslen-Wilson et al., 1999; Zhou, Shu et al., 1999, for discussion). Apparent support for this comes from two reports of early phonological activation that both involve single-character primes and targets, although both of these studies suffered from some methodological deficits. Weekes, Chen, and Lin (1998) found significant phonological priming at 50- and 80-ms SOAs for single-character targets, with equally early semantic priming and a complex interaction with character type. Cheng and Shih (1988), also using single characters, found significant phonological effects at 50-ms SOAs, but without a semantic comparison condition. Neither of these results are inconsistent with our core claim so far that phonological activation, if detectable, does not occur earlier than semantic activation. Nonetheless, it is clearly important to rerun our current study using single-character primes and targets rather than compounds made up of two characters.

Experiment 2

Experiment 2 used a similar design to Experiment 1 to examine the relative time course of semantic and phonological activation in reading single-character words or morphemes. Once again, a within-item design was used to compare semantic and phonological priming effects. A target character (e.g., 读 du[2], *read*) was preceded either by a semantically related character (e.g., 念 nian[4], *read aloud*), a character homophonic to the target (e.g., 独 du[2], *single*), a character sharing the same segmental elements but not lexical tone with the target (e.g., 度 du[4], *degree*), or by an unrelated character (e.g., 粉 fen[3], *powder*). Participants were asked to make a character decision to the target, that is, to decide whether it was a real character used in Chinese. The SOA between primes and targets was manipulated. The critical questions for the present experiment, as in Experiment 1, were whether there were significant priming effects for semantic and phonological primes, with similar or different time courses.

In earlier studies, we have observed significant semantic priming effects for Chinese characters at very short SOAs (43 or 57 ms; e.g., Zhou & Marslen-Wilson, 1997, 1999a, 1999b, 1999c; Zhou, Shu et al., 1999). However, Perfetti and Tan (1998) and Perfetti and Zhang (1995) did not observe such effects when the SOA between primes and targets was shorter than 80 ms, even using the same primed naming task. One difference between the studies was that Perfetti and his colleagues used synonyms as primes and targets, whereas the semantically related prime–target pairs in our experiments covered a wider range of semantic relations, such as synonym, antonym, category coordinate, and superordinate–subordinate. In this experiment, we used two groups of stimuli, one containing only synonyms and the other containing semantic pairs having a mixture of different semantic relations. By comparing the pattern of priming effects for the two groups of stimuli, we would be able to check whether any discrepancies between the present study and Perfetti's studies might be caused by differences in the type of semantic relation between prime and target.

Method

Design and materials. The design and sample stimuli are presented in Table 3. The critical stimuli are listed in Appendix B. A total of 124 targets, together with their semantic, homophonic, semihomophonic, and control primes, were used as critical stimuli. The targets were divided into two groups, synonym and mixed. In the synonym group, 56 targets had their synonyms as semantic primes. In the mixed group, the 68 targets had heterogeneous semantic relations with their primes. Neither semantic, nor homophonic, nor semihomophonic primes were orthographically similar to the targets. Unrelated control primes were created by repairing semihomophonic primes with the targets in the same group. The four types of primes were matched on frequency and visual complexity (in terms of the number of strokes per character). The attributes of the stimuli are reported in Table 3.

Besides the critical stimuli, there were also 62 pairs of primes and targets that were neither semantically, nor phonologically, nor orthographically related. These pairs were used as fillers to reduce the proportion of related stimuli in the test. There were also 186 pairs of primes and targets in which the primes were real characters and the targets were noncharacters requiring "no" responses in the character-decision task. Noncharacters were created by replacing radicals or components of real characters with other components that normally appeared at the same position, or by adding or taking out one or more strokes from the base characters. All of these

Table 3
Design and Sample Stimuli in Experiment 2

Stimulus group	Semantic	Homophone	Semihomophone	Control	Target
Synonym	念	独	度	粉	读
Pinyin	nian(4)	du(2)	du(4)	fen(3)	du(2)
Gloss	*read aloud*	*single*	*degree*	*powder*	*read*
Frequency	616	636	642	642	497
Stroke	8.8	8.9	9.0	9.0	8.9
Mixed	西	冬	动	衣	东
Pinyin	xi(1)	dong(1)	dong(4)	yi(1)	dong(1)
Gloss	*west*	*winter*	*move*	*clothes*	*east*
Frequency	644	633	628	628	678
Stroke	8.9	9.1	9.0	9.0	9.8

noncharacters were "legal" noncharacters that looked like real ones with orthographic components appearing at usual positions, but had no meaning or pronunciation. Because of the limited number of radicals in the language, most radicals used in noncharacters were also used in the critical stimuli. None of the noncharacters were orthographically similar to their corresponding primes. Participants were explicitly told in instruction that noncharacters were those that they had not seen before in Chinese.

A Latin square design was used to assign the four types of primes and their targets to four test versions. The same targets appeared in each version only once and were preceded by different types of primes. Consequently, in each version there were 31 (out of 372) targets preceded by semantic primes, 62 preceded by homophonic or semihomophonic primes. A pseudorandom order was used to arrange prime–target pairs so that there were no more than 4 consecutive targets requiring the same responses. The same sequence was used for the four test versions so that across the four versions the same targets and primes for filler targets appeared in the same position. The only differences between versions were the primes for the critical targets. Because a few items had the same pronunciations, we carefully separated them in the testing sequence.

There were also 30 pairs of practice items. Among them, half of the targets were real characters and half were noncharacters. A few real targets were either semantically or phonologically related to their primes. There was a break after practice and two breaks in the middle of the main test session. The first three item pairs after each break were always fillers. Again, the SOA between primes and targets was set at either 57 ms or 200 ms.

Procedure. The creation of image files was carried out in a similar way to that in Experiment 1, except that the characters were in a 64-point font. This was because the strokes of noncharacters created from real characters looked slightly thicker than the same strokes in real characters if the font was smaller than 64. The equipment and experimental procedures were the same as in Experiment 1. Both primes and targets were in songti font. A character was about 3.4 × 2.2 cm in size, and participants, tested in groups of 3 or less, were seated about 60 cm from the screen. In each trial, an eye fixation signal ("+") was first presented at the center of the screen for 300 ms, followed by a blank screen for another 300 ms. The prime was presented and remained on the screen for 57 ms or 200 ms, depending on the SOA condition. The target was then presented at the same location for 400 ms. Participants were simply asked to judge, by pressing buttons in front of them, whether the target was a real character used in Chinese.

Participants. A total of 97 participants, all undergraduate students at the Beijing Normal University, were tested, 57 at the SOA of 57 ms and 40 at the SOA of 200 ms. They were native speakers of Mandarin and were not tested for Experiment 1.

Results

One participant in the 57-ms SOA group was excluded from the data analyses because of his high response error rate to noncharacter targets (over 30%). This left 14 participants in each version at an SOA of 57 ms and 10 participants in each version at an SOA of 200 ms. Mean reaction times, based on untrimmed correct responses, were computed for each participant and each item and are reported in Table 4. Error percentages for priming conditions are also reported. Priming effects in reaction times, as assessed against the control baselines, are plotted in Figure 2.

Overall analyses were conducted first, with prime type (semantic, homophonic, semihomophonic, and control) as a within-participant, within-item factor; stimulus group (synonym vs. mixed) as a between-items factor; and the SOA (57 ms vs. 200 ms) as a between-participants factor. In reaction times, there was a highly significant main effect of prime type both by participants,

Table 4
Mean Reaction Times (in Milliseconds) and Error Percentages in Experiment 2

		Semantic		Homophone		Semihomophone		Control	
Stimulus group	SOA	*M*	%	*M*	%	*M*	%	*M*	%
Synonym	57 ms	507	2.6	536	4.6	550	3.6	543	5.1
	200 ms	512	4.5	535	4.5	531	6.4	559	7.3
Mixed	57 ms	509	2.7	539	4.2	544	4.2	545	5.8
	200 ms	516	2.2	537	6.1	542	6.9	556	5.4

Note. SOA = stimulus onset asynchrony.

