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Phonology, Orthography, and Semantic Activation in Reading Chinese

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Phonological and orthographic constraints on semantic activation in reading Chinese were investigated using a phonologically mediated semantic priming technique. In Experiment 1, we observed no significant mediated priming and homophone density effects for homophone mediated primes having no orthographic similarity with semantic primes. Such primes, when they contained regular phonetic radicals, did produce significant effects in Experiment 2. In Experiment 3, targets were facilitated to the same extent by mediated primes that were either orthographically similar and homophonic to or only orthographically similar to semantic primes. In Experiment 4, facilitatory effects equivalent to semantic priming were observed for orthographically similar homophone mediated primes containing regular and consistent phonetic radicals. We argue that access to semantics in reading Chinese is constrained by both phonology and orthography operating in interaction with each other, and that phonology has no inherently privileged role over orthography in constraining semantic activation.

Key Words: reading Chinese; semantic access; mediated priming; phonological mediation; orthographic constraints.

Access to lexical semantics is the fundamental process in reading. It is traditionally assumed that word meaning can be accessed in two ways. One is by direct visual access, where visual features in the input are projected onto underlying orthographic representations in the lexicon, whose activation is transformed directly into the activation of semantic properties. The other is by a phonologically mediated process, where orthographic activation leads to the activation of corresponding phonological representations which, in turn, activates semantic representations corresponding to the phonological form. Different theories of visual word recognition have placed different emphases on these two pathways to semantics, and history has witnessed a pendulum-like swing between the strong phonological view and the strong visual view of access to lexical semantics (see Frost, 1998; McCusker, Hillinger, & Bias, 1981, and Taft & van Graan, 1998, for reviews). Although dual-route theories (e.g., Besner & Smith, 1992; Carr & Pollatsek, 1985; Coltheart, 1978; Coltheart, Curtis, Atkins, & Haller, 1993; Seidenberg & McClelland, 1989; Plaut, McClelland, Seidenberg, & Patterson, 1996) differ in terms of the types of knowledge representations and processes involved, in the relative importance of the two processes in reading alphabetic words, and in the way phonological information is activated, they share the idea that both visual

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and phonological routes are used in accessing lexical semantics and that each route determines semantic activation at least some of the time (Jared & Seidenberg, 1991). Dual-route theories contrast with other theories, such as "resonance" theory (van Orden & Goldinger, 1994; van Orden, Pennington, & Stone, 1990; van Orden, Jansen op de Haar, & Bosman, 1997), which propose a predominant role for phonology in access to meaning. For these theories, the visual–phonological correlation is strengthened during learning and reaches coherence before visual–semantic correlation. The self-consistency between visual and phonological properties rapidly organizes the lexical processing system and dominates over less consistent, less efficient visual–semantics relations. Direct visual access to semantics either does not exist or plays only a minor role in semantic activation.

The role of phonology in access to lexical semantics, in association with other related issues concerning phonology in visual word recognition (see Frost, 1998; Seidenberg & McClelland, 1989; Taft & van Graan, 1998), has attracted much attention in recent research into nonalphabetic scripts, such as logographic Chinese. Although it has been demonstrated that phonological information is automatically activated in reading Chinese (e.g., Perfetti & Zhang, 1995; Zhou & Marslen-Wilson, 1999a), this phonological activation, by itself, seems to have no strong influence on semantic activation. With one or two exceptions, studies on the reading of Chinese or Japanese *kanji*, for skilled readers, have observed either no or weak independent effects of phonology on semantic activation (e.g., Chen, Cheung, & Flores d'Arcais, 1995; Leck, Weekes, & Chen, 1995; Sakuma, Sasanuma, Tatsumi, & Masaki, 1998; Wydell, Patterson, & Humphreys, 1993; Zhou & Marslen-Wilson,1998a; Zhou, Shu, Bi, & Shi, 1999; Zhou, Marslen-Wilson, Taft, & Shu, 1999; but see Tan & Perfetti, 1997), even though most of these studies used the same experimental techniques, such as semantic categorization (e.g., Jared & Seidenberg, 1991; van Orden, 1987; van Orden, Johnston, & Hale, 1988) and phonologically mediated semantic priming (e.g., Fleming, 1993; Lesch & Pollatsek, 1993; Lukatela & Turvey, 1991, 1994), that demonstrated robust phonological effects with English. The contrast between the functions of phonology in reading alphabetic and logographic scripts sharpens our understanding of the language-specific and universal mechanisms of lexical processing.