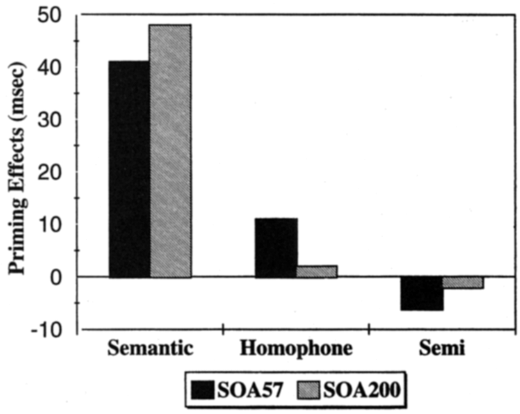

Figure 2. Experiment 2: Priming effects for semantic and phonological primes across SOAs. These effects are averaged across synonym and mixed groups. SOA = stimulus onset asynchrony.

$F_1(3, 282) = 62.596$, $p < .001$, $MSE = 851$, and by items, $F_2(3, 363) = 44.678$, $p < .001$, $MSE = 1{,}164$, indicating that, overall, responses to targets were facilitated by semantic or phonological primes. Post hoc Newman–Keuls tests showed that responses for semantic primes (511 ms) were significantly faster ($p < .01$) than responses for homophone primes (537 ms), semihomophone primes (542 ms), and control primes (550 ms). The main effect of stimulus group and the main effect of SOA were not significant ($F_1 < 1$, $F_2 < 1$), suggesting that the patterns of priming effects for the synonym group did not differ from that for the mixed group. However, the interaction between SOA and prime type was significant, $F_1(3, 282) = 6.377$, $p < .001$, $MSE = 851$, and $F_2(3, 363) = 4.510$, $p < .01$, $MSE = 1{,}234$, indicating that the patterns of priming effects for semantic and phonological primes were different at different SOAs. It is clear from Figure 2 that this interaction was mainly due to the variation of phonological priming effects across the SOA conditions.

Planned tests were conducted respectively for semantic and phonological priming effects, as assessed against controls. At the SOA of 57 ms, the semantic priming effect was highly significant, $F_1(1, 55) = 76.448$, $p < .001$, $MSE = 914$, and $F_2(1, 122) = 51.462$, $p < .001$, $MSE = 1{,}485$. In contrast, the homophone priming effect was not significant, $F_1(1, 55) = 2.544$, $p > .1$, $MSE = 816$, and $F_2 < 1$, nor was the effect for semihomophone primes ($F_1 < 1$, $F_2 < 1$). At the SOA of 200 ms, the semantic priming effect was again highly significant, $F_1(1, 39) = 92.357$, $p < .001$, $MSE = 754$, and $F_2(1, 122) = 70.860$, $p < .001$, $MSE = 1{,}763$. The homophone priming effect was also significant, $F_1(1, 39) = 25.457$, $p < .001$, $MSE = 685$, and $F_2(1, 122) = 18.225$, $p < .001$, $MSE = 156$, as was the priming effect for semihomophones, $F_1(1, 39) = 15.996$, $p < .001$, $MSE = 1{,}098$, and $F_2(1, 122) = 17.898$, $p < .001$, $MSE = 1{,}549$. Therefore, semantic priming effects appear at both the short and the long SOAs, whereas phonological priming effects appeared only at the long SOA. Even here, the phonological effects were still significantly smaller than the semantic effect, as revealed by the comparison between semantic and homophone primes, $F_1(1, 39) = 37.036$, $p < .001$, $MSE = 470$, and $F_2(1, 122) = 20.281$, $p < .001$, $MSE = 1{,}538$, and by the comparison between semantic and semihomophone primes, $F_1(1, 3) = 32.721$, $p < .001$, $MSE = 528$, and $F_2(1, 122) = 20.411$, $p < .001$, $MSE = 1{,}804$. The difference between homophone primes and semihomophone primes was not significant ($F_1 < 1$, $F_2 < 1$).

The analyses of error rates revealed a significant main effect of SOA, $F_1(1, 94) = 5.499$, $p < .05$, $MSE = 0.0071$, and $F_2(1, 121) = 6.727$, $p < .05$, $MSE = 0.0053$, with more errors committed at the SOA of 200 ms than at the short SOA. More important, the main effect of prime type was highly significant, $F_1(3, 282) = 10.862$, $p < .001$, $MSE = 0.0025$, and $F_2(3, 363) = 8.539$, $p < .001$, $MSE = 0.0048$. Post hoc Newman–Keuls tests showed that the error rate for semantic primes was significantly lower ($p < .01$) than the rates for the other three types of primes, which did not differ from each other. The main effect of stimulus group was not significant ($F_1 < 1$, $F_2 < 2$), nor were the interactions between prime type, stimulus group, and SOA.

Discussion

The data from the present experiment do not support the proposition that phonological activation occurs earlier than semantic activation in reading Chinese. At the short SOA of 57 ms, we found significant facilitatory effects for semantic primes in both synonym and mixed groups. However, no significant priming effects were found for either homophone or semihomophone primes. The strong semantic priming effects were consistent with the findings in Experiment 1 for compound words and in other experiments for single-character words (e.g., Chen & Shu, 1997; Zhou & Marslen-Wilson, 1997, 1999a, 1999b, 1999c; Zhou, Shu et al., 1999). These effects suggest that semantic activation in reading Chinese characters occurs very early and that the appearance of semantic priming effects does not depend on the type of semantic relation between prime and target.

The emergence of phonological priming effects at the long SOA indicates that the weakness of phonological effects at the short SOA was not due to a general insensitivity of the character-decision task to phonological activation. Furthermore, it suggests that phonological activation and/or its influence on semantic activation may be a slow process. Although phonological activation may start early, it takes time for this activation to build up and to influence other lexical processes. The possibility still remains, however, that the picture that emerges here of the relative strength and timing of phonological and semantic activation is a consequence of the task, with character decision, like responses to compound words, being relatively more sensitive to semantic (and orthographic) information than to phonological information in the lexicon. In Experiment 3, we used a primed naming task to tap more directly and unequivocally into phonological activation.

Experiment 3

The purpose of Experiment 3 was to investigate whether we could obtain evidence of earlier phonological than semantic activation when the experimental task was biased toward the use of phonological rather than semantic information. If phonology is activated earlier and more strongly than semantics in reading Chinese, the difference between them should be most detectable in the primed naming task, in which the vocalization of a target character can be made only when its phonological representation is activated to a sufficiently high level. It is here that the assumed greater speed and efficiency of the orthography to phonology route would show through most directly. Although semantic primes could also speed naming, they should only do so through a more indirect, top-down route, implying that priming should appear later and be less effective.

We used the same critical stimuli as in Experiment 2 to provide a direct comparison of semantic and phonological effects in character-decision and naming tasks. Furthermore, we manipulated the SOA between primes and targets to track the time course of semantic and phonological activation. The same SOAs used in Experiments 1 and 2 were used here.

Table 5
Mean Reaction Times (in Milliseconds) in Experiment 3

Stimulus group	SOA	Semantic	Homophone	Semi-homophone	Control
Synonym	57 ms	582	575	604	597
	200 ms	620	615	633	636
Mixed	57 ms	572	575	598	590
	200 ms	606	612	635	623

Note. SOA = stimulus onset asynchrony.

Method

Design and materials. The design and critical stimuli are presented in Table 3. The 124 targets, 56 in the synonym group and 68 in the mixed group, were preceded by four types of prime: semantic, homophone, semihomophone, and control. The noncharacters and their primes used in Experiment 2 were discarded, leaving only the 62 unrelated prime–target pairs as filler items. The same critical items used in the four test versions were used in the present experiment. In each version, there were 31 (out of 186) targets preceded by semantic primes, 62 preceded by homophonic or semihomophonic primes. A pseudorandom order was used to arrange prime–target pairs, and the same sequence was used for the four counterbalanced test versions. Across the four versions, the same targets and primes for filler targets appeared in the same position. The only differences between versions were the primes for the critical targets. There were 22 prime–target pairs acting as practice items.

Procedure. The preparation of stimuli and the presentation of stimuli to participants was carried out in the same way as in Experiment 2, except that characters were in a 48-point font (2.4 × 1.6 cm in size). Participants were tested one by one in quiet rooms. They were asked to read aloud the second character of each pair as quickly and as accurately as possible into a microphone interfaced with the computer. Naming latencies were recorded from the onsets of targets to the onset of the participant's vocalization. Naming errors were recorded by the experimenter on pre-printed sheets.

Participants. A total of 81 participants were tested, 40 at the SOA of 57 ms and 41 at the SOA of 200 ms. They were undergraduate students at Beijing Normal University and at Capital Normal University in Beijing, respectively. All were native speakers of Mandarin Chinese and were paid for their participation. None of them had been tested in Experiment 2.

Results

One participant at the SOA of 200 ms was discarded because of too many missing responses (over 10%) to critical targets. A total of 141 (2.8%) responses were excluded from the remaining data because of naming errors, because of the failure of the computer to register response times, or because of extraneous noise. Incorrect responses, stuttering, and no response within 2 s of the presentation of targets were counted as naming errors. There were 17 (1.4%) naming errors for semantic primes, 15 (1.2%) for homophone primes, 31 (2.5%) for semihomophone primes, and 14 (1.1%) for control primes. At the SOA of 57 ms, a total of 154 (3.1%) responses were excluded from analyses. Among them, there were 22 (1.8%) naming errors for semantic primes, 18 (1.5%) for homophone primes, 27 (2.2%) for semihomophone primes, and 26 (2.1%) for control primes. Because the total number of errors was small and there were too many empty data points for individual items or participants, we did not carry out further statistical analyses for these errors. Mean naming latencies were computed for each participant and each item on the basis of correct, untrimmed responses. The overall mean latencies for each condition are presented in Table 5, and the priming effects, as assessed against the control conditions, are reported in Figure 3.

Overall analyses of naming latencies across stimulus group and across the SOA condition were conducted. The main effect of prime type was highly significant both by participants, $F_1(3, 234) = 45.831$, $p < .001$, $MSE = 459$, and by items, $F_2(3, 366) = 29.067$, $p < .001$, $MSE = 1{,}129$. Post hoc Newman–Keuls tests showed that the mean naming latencies for semantic primes (595 ms) and homophone primes (595 ms) were significantly faster ($p < .01$) than the naming latencies for semihomophone primes (617 ms) and control primes (611 ms). However, there was no difference between semantic and homophone primes, indicating that the naming of targets was equally facilitated by these primes. Moreover, the overall 6-msec inhibitory effect for semihomophone primes, as assessed against the unrelated control primes, was significant by participants ($p < .05$) and marginally significant by items ($.05 < p < .1$), suggesting that the mismatch of tonal information between primes and targets delayed the vocalization of targets. There were no significant interactions between prime type and SOA ($F_1 < 1$, $F_2 < 1$); between prime type and stimulus group, $F_1(3, 234) = 2.056$, $p > .1$, $MSE = 489$, and $F_2(3, 336) = 1.405$, $p > .1$, $MSE = 1{,}129$; or between prime type, stimulus group, and SOA ($F_1 < 1$, $F_2 < 1$). These figures indicated that the patterns of priming effects were essentially the same for the synonym and mixed stimuli and for the two SOA conditions. The main effect of SOA was significant, $F_1(1, 78) = 7.574$, $p < .01$, $MSE = 27{,}495$, and $F_2(1, 122) = 334.007$, $p < .001$, $MSE = 12{,}733$, indicating that the mean naming latency for the 57-ms SOA (586 ms) was significantly faster than the latency for the 200-ms SOA (622 ms). This may simply reflect the fact that the participants for the two SOA conditions came from slightly different populations.[3]

Discussion

Unlike Experiment 2, the present experiment revealed equal facilitatory effects for semantic and homophone primes in naming at both the short and the long SOAs. The significant semantic

[3] Different entry requirements were used for the students of the two universities. Moreover, undergraduate students at the Capital Normal University had no or little experience in participating in psychological experiments.

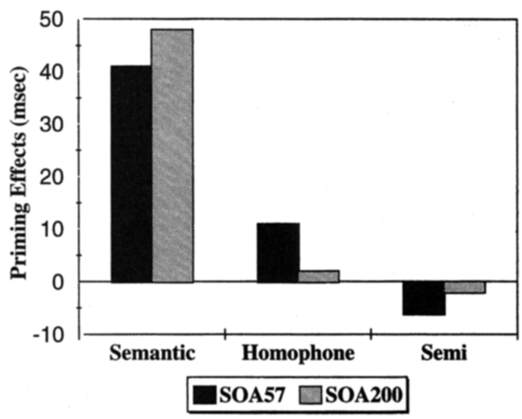

Figure 3. Experiment 3: Priming effects for semantic and phonological primes across SOAs. These effects are averaged across synonym and mixed groups. SOA = stimulus onset asynchrony.

priming effect suggests, as before, that semantic activation is a very early process in reading Chinese and that this spreads rapidly to the phonological representations of targets, resulting in facilitatory effects in naming (see O'Seaghdha & Marin, 1997; Zhou & Marslen-Wilson, 1997, for studies of how semantic activation spreads into phonology).

The equally strong homophone priming effect found here for naming is consistent with the view that phonological activation in reading Chinese also occurs very early and can be picked up by the naming task, which taps directly into phonology. However, it is not clear from the present data to what extent this rapid phonological activation is due to the demands of the naming task, how far it reflects a direct mapping from orthography to phonology, and how far it reflects the indirect spread of semantic activation. Whatever the source of these strong phonological effects, there is still no evidence that phonological activation in reading Chinese is earlier or stronger than semantic activation, even when we use a task that requires the rapid use of phonological information, which should provide optimal conditions for early phonological effects to emerge.

The finding of inhibitory or null priming effects for semihomophones underlines the importance of lexical tone in the Chinese mental lexicon (Xu et al., 1999; Zhou, 2000; Zhou & Marslen-Wilson, 2000a). For semihomophones, although sharing segmental templates could facilitate the vocalization of targets, the mismatch in tonal, suprasegmental information is sufficient to produce inhibitory or null priming effects (see Zhou et al., 1998, for similar findings with school children).

Experiment 4

An additional source of evidence supporting the argument for earlier phonological than semantic activation in reading Chinese comes from experiments using synonym and homophone judgment tasks. Perfetti and Zhang (1995) observed phonological inference effects in synonym judgments for homophones that were not semantically related and semantic interference effects in homophone judgments for synonyms that were not homophones. The crucial finding was that phonological interference effects appeared earlier than semantic interference effects when the SOA between the consecutively presented first and second characters was manipulated.