The purpose of the present research was to investigate further to what extent access to meaning in reading Chinese characters is constrained by phonological and orthographic information. We begin with a brief review of recent research on the role of phonology in semantic activation in reading Chinese.

PHONOLOGY AND SEMANTIC ACTIVATION: EXPERIMENTAL EVIDENCE

A number of studies have demonstrated that phonology is automatically activated in reading logographic Chinese even when the experimental tasks make no obvious use of this phonological activation (e.g., Perfetti & Zhang, 1995; Zhou & Marslen-Wilson, 1999a; but see Chen et al., 1995). What is more contentious is the extent to which this phonological activation, for skilled readers, constrains access to semantics. Although the question of whether phonology is automatically activated in initial lexical processing is closely related to the question of whether phonology mediates access to meaning, the two questions need to be carefully distinguished (Frost, 1998; Seidenberg & McClelland, 1989; Taft & van Graan, 1998; Zhou et al., 1999). Claims about mandatory phonological activation, for example, do not necessarily entail the further claim that access to meaning is predominantly phonologically mediated.

There have been a number of approaches to the investigation of the role of phonology in access to semantics. One indirect approach is to compare the relative time course of phonological and semantic activation in reading Chinese. If phonology plays a central role in constraining access to semantics, phonological information should become available earlier than semantic information. The activation of phonological information in reading Chinese should be very early and should precede the activation of semantic information. In several studies using either backward masking, synonym and homophone judgment, or primed naming techniques, Perfetti and his colleagues (Perfetti & Zhang, 1991, 1995; Perfetti & Tan, 1998; Tan, Hoosain, & Peng, 1995; Tan, Hoosain, & Siok, 1996) made precisely this claim. Typically, two sets of target words were used in these studies, one set preceded (or followed) by semantically related words and one set by phonologically related words. By varying stimulus onset asynchrony (SOA) between the first and second characters, these authors found that homophone priming (or interference) effects appeared earlier than semantic priming (or interference) effects. The results suggested that phonological activation in reading Chinese is not only automatic but also earlier than semantic activation. This earlier phonological activation could play a strong role in constraining semantic activation.

One problem with the above argument is that some of the supporting evidence has proved difficult to replicate, even with the same stimuli and similar experimental procedures. For example, Perfetti and Tan (1998) reported very large effects for semantic pairs and even larger effects for homophone pairs (often over 80 ms) in the primed naming task. In a direct replication of this study, however, Chen and Shu (1997) found significant but much smaller semantic priming effects and only weak phonological priming effects in primed naming, which is biased toward the use of phonological information. In a systematic study of the relative time course of phonological and semantic activation in reading Chinese, Zhou and Marslen-Wilson (1999a) used various tasks with two-character compound words and single-character words, including lexical decision, character decision, primed naming, and phonological and semantic judgment, and found no evidence that phonological effects appeared earlier than semantic effects. Indeed, semantic effects appeared earlier and/or had larger magnitudes than phonological effects in most tasks except primed naming. In a further study, Zhou and Marslen-Wilson (1998b) did observe larger phonological effects than semantic effects, but only for the primed naming task at a short SOA (57 ms) and only for characters containing homophonic phonetic radicals.

Another problem with comparing the relative time course of phonological and semantic effects is that these comparisons do not allow us to pinpoint the role of phonological activation in access to semantic activation. The issue of relative time course of phonological and semantic activation does not logically bear upon the issue of phonological constraints on semantic activation, even though these issues are related. If we assume "triangular" relations among orthography, phonology, and semantics (e.g., Perfetti & Tan, 1998; Seidenberg & McClelland, 1989; Zhou et al., 1999), it is difficult, in such paradigms, to decide whether semantic activation is mainly produced by direct computation from orthography or because of phonological mediation, and whether phonological activation is mainly produced by direct computation from orthography or because of semantic mediation (Zhou & Marslen-Wilson, 1999a).

More direct evidence comes from two lines of research using the semantic categorization task and the phonologically mediated semantic priming paradigm. In the semantic categorization task, participants are asked to decide whether a target item belongs to a prescribed semantic category (e.g., *flower*). The stimuli included words (e.g., *rows*) or nonwords (e.g., *roze*) homophonic to category exemplars (e.g., *rose*). The presence of a homophone or a pseudohomophone activates the phonological representation of the category exemplar. If phonology mediates access to meaning, the semantic representation of the category exemplar should be activated and hence delay the "no" response (but see Taft & van Graan, 1998 for an alternative account). This rationale has motivated several studies on English and robust interference effects have been observed for homophones and pseudohomophones (e.g., van Orden, 1987; van Orden et al., 1988; but see Coltheart, Patterson, & Leahy, 1994; Jared & Seidenberg, 1991; Taft & van Graan, 1998, for qualifications of the findings). Studies on Chinese characters and Japanese *kanji* using this technique have produced mixed but reconcilable data.