In this experiment, we reexamined the time course of semantic effects in the phonological judgment task, using the same stimuli as in Experiments 2 and 3 (see Table 3). In this task, both homophones (e.g., 独 du[2], *single,* and 读 du[2], *read*) and semihomophones (度 du[4], *degree,* and 读 du[2], *read*) required "yes" responses. However, both semantically related characters (念 nian[4], *read aloud,* and 读 du[2], *read*) and the unrelated control pairs (粉 fen[3], *powder,* and 读 du[2], *read*) required "no" responses. The rationale here was that semantic activation, and the semantic relationship between the semantic pairs, would send positive signals to the decision system, delaying the "no" responses, which was based on negative signals sent by phonology (Perfetti & Zhang, 1995). The crucial questions here, therefore, were whether the response latencies and error rates of the semantic pairs differed significantly from those of the control pairs and whether the potential semantic effects varied according to the SOA between the first and second characters.

One difference between this experiment and that of Perfetti and Zhang (1995) was that this experiment used semantically related characters with different kinds of semantic relations. This allowed us to examine whether the pattern of semantic effects in phonological judgment was influenced by the type of semantic relation between the first and second characters. The second difference from Perfetti and Zhang (1995) was that the phonologically related characters here could be either homophones or semihomophones differing on tones. This could increase the difficulties in making phonological judgment, allowing more time for semantic effects to appear. This made the comparison between semantic and homophone interference effects more balanced because both phonologically and semantically related pairs now had mismatching properties (but see Footnote 5). The third difference was that this experiment included a shorter SOA (57 ms) between the first and second characters than Perfetti and Zhang (1995) used. This was simply to follow the previous three experiments. A slightly longer SOA (86 ms), comparable with the shortest one used by Perfetti and Zhang (1995), was used in a later, follow-up experiment (see *Discussion*), and the data are also included in Table 6 and Figure 4.

Method

Design and stimuli. The critical stimuli were the same as those in Experiments 2 and 3 and are illustrated in Table 3. Because of the change in the experimental task, it is more appropriate to refer to the prime as the first character and the target as the second character. The crucial comparison here was between "no" responses to semantic pairs (e.g., 念 nian[4], *read aloud,* and 读 du[2], *read*) and the unrelated control pairs (粉 fen[3], *powder,* and 读 du[2], *read*); although the comparison between "yes" responses to homophone pairs (e.g., 独 du[2], *single,* and 读 du[2], *read*) and semihomophone pairs (度 du[4], *degree,* and 读 du[2], *read*) also provides information concerning the activation of tonal information.

As in Experiments 2 and 3, we divided the 124 critical targets and their corresponding three types of first characters into two groups: synonym and mixed. These stimuli were split into four counterbalanced test versions. Another 16 pairs of characters, 8 of them semantically related, were added to each version. They were used as dummy items after breaks in testing. There were also 32 pairs of practice items, with one fourth of them semantically related, of which one fourth were homophones and one fourth were semihomophones.

Table 6
Mean Reaction Times (in Milliseconds) and Error Percentages in Experiment 4

		"No" responses				"Yes" responses			
		Semantic		Control		Homophone		Semihomophone	
Stimulus group	SOA	*M*	%	*M*	%	*M*	%	*M*	%
Synonym	57 ms	785	10.1	837	14.1	714	12.1	738	13.9
	86 ms	769	7.4	815	9.0	687	10.0	730	11.9
	200 ms	619	6.1	624	4.5	563	6.6	589	7.7
Mixed	57 ms	749	10.8	807	11.6	716	13.1	739	13.3
	86 ms	741	5.5	788	4.5	678	8.5	716	12.7
	200 ms	610	5.6	605	3.5	554	8.2	578	7.9

Note. See *Discussion* of Experiment 4 for the effects at the stimulus onset asynchrony (SOA) of 86 ms.

Procedure. The creation of image files and the presentation of stimuli to participants were conducted in the same way as in Experiment 3. Participants were asked to judge as quickly and as accurately as possible whether the first and second characters they saw at the center of the computer screen were phonologically related. They were explicitly told that only those character pairs with the same pronunciation or with pronunciations differing only in lexical tone required "yes" responses, even though there were few, if any, prime–target pairs that shared their initial consonants or rhyming parts. Participants made their decisions by pressing "yes" or "no" keys on response boxes in front of them. This was different from Perfetti and Zhang's (1995) procedure, in which participants had to make oral responses to indicate "yes" or "no" decisions.

There was a break after practice and a break in the middle of the formal test. At the SOA of 57 ms, participants were allowed to go through practice items twice if they had difficulties in identifying the first characters and in making decisions. Even so, the testing of many participants had to be discontinued because they could not carry out the task or because many of their responses were very slow (>2,500 ms).

Participants. One hundred five participants at the Beijing Normal University were tested, 61 for the SOA of 57 ms and 44 for the SOA of 200 ms. They had not been tested in Experiments 2 and 3. All were native speakers of Mandarin Chinese and were paid for their participation.

Results

The phonological judgment task proved to be very difficult for about one third of participants at the SOA of 57 ms, chiefly because they could not fully identify the first characters at their short exposures. The testing of these participants was discontinued. The data reported here were based on 42 participants who did reasonably well in this task. Each test version had at least 10 participants. Due to high error rates (over 60%) in "yes" responses to homophones or semihomophones (5 and 4 pairs, respectively), we excluded nine quartets of critical stimuli, including responses to semantic and control pairs, from the analyses: 4 in the synonym group and 5 in the mixed group. This left 115 quartets of critical stimuli as the basis on which the mean reaction times and response error rates were computed. The pattern of effects did not change whether these stimuli were excluded or not.[4]

At the SOA of 200 ms, one participant was excluded because of his high response error rates. This left 10 participants in one test version and 11 participants in other versions. Three quartets of stimuli, 1 in the synonym group and 2 in the mixed group, were excluded from analyses because of high error rates in "yes" responses to phonologically related pairs.

Mean reaction times, based on correct responses, were computed for participants and items without the data being further trimmed. They are reported, together with response error percentages, in Table 6. Semantic effects, as assessed against the unrelated control pairs, are also reported in Figure 4. Statistical analyses were conducted separately for "no" responses to semantically related and control pairs and for "yes" responses to homophones and semihomophones. Overall analyses were first conducted with three factors: SOA (57 and 200 ms), stimulus group (synonym and mixed), and relation type (semantic vs. control in "no" responses, and homophone vs. semihomophone in "yes" responses).

"No" responses. There was a significant main effect of SOA, $F_1(1, 83) = 92.392$, $p < .001$, $MSE = 29{,}430$, and $F_2(1, 111) = 1{,}127.174$, $p < .001$, $MSE = 3{,}295$, indicating that the mean reaction time at the SOA of 200 ms (614 ms) was significantly faster than the time at 57 ms (794 ms). This was not surprising given that participants had difficulties in identifying the first characters when the SOA was short. The main effect of stimulus group was significant, $F_1(1, 83) = 23.662$, $p < .001$, $MSE = 1{,}880$, and $F_2(1, 111) = 8.180$, $p < .01$, $MSE = 8{,}036$, indicating that responses to synonym stimuli (716 ms) were slower

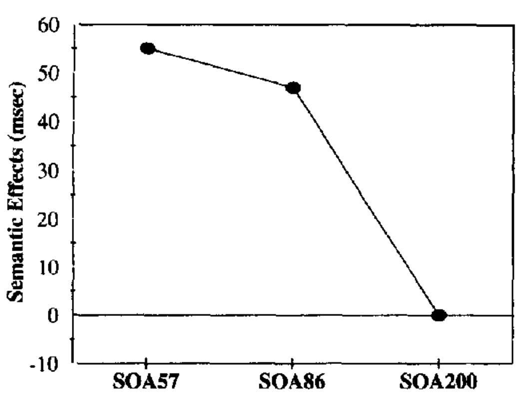

Figure 4. Experiment 4: Semantic effects in phonological judgment. These effects are averaged across synonym and mixed groups. Semantic effects are assessed against unrelated controls. See *Discussion* for the effect at the SOA of 86 ms. SOA = stimulus onset asynchrony.

[4] The pattern of effects also did not change if we adopted more strict criteria of excluding stimuli. Two more quartets of stimuli would have been lost if the normal exclusion rate of 50% errors was used.

than responses to mixed stimuli (692 ms). More important, the main effect of relation type was highly significant, $F_1(1, 83) = 26.298, p < .001, MSE = 2{,}503$, and $F_2(1, 111) = 12.080, p < .001, MSE = 8{,}268$. Responses to the semantically related pairs (689 ms) were significantly faster than responses to the unrelated control pairs (718 ms). However, the interaction between relation type and SOA was also highly significant, $F_1(2, 83) = 26.120, p < .001, MSE = 2{,}503$, and $F_2(1, 111) = 27.289, p < .001, MSE = 3{,}192$, indicating that the patterns of "no" responses to semantic and control pairs were different at different SOAs. No other interactions reached significance.

Planned comparisons between semantic and control conditions, collapsing over stimulus group, showed a significant effect at the SOA of 57 ms, $F_1(1, 41) = 30.394, p < .001, MSE = 4{,}302$, and $F_2(1, 113) = 19.381, p < .001, MSE = 9{,}054$. Reaction times were faster to semantically related characters (766 ms) than to unrelated characters (821 ms). At the SOA of 200 ms, however, responses to semantic pairs did not differ from the control pairs ($F_1 < 1$, $F_2 < 1$).

In the error analyses, there was a significant main effect of SOA, $F_1(1, 83) = 23.084, p < .001, MSE = 0.0166$, and $F_2(1, 111) = 57.866, p < .001, MSE = 0.0091$, with more errors at the SOA of 57 ms (11.6%) than at 200 ms (4.8%). The interaction between SOA and relation type was also significant, $F_1(1, 83) = 7.563, p < .01, MSE = 0.0048$, and $F_2(1, 111) = 6.892, p < .001, MSE = 0.0064$, indicating that the patterns of effects were different at the two SOA conditions. Planned tests showed a significant main effect of relation type at the short SOA, $F_1(1, 41) = 4.840, p < .05, MSE = 0.0050$, and $F_2(1, 113) = 2.786, .05 < p < .1, MSE = 0.0111$, with fewer errors to semantically related characters (10.6%) than to unrelated control characters (12.9%). At the longer SOA, however, the pattern was reversed, with more errors made to semantic pairs (5.9%) than to control pairs (4.0%). The difference was marginally significant in statistical analyses, $F_1(1, 42) = 2.840, .05 < p < .1, MSE = 0.0035$, and $F_2(1, 119) = 2.820, .05 < p < .1, MSE = 0.0067$.

"Yes" responses. The main effect of relation type was significant, $F_1(1, 83) = 21.280, p < .001, MSE = 2{,}272$, and $F_2(1, 111) = 10.011, p < .01, MSE = 6{,}562$, with responses to homophone characters being faster than responses to semihomophone characters (635 ms vs. 659 ms). Not surprisingly, it was more difficult for participants to accept semihomophones than homophones as phonologically related characters. There was also a significant main effect of SOA, $F_1(1, 83) = 67.202, p < .001, MSE = 30{,}154$, and $F_2(1, 111) = 1{,}136.573, p < .001, MSE = 2{,}572$, indicating that the mean reaction time at the SOA of 200 ms (568 ms) was significantly faster than the time at the SOA of 57 ms (726 ms). The main effect of stimulus group was not significant, nor were the interactions between the three variables ($F_1 < 1, F_2 < 1$). In the analyses of error rates, the only significant result was the main effect of SOA, $F_1(1, 83) = 17.014, p < .001, MSE = 0.0145$, and $F_2(1, 111) = 39.739, p < .001, MSE = 0.0104$, indicating that error rate at the SOA of 200 ms (7.3%) was significantly lower than the rate at 57 ms (13.1%).

Discussion

The data from this experiment show that semantic effects in phonological judgment change over SOAs. Semantically related pairs tend to be more difficult to reject than unrelated control pairs at the longer SOA but show robust facilitatory effects at the short SOA. This applies to both the synonym pairs and the mixed pairs. The semantic effect at the SOA of 57 ms was particularly interesting: It was not only early but also facilitatory. This is inconsistent with the findings of Perfetti and Zhang (1995), who observed strong interference effects for semantic pairs at the SOAs of 140, 260, and 310 ms but a null effect at the SOA of 90 ms.

We were surprised by the facilitatory semantic effect at the short SOA. Was it a spurious effect, distorted by the fact that about one third of participants were discarded because of their inability to carry out the task? Or was it restricted only to students at Beijing Normal University, who might have become experienced participants in psychology experiments? We reran the experiment with the same stimuli and experimental procedures but with a longer SOA (86 ms) at the Capital Normal University in Beijing. A total of 42 undergraduate students were tested, with 2 of them being excluded from the data analyses because of their high response error rates (over 30%). These students did not participate in Experiment 3 and had rarely, if ever, taken part in other psychology experiments. Six quartets of stimuli were discarded because of the high error rates in the "yes" responses to the phonologically related pairs. The mean reaction times and response error rates are reported, with the data from the SOAs of 57 ms and SOA 200 ms, in Table 6. The semantic effect is also plotted in Figure 4.

The patterns of effects at the SOA of 86 ms are essentially the same as those at the SOA of 57 ms. In "no" responses to semantically related and unrelated control pairs, there was a significant main effect of relation type, $F_1(1, 39) = 33.257, p < .001, MSE = 2{,}124$, and $F_2(1, 116) = 14.751, p < .001, MSE = 8{,}197$, with faster responses to semantically related characters (755 ms) than to unrelated control pairs (801 ms). The same pattern was observed for the synonym and mixed stimuli. In "yes" responses to phonologically related characters, homophones (682 ms) were significantly faster than semihomophones (722 ms). Participants also committed fewer errors on homophones than on semihomophones (9.3% vs. 12.4%).[5]

The positive semantic effects at the short SOAs in the phonological judgment task again demonstrate that semantic information is activated very early in reading Chinese. This semantic activation, although not required by the experiment task, seems to have facilitated the activation of phonology and hence the decision based on the phonological properties of the target characters. The presentation of the first characters activated their semantic representations, through direct computation from orthography and through phonological mediation. Because the second characters, for semantic pairs, shared many semantic properties with the first characters, the activation of semantic representations of the second characters was then facilitated. This semantic activation spreads immediately to the phonological representations of the second characters (see O'Seaghdha & Marin, 1997; Zhou & Marslen-Wilson, 1997, for evidence), allowing the decision system to

[5] A positive effect was also found for semantic pairs when the semihomophone condition was excluded from the experiment. We reran the experiment at Peking University, using an SOA of 86 ms, and found a significant 25-ms facilitatory effect for the semantically related pairs as compared with the unrelated pairs.

compare more rapidly the two phonological patterns of the first and second characters and to make the "no" decision.