Leck et al. (1995) found that characters (e.g., 弧 hu[2], *curve;* or 呱 gua[1], *making noise*) sharing orthographic components with the exemplar characters (e.g., 狐 hu[2], *fox*) were more difficult to reject as exemplars of a semantic category (e.g., *animal*) than controls[1]. The magnitudes of the interference effects were essentially the same whether or not the critical characters were homophonic to the category exemplars. However, the latencies for rejecting homophonic characters (e.g., 湖 hu[2], *lake*) that had no orthographic similarity with the exemplar characters were not significantly different from the baseline unrelated condition. This absence of a significant independent phonological effect is consistent with Chen et al. (1995) who did not observe interference from homophone foils that were orthographically dissimilar to category exemplars. Wydell et al. (1993) investigated whether there was phonologically mediated access to meaning in Japanese kanji two-character compound words. The homophone foils were either orthographically similar to the category exemplars—sharing one character (i.e., one morpheme) with them—or orthographically dissimilar. While orthographically similar words, whether they were homophonic to category exemplars or not, were more difficult to reject than matched control words, the visually dissimilar homophones were no more difficult to reject than control words (see also Sakuma et al., 1998). However, the interference effect was larger for orthographically similar homophones than for orthographically similar nonhomophones, suggesting that phonology can influence semantic activation when it co-occurs with appropriate orthographic information.

The stronger effects of phonological factors in Wydell et al.'s (1993) study may reflect differences between Chinese and Japanese scripts, or it may reflect other differences between the studies. Leck et al. (1995) used semantic categories with many more members than Wydell et al. (1993), and this may have encouraged top-down effects in the Japanese study (cf. Jared & Seidenberg, 1991). In addition, Wydell et al. (1993) used compound words in which the homophones shared one morpheme with the category exemplars, while Leck et al. (1995) used single-character words. It is possible that the phonological and semantic activation of the compound exemplars in the presence of homophones was partially due to morphological processing of the shared morphemes in the homophones and category exemplars (see Sakuma et al., 1998; Zhou & Marslen-Wilson, 1998a; Zhou et al., 1999, for evidence).

Overall, these semantic categorization studies show a strong role for orthography in the semantic activation of Chinese or Japanese kanji and relatively weak effects of phonology. However, phonological information does interact with orthographic (and morphological) information in processes of semantic activation.

Another line of research uses phonologically mediated semantic priming techniques, in which semantic targets (e.g., *frog*) are preceded not only by their semantic associates (e.g., *toad*), but also by words (e.g., *towed*) or nonwords (e.g., *tode*) that are homophonic to the associates. If semantic representations are activated through phonological representations, facilitation should be observed not only between semantic primes and targets, but also between homophone and pseudohomophone primes and targets. When a prime is presented, whether it is a semantic prime or a homophonic or pseudohomophonic prime, the shared phonological representation is activated and used to access to lexical semantic representations corresponding to the phonological representation (but see Taft & van Graan, 1998). This activation of semantic representations spreads to other words, including the target word, which share semantic properties with one of the activated semantic representations. The target word is thus preactivated and responses to the subsequently presented target are facilitated.

This technique has been successfully used in studies investigating the role of phonology in reading alphabetic scripts (e.g., Fleming, 1993; Lesch & Pollatsek, 1993; Lukatela & Turvey,

[1] Throughout the paper, the pronunciations of Chinese characters are given in *Pinyin*, the Chinese alphabetic system. Numbers in brackets represent the lexical tones of syllables.