Why was a trend toward an interference effect (as revealed in the error analyses), rather than a facilitatory effect, observed at the longer SOA for the same semantic pairs? As Perfetti and Zhang (1995) argued, in the phonological judgment task, the decision system has to distinguish between two types of signals: the negative signals based on phonology and the positive signals based on semantics. The comparison between phonological representations of the first and second characters of semantic pairs sends negative signals to the decision system. This comparison could be facilitated by semantic priming between the first and second characters, as outlined above. However, the comparison between semantic representations of the first and second characters, when the first character has had sufficient time to be fully activated, sends positive signals to the decision system. The effect of these conflicting signals could counterbalance the semantically mediated phonological facilitation, resulting in a null or interference effect for semantic pairs in phonological judgment. As the SOA between the first and second characters becomes longer, this semantically mediated phonological facilitation decreases while the interference from the semantic level increases, resulting in overall inhibitory effects for semantic pairs in phonological judgement, as shown by Perfetti and Zhang (1995).

The evidence for very early semantic activation again does not preclude the possibility of very early phonological activation. Indeed, the fact that most participants could make positive responses to homophones and semihomophones at the SOA of 57 ms indicates that phonological activation can occur very early. The fact that semihomophones were more difficult to be accepted as phonologically related than homophones also suggests that the phonological judgment task, like the naming task but unlike the character decision task, is sensitive to suprasegmental information. Suprasegmental (tonal) information, like the segment information, is activated very early when an experimental task taps directly into phonology. A mismatch of phonological properties at the suprasegmental level can lead to difficulties in accepting the paired characters as phonologically related. We replicated this effect in a recent study (Zhou & Marslen-Wilson, 2000a) in which we observed even more fine-graded tonal effects in phonological judgements to visually presented characters.

Perfetti and Zhang (1995), as we noted earlier, also ran a semantic judgment task, finding phonological interference effects consistent with an early activation of phonological information. We have tested our current stimuli in a further experiment also using semantic judgement. As did Perfetti and Zhang (1995), we required "no" responses for homophone pairs (e.g., 独 du[2], *single,* and 读 du[2], *read*), for semihomophone pairs (度 du[4], *degree,* and 读 du[2], *read*), and for the unrelated control pairs (粉 fen[3], *powder,* and 读 du[2], *read*), and "yes" responses for semantic pairs (e.g., 念 nian[4], *read aloud,* and 读 du[2], *read*). Homophone and semihomophone pairs were found to be more difficult to reject as semantically related than unrelated controls at both the short (57 ms) and long (200 ms) SOAs. However, unlike in Perfetti and Zhang's study (1995), these phonological interference effects appeared only in response error rates, not in reaction times. Yet this replicates Perfetti and Zhang's findings (1995) in showing that the phonological information linked to Chinese characters is automatically activated and that this phonological activation interferes with an experimental task that does not require this activation.

General Discussion

The main purpose of the present study was to investigate the relative time course of semantic and phonological activation in reading Chinese. This issue is important because it relates to whether phonology plays a strong role in access to lexical semantics. The data from the four sets of experiments reported here are inconsistent with suggestions made by Perfetti and his colleagues (Perfetti & Tan, 1998; Perfetti & Zhang, 1995; Tan et al., 1995; Tan et al., 1996), but are consistent with many other studies showing that phonology has no privileged role in visual lexical processing in Chinese. In Experiment 1, we observed strong semantic priming effects in lexical decision to compound words at both the short (57 ms) and long (200 ms) SOAs. In contrast, no significant phonological priming effects were found for homophones or semihomophones at either SOA. In Experiment 2, although semantic priming effects were found in character decision at both the short and long SOAs, the phonological priming effects for homophones and semihomophones, which were smaller than the semantic effects, were observed only at the long SOA. Experiment 3 showed equal facilitatory priming effects for semantic and homophone primes in a naming task at both the short and long SOAs. The semihomophone primes, however, tended to inhibit the vocalization of targets. Experiment 4, using a phonological judgment task, revealed strong facilitatory effects in both reaction times and response error rates for semantically related characters at short SOAs but an interference effect in error rates for such pairs at the long SOA.

The Relative Time Course of Semantic and Phonological Activation

Taken together, these data provide no support for the view that phonological information in the lexicon is activated earlier than semantic information in reading Chinese. A comparison of the priming effects in Experiments 1, 2, and 3 clearly shows that although semantic priming effects remained strong across different experimental tasks, phonological priming effects varied significantly along a continuum. These effects provide us with information about how the tasks tap into semantic or phonological activation and to what extent conclusions concerning the relative time course of semantic and phonological activation could be influenced by task biases. We suggest that lexical decision to compound words biases toward the use of semantic information, whereas primed naming biases toward the use of phonological information. When the task biases more toward the use of phonological information, phonological priming effects naturally become stronger. However, even when there is a strong bias, as in naming, toward the use of phonological information, early semantic priming effects are still present and are just as strong as phonological effects.

Because both compound words and compound nonwords are made of constituents with morphemic meanings and with familiar orthographic and phonological forms, lexical decision to compound words needs to be made on the basis of semantic activation rather than on the basis of orthographic or phonological properties.

Participants must rely mainly on the activation of semantic properties of whole compound words to make "yes" responses and on computation between morphemic meanings of constituents of compound nonwords, which does not produce coherent semantic patterns, to make "no" responses. The absence of significant phonological priming effects in Experiment 1 suggests either that the phonological properties of compound words are not activated, or more likely, that the phonological information is activated but it places no strong constraints on semantic activation in initial lexical processing.

For the character-decision task, because noncharacters are orthographically unfamiliar and theoretically not pronounceable, the decision system can use semantic, orthographic, or phonological activation, or any combination between them, to distinguish real characters from noncharacters. The absence of phonological priming effects at the short SOA and the presence of such effects at the longer SOA in Experiment 2 suggest that it takes time for phonological activation to build up and to influence the processing of targets. Apparently, this slow buildup of phonological activation can be either accelerated by the demands of the naming task or tapped into more efficiently in naming. Compared with semantic priming effects, phonological priming effects should be easier to detect in this task. This is because the facilitation of phonological activation of semantic targets has to be mediated by the semantic overlap between primes and targets, whereas the facilitation of phonological activation of phonological targets takes place directly at the phonological level, needing no semantic mediation (O'Seaghdha & Marin, 1997; Zhou & Marslen-Wilson, 1997). However, we observed only equal facilitation for semantic and homophone primes in naming.

This is not to say that phonological activation is never earlier than semantic activation in reading Chinese. It is possible that under certain circumstances we could find certain types of characters whose phonological activation is very efficient. One candidate for this efficient phonological activation is "regular" complex characters whose phonetic radicals have the same pronunciations as the whole characters. The sublexical phonological processing of phonetic radicals could facilitate the phonological activation of whole characters (Fang et al., 1986; Hue, 1992; Peng et al., 1994; Seidenberg, 1985; Zhou & Marslen-Wilson, 1999b), whereas the sublexical semantic processing of phonetic radicals could interfere with the semantic activation of whole characters (Zhou & Marslen-Wilson, 1999b, 1999c). In a recent study, we indeed observed larger homophone priming effects than semantic priming effects for such regular characters at the SOA of 57 ms. However, this pattern appeared only in the naming task. Essentially the same patterns of priming effects as those in Experiment 3 were observed here in character decision for these regular characters, in which homophone primes produced little facilitatory effects at the short SOA but significant effects at a longer SOA (200 ms).

Phonology, Orthography, and Semantic Activation in Reading Chinese

Traditionally, dual-route theories of lexical processing assume that access to semantics can go either through the direct computation from orthography or through phonological mediation in which orthographic activation passes to phonology representation and then to semantic representations. Moreover, these two routes are rather independent from each other. However, interactive and connectionist theories of lexical processing lead us to view semantic (and phonological) activation as the result of interactive processes in which different types of knowledge all come into play. Data from some studies on English (e.g., Coltheart, Patterson, & Leahy, 1994) and Hebrew (see Frost, 1998) suggest that orthographic and phonological information interact in their constraints on semantic activation, although phonology seems to play a primary role in this process (e.g., Henderson, Dixon, Petersen, Twilley, & Ferreira, 1995; Lesch & Pollatsek, 1993; Lukatela & Turvey, 1991, 1994; Van Orden, 1987; Van Orden et al., 1990). Studies of logographic Chinese or Japanese Kanji provide more evidence for the argument that access to lexical semantics in reading Chinese is driven by both orthographic and phonological information, even though orthographic activation seems to play a more important role than phonology. Moreover, orthographic and phonological activation is a multiple constraint–satisfaction process that can be influenced by various properties of Chinese characters, such as sublexical phonological regularity or semantic transparency of semantic radicals. Semantic activation also continuously feeds back to facilitate phonological and orthographic activation.

Evidence supporting this interactive view of semantic activation in reading Chinese comes from experiments using various experimental tasks and techniques. In a study on pseudohomophone effects in reading Chinese, we (Zhou & Marslen-Wilson, 2000b) found that pseudohomophones that were created by replacing only one constituent of compound words with homophonic characters were more difficult to reject in lexical decision than were control nonwords that also shared one morpheme with the base words. However, such a pseudohomophone effect was greatly reduced when pseudohomophones were created by replacing both constituents of compound words. The pseudohomophone effect was also modulated by the frequency of constituent characters. This pattern suggests that the phonological activation and possibly the semantic activation of base words, by the presence of pseudohomophones, depends crucially on the interaction between the phonological properties of whole words and the morphological processing of common morphemes shared between pseudohomophones and base words. Similar patterns were also found for both compound words and single-character words in the semantic categorization task (e.g., Leck et al., 1995; Sakuma et al., 1998; Wydell et al., 1993) and in the phonologically mediated semantic priming paradigm (e.g., Zhou & Marslen-Wilson, 1999a; Zhou, Shu et al., 1999). Sakuma et al., for example, found a homophone interference effect for homophones sharing one character with category exemplars but not for homophones sharing no characters with exemplars. Similarly, Leck et al. found that the homophone interference effect was most salient for homophone characters that were orthographically similar to the exemplar characters, and much less so or nonsignificant for homophone characters that were orthographically different from the exemplar characters (see also Chen et al., 1995). We (Zhou & Marslen-Wilson, 1999a) found that target characters were facilitated not only by their semantic associates but also by characters that were orthographically similar to or homophonic to the associates, although the homophony between mediated primes and semantic primes by itself did not guarantee significant mediated priming.

These data suggest that semantic activation in reading Chinese is not simply due to direct computation from orthography or to mediation though phonological activation. It is the interaction between phonology and orthography (and morphology) that normally determines semantic activation. Studies comparing the time course of phonological and semantic activation can only give us an incomplete picture of lexical processes in reading Chinese. More research with different techniques is needed to determine the variables entering the multiple constraint–satisfaction processes of semantic activation.

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(Appendixes follow)

Appendix A

Stimuli Used in Experiment 1

No.	Semantic prime	Semantic control	Phonological prime	Phonological control	Target
1	平庸	草原	注明	笔试	著名
2	偏见	牺牲	骑士	序幕	歧视
3	数学	轻蔑	攻势	劣势	公式
4	管理	特征	晶莹	兴致	经营
5	信徒	信件	前程	游记	虔诚
6	溺爱	故事	浇灌	同化	娇惯
7	遮盖	同志	演示	首位	掩饰
8	农村	眼睛	现成	加剧	县城
9	顽皮	沙发	导弹	事例	捣蛋
10	蝴蝶	改编	密封	援助	蜜蜂
11	憔悴	保护	销售	占有	消瘦
12	便宜	繁殖	幽会	轻捷	优惠
13	卫生	义务	捷径	倾心	洁净
14	结果	设备	元音	宝剑	原因
15	开关	营养	店员	遗弃	电源
16	新年	干净	终生	西洋	钟声
17	伤员	野蛮	单价	祝愿	担架
18	思维	病床	技艺	闻名	记忆
19	群众	黄昏	手掌	数目	首长
20	尖锐	污浊	风力	全力	锋利
21	坚强	说明	抑制	声誉	意志
22	阴谋	森林	轨迹	继续	诡计
23	轻蔑	管理	笔试	现成	鄙视
24	牺牲	偏见	劣势	晶莹	烈士
25	草原	溺爱	序幕	攻势	畜牧
26	特征	信徒	兴致	前程	性质
27	信件	平庸	游记	骑士	邮寄
28	故事	遮盖	同化	浇灌	童话
29	保护	数学	首位	演示	守卫
30	眼睛	农村	事例	密封	视力
31	沙发	顽皮	加剧	注明	家具
32	改编	蝴蝶	援助	导弹	原著
33	同志	憔悴	占有	销售	战友
34	干净	尖锐	轻捷	幽会	清洁
35	污浊	开关	倾心	元音	清新
36	设备	伤员	遗弃	终生	仪器
37	营养	结果	宝剑	店员	保健
38	繁殖	新年	声誉	捷径	生育
39	病床	思维	祝愿	单价	住院
40	野蛮	便宜	闻名	手掌	文明
41	黄昏	群众	西洋	技艺	夕阳
42	义务	坚强	全力	轨迹	权利
43	森林	卫生	数目	抑制	树木
44	说明	阴谋	继续	风力	记叙
45	诽谤	头发	妖艳	礼节	谣言
46	手绢	明白	冒进	批复	毛巾
47	思想	华侨	遗失	福气	意识
48	审判	表面	发源	消化	法院
49	运动	情侣	精致	通报	静止
50	困难	拯救	检举	晚会	艰巨
51	措施	离别	颁发	愤慨	办法
52	轻松	数学	优先	武力	悠闲
53	完成	火苗	事先	宴会	实现
54	婚礼	委屈	东方	修理	洞房
55	注册	亲戚	等级	失职	登记
56	主动	遭遇	支援	经理	志愿
57	文献	幽默	估计	愿望	古籍
58	储存	漂亮	对方	学院	堆放
59	飞翔	聪明	条约	现实	跳跃
60	文物	炫耀	意志	指挥	遗址
61	糊涂	支票	情形	先进	清醒
62	纵容	游泳	主张	实验	助长
63	吵闹	许诺	大家	化学	打架
64	筛选	侵略	提出	政府	剔除
65	女儿	生物	西服	遗书	媳妇
66	参加	文学	除夕	砍伐	出席
67	待遇	发育	礼仪	胜仗	利益
68	歌剧	站岗	隐约	烧饼	音乐
69	国境	观点	辩解	喜报	边界
70	整理	告诫	手势	体型	收拾
71	了解	杜绝	人事	出力	认识
72	开始	虚幻	处罚	事迹	出发
73	商店	遗留	时常	假如	市场
74	打扮	退出	树立	电力	梳理
75	护士	钟表	议员	参与	医院
76	通知	仪式	高速	纺织	告诉
77	汽油	数学	究竟	立刻	酒精
78	通讯	命令	优点	事件	邮电
79	围巾	背叛	贸易	管理	毛衣
80	主动	合谋	资源	传统	自愿
81	取消	常规	接触	重视	解除
82	家乡	应付	机关	统治	籍贯
83	解剖	报告	胜利	组织	生理
84	审问	障碍	工人	知识	供认
85	头发	诽谤	批复	发源	皮肤
86	明白	手绢	礼节	冒进	理解
87	情侣	思想	福气	遗失	夫妻
88	表面	审判	失职	妖艳	实质
89	华侨	运动	通报	精致	同胞
90	拯救	文物	晚会	检举	挽回
91	离别	措施	愤慨	支援	分开
92	数学	轻松	武力	优先	物理
93	火苗	完成	宴会	大家	烟灰
94	委屈	婚礼	愿望	东方	冤枉