1991, 1994). Lukatela and Turvey (1994), for example, found that at brief SOA's, the naming of target words was facilitated to a similar extent by semantic primes and by homophone and pseudohomophone primes, which shared many orthographic properties with the semantic primes. The facilitatory effects for the latter primes disappeared when the SOA was longer than 250 ms. In contrast, words that were orthographically similar to but not homophonic with semantic primes did not show significant priming effects. The latter finding was taken as evidence that the priming effects for homophone and pseudohomophone mediated primes were mainly due to their homophony rather than orthographic similarity to semantic primes and that orthography by itself has no direct effects on semantic activation in reading alphabetic words.[2]

A study using the same technique on Chinese (Zhou et al., 1999), however, found no significant effects of mediated homophone or pseudohomophone priming. Zhou et al. (1999) used the phonologically mediated semantic priming technique on both Chinese two-character compound words and single-character words or morphemes. For compound words, a target (e.g., 卫生 wei[4] sheng[1], *hygiene*) was preceded either by its semantic associate (e.g., 洁净 jie[2] jing[4], *clean*), or by a word homophonic to this associate (e.g., 捷径 jie[2] jing[4], *shortcut*), or by an unrelated control word. Facilitatory priming effects were found for semantic primes in lexical decision and, to a lesser extent, in naming, but there were no significant effects for the mediated homophone primes in either task. Moreover, pseudohomophones (e.g., 安权 an[1] quan[2]) derived from compound words (e.g., 安全 an[1] quan[2], *safe*) had no significant effects on targets (e.g., 卫生 wei[1] xian[3], *dangerous*) which were semantically related to these base words. The absence of phonologically mediated semantic priming in compound words is consistent with the finding that, in lexical decision with short SOAs, there are in general no significant direct phonological priming effects between orthographically different homophonic compounds (e.g., 捷径 jie[2] jing[4], *shortcut*, and 洁净 jie[2] jing[4], *clean*) or compounds having homophonic morphemes (e.g., 滑翔 hua[2] xiang[2], *glide*, and 华贵 hua[2] gui[4], *luxurious*) (Zhou et al., 1999; Zhou & Marslen-Wilson, 1999a). It is also consistent with the pseudohomophone effects in lexical decision, in which pseudohomophones created by replacing only one constituent of compounds, but not pseudohomophones created by replacing both constituents of compound words with homophonic characters, are significantly more difficult to reject than control nonwords (Zhou & Marslen-Wilson, 1998a). Without the support of appropriate orthographic and morphological information, phonological activation by itself has little influence on the semantic activation of compounds.

When the phonologically mediated semantic priming technique was applied to single-character words or morphemes, Zhou et al. (1999) did not find significant priming effects for mediated homophone primes that were orthographically different from semantic primes. In one experiment, the authors varied the relative frequency of semantic primes and mediated primes. In another experiment, they varied the homophone density (i.e., the number of characters homophonic to semantic and mediated primes) of mediated primes. If semantic information is activated through phonological mediation, then competition between semantic representations corresponding to the same phonological form should be affected by the homophone density: the higher the homophone density, the stronger the competition between

[2] However, although orthography on its own may have no direct influence on access to semantics in reading alphabetic words, it may still play a significant role when it interacts with appropriate phonological information. Homophones used in mediated priming (e.g., Lesch & Pollatsek, 1993) or semantic categorization (e.g., van Orden, 1987) were mostly orthographically similar. The difficulty in finding orthographically different homophones in alphabetic scripts prevents us from examining effectively whether the homophone mediated priming effects are solely or predominantly due to phonological mediation. It is nevertheless possible to argue that, in normal reading, phonological mediation to semantics depends to a large extent on its interaction with appropriate orthographic information (see Coltheart et al., 1994).

homophone competitors and the weaker the semantic activation of semantic and homophone primes used in experiments. Both manipulations revealed no significant mediated priming effects at either the short (57 ms) or the long (200 ms) SOAs, although robust semantic priming was observed in the same experiments.

The absence of a significant phonologically mediated priming effect in Zhou et al. (1999), however, is contradicted by Tan and Perfetti (1997), who reported strong and long-lasting priming effects for mediated homophone primes with no orthographic similarity to the semantic primes. As in Zhou et al. (1999), Tan and Perfetti (1997) manipulated the homophone density of semantic and homophone primes, although their definition of density was slightly different. While Zhou et al. (1999) counted homophone neighbors over characters with exactly the same pronunciations, Tan and Perfetti (1997) counted homophone neighbors across characters with the same segmental templates that have either the same or different lexical tones. Characters from the low-density neighborhood in Zhou et al. (1999) may still have many neighboring and competing characters differing only in lexical tones. Tan and Perfetti (1997) found that at SOA's of 129 and 243 ms, target characters were named faster when they were preceded by either semantic or homophone mediated primes than by unrelated control primes. The priming effects for the mediated primes (and for semantic primes) varied according to homophone density, with primes from the smallest density neighborhood producing the biggest effect. These findings, if replicated, may suggest that phonology, after all, places the same strong constraints on semantic activation in reading Chinese as in reading alphabetic scripts.