Appendix A (*continued*)

No.	Semantic prime	Semantic control	Phonological prime	Phonological control	Target	No.	Semantic prime	Semantic control	Phonological prime	Phonological control	Target
95	亲戚	注册	学院	等级	血缘	110	应付	国境	出力	礼仪	处理
96	遭遇	主动	经理	意志	经历	111	告诫	了解	体型	人事	提醒
97	幽默	文献	消化	估计	笑话	112	虚幻	开始	事迹	处罚	实际
98	漂亮	储存	修理	条约	秀丽	113	遗留	通知	参与	辩解	残余
99	聪明	飞翔	指挥	事先	智慧	114	退出	打扮	假如	树立	加入
100	炫耀	困难	现实	提出	显示	115	仪式	护士	电力	高速	典礼
101	支票	糊涂	先进	情形	现金	116	杜绝	审问	纺织	手势	防止
102	许诺	纵容	实验	主张	誓言	117	数学	汽油	立刻	胜利	理科
103	游泳	吵闹	化学	对方	滑雪	118	钟表	整理	事件	究竟	时间
104	侵略	筛选	政府	颁发	征服	119	背叛	围巾	重视	机关	忠实
105	生物	女儿	喜报	除夕	细胞	120	合谋	主动	传统	贸易	串通
106	文学	参加	遗书	隐约	艺术	121	命令	取消	知识	接触	指示
107	发育	待遇	胜仗	议员	生长	122	障碍	通讯	组织	工人	阻止
108	站岗	歌剧	烧饼	西服	哨兵	123	报告	家乡	统治	优点	通知
109	观点	商店	砍伐	时常	看法	124	常规	解剖	管理	资源	惯例

Note. The first 44 rows are stimuli for the homophone group, in which the phonological primes are homophonic to their targets. The rest are stimuli for the semihomophone group, in which phonological primes differ in tones from the targets.

(*Appendix B follows*)

Appendix B

Stimuli Used in Experiment 2

No.	Semantic prime	Homophone prime	Semi-homophone	Control prime	Target	No.	Semantic prime	Homophone prime	Semi-homophone	Control prime	Target
1	翼	斥	尺	选	翅	48	找	旬	训	谢	寻
2	河	穿	串	病	川	49	齿	崖	押	阴	牙
3	嗅	纹	温	埋	闻	50	挪	疑	意	苗	移
4	卒	冰	病	超	兵	51	喝	引	阴	导	饮
5	颈	博	波	吃	脖	52	好	幽	游	意	优
6	窝	潮	超	贺	巢	53	寄	油	幼	咱	邮
7	晚	持	吃	口	迟	54	呆	鱼	育	此	愚
8	戳	赐	此	品	刺	55	夸	暂	咱	幼	赞
9	窃	道	导	额	盗	56	逮	桌	苗	育	捉
10	念	独	度	粉	读	57	恨	艾	癌	球	爱
11	坏	饿	额	田	恶	58	明	岸	安	九	暗
12	墓	焚	粉	度	坟	59	忧	杯	被	管	悲
13	兄	割	革	统	哥	60	纸	比	闭	安	笔
14	返	规	贵	丝	归	61	缝	财	彩	贡	裁
15	冷	含	汉	革	寒	62	午	尘	趁	敌	晨
16	匣	核	贺	贵	盒	63	喝	痴	池	港	吃
17	赤	洪	轰	交	红	64	门	疮	闯	野	窗
18	妙	家	甲	啥	佳	65	酥	翠	催	灯	脆
19	足	角	交	波	脚	66	麦	道	岛	闭	稻
20	洞	恐	空	甲	孔	67	桌	邓	灯	催	凳
21	匪	扣	门	雷	寇	68	高	滴	敌	贺	低
22	狱	劳	老	利	牢	69	西	冬	动	衣	东
23	倦	类	雷	押	累	70	静	洞	董	凡	动
24	内	礼	利	老	里	71	帆	惰	朵	癌	舵
25	售	麦	埋	牧	卖	72	粥	犯	凡	件	饭
26	丽	每	煤	畔	美	73	桶	钢	港	透	缸
27	妈	亩	牧	尺	母	74	切	歌	格	户	割
28	登	潘	畔	煤	攀	75	守	公	贡	桥	攻
29	友	蓬	碰	棋	朋	76	买	够	狗	使	购
30	穷	频	品	空	贫	77	坛	冠	管	猴	罐
31	扔	汽	棋	轰	弃	78	泉	禾	贺	限	河
32	币	前	签	师	钱	79	瓶	胡	户	死	壶
33	拿	曲	驱	温	取	80	快	及	积	首	急
34	总	泉	劝	游	全	81	加	检	件	树	减
35	鸟	确	缺	碰	雀	82	刀	建	肩	积	剑
36	宰	沙	啥	劝	杀	83	啼	窖	角	席	叫
37	赢	剩	声	缺	胜	84	巷	接	节	被	街
38	看	事	师	签	视	85	弟	解	结	躺	姐
39	败	叔	熟	驱	输	86	姑	救	酒	洗	舅
40	庙	饲	丝	挺	寺	87	新	救	九	库	旧
41	加	天	田	熟	添	88	散	剧	局	坦	聚
42	止	庭	挺	委	停	89	笑	枯	库	两	哭
43	孩	铜	统	声	童	90	橙	离	礼	局	梨
44	险	微	委	串	危	91	菜	梁	两	董	粮
45	乐	洗	细	汉	喜	92	鼓	螺	裸	牵	锣
46	偏	邪	谢	训	斜	93	菊	煤	妹	强	梅
47	转	玄	选	细	旋	94	深	遣	牵	彩	浅

Appendix B (*continued*)

No.	Semantic prime	Homophone prime	Semi-homophone	Control prime	Target	No.	Semantic prime	Homophone prime	Semi-homophone	Control prime	Target
95	炮	腔	强	妹	枪	110	尾	投	透	绍	头
96	击	悄	桥	酒	敲	111	肚	位	尾	通	胃
97	绿	倾	庆	闪	青	112	浓	西	洗	池	稀
98	春	丘	球	节	秋	113	粗	戏	席	角	细
99	恶	扇	闪	格	善	114	狠	兄	雄	裸	凶
100	煮	梢	绍	雄	烧	115	雾	淹	眼	结	烟
101	县	世	使	闯	市	116	猪	阳	央	直	羊
102	肥	受	首	动	瘦	117	根	夜	野	移	叶
103	猫	属	树	趁	鼠	118	叔	移	衣	填	姨
104	草	数	蔬	礼	树	119	难	益	移	阵	易
105	公	丝	死	尾	私	120	胜	营	硬	肩	赢
106	听	潭	坦	蔬	谈	121	前	厚	猴	硬	后
107	盐	堂	躺	岛	糖	122	线	真	阵	狗	针
108	苦	田	填	朵	甜	123	懂	支	直	央	知
109	异	童	通	竹	同	124	炒	主	竹	庆	煮

Note. The first 56 rows are stimuli used in the synonym group, and the rest are stimuli in the mixed group.

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