In this paper, we began by trying to replicate Tan and Perfetti (1997) with their original stimuli. We then carried out three experiments that manipulated the orthographic similarity between mediated primes and semantic primes and the sublexical phonological regularity between mediated primes and their phonetic radicals. We also examined the time course of phonological and orthographic constraints on semantic activation.

TABLE 1

Experiment 1: Experimental Design and Sample Stimuli

	Semantic prime	Mediated prime	Control prime	Target
Low homophone density				
	阔	括	卡	宽
Pinyin	kuo(4)	kuo(4)	ka(3)	kuan(1)
Gloss	*broad*	*include*	*block*	*wide*
Frequency	401	218	179	406
Stroke	9.1	10	8.3	8.9
Medium homophone density				
	岁	碎	抗	年
Pinyin	sui(4)	sui(4)	kang(2)	nian(2)
Gloss	*year*	*smash*	*bridge*	*year*
Frequency	470	257	587	809
Stroke	8.1	7.9	7.7	8.3
High homophone density				
	叙	蓄	搁	谈
Pinyin	xu(4)	xu(4)	ge(1)	tan(2)
Gloss	*chat*	*save up*	*endure*	*talk*
Frequency	268	225	154	650
Stroke	8.1	9	9.7	8.4

EXPERIMENT 1

This experiment replicated Tan and Perfetti (1997) directly, with the same stimuli and experimental procedures. The SOA between primes and targets was set at the shortest interval (129 ms) used by Tan and Perfetti (1997). If homophone density plays a strong role in modulating phonological constraints on semantic activation, we should observe not only significant mediated priming effects, but also an interaction between mediated priming and homophone density.

Method

Materials and design. The design and sample stimuli are presented in Table 1. Target characters (e.g., 年 nian[2], *year*) were preceded by three types of primes: semantic primes (e.g., 岁 sui[4], *year*), which were mostly synonyms of the targets; homophones of the semantic primes (e.g., 碎 sui[4], *smash*), which acted as the phonologically mediated primes; and unrelated controls (e.g., 抗 kang[4], *resist*). The semantic and mediated primes, which were not orthographically similar, were differentiated into three categories according to their homophone density. Low homophone density was defined as semantic and homophone primes that had five or fewer other characters pronounced in the same way (but not necessarily with the same lexical tones). In other words, the homophone neighborhood had a density of five or fewer characters (i.e., $N \leq 5$). Medium homophone density was defined as $7 < N \leq 15$, and high homophone density had members of 20 or more ($N \geq 20$).

There were 15 quartets of primes and targets in each category. Control primes were not perfectly matched with mediated primes on frequency and visual complexity (in terms of the number of strokes per character), but we did not expect these discrepancies to have a systematic influence on the pattern of priming effects. As in Tan and Perfetti (1997), no filler items were used.

Targets and their primes were split, using a Latin square design, into three counterbalanced test versions. In each version, five targets of each density category were preceded by semantic primes, five by mediated primes, and five by control primes. The same targets appeared only once in a particular test version. A pseudorandom ordering was used to arrange the stimuli in each version, so that, across the test versions, the same target appeared in the same position in the testing sequence. The only difference between versions was that the primes for a particular target were different. In each version one third (15/45) of pairs of primes and targets were semantically related and one third were not related. Another third of the prime-target pairs were related via the homophony between semantic primes and the mediated primes.

A potential problem with the original stimuli was that some syllables (with the same or different tones) were used more than once in primes or targets. For example, the character 忙 (mang[2], *busy*) was used twice, once as a semantic prime and once as a target. Some targets or primes were pronounced in the same way (e.g., 赤 chi[4], *red;* 斥 chi[4], *scold*) or differed only in tones (e.g., 忧 you[1], *worry;* 邮 you[2], *mail*). This problem occurred for 12 syllables and 16 targets. To reduce the potential influence of the repetition on naming latencies, we split the characters with similar pronunciations into different versions or else ensured that there were several intervening items between them in a testing sequence.

Procedure. All stimuli for this and the following experiments were generated using a computer word processing program and captured as pictures on the screen by a snapshot program. Each character was excised and stored as an individual image file on a computer hard disk. Both primes and targets were created in 48-point *songti* font[3]. A character was about 2.4×1.6 cm in size and participants were seated about 60 cm from the screen.

Presentation of stimuli to participants and recording of reaction times was controlled by the experimental software DMASTR, which was made available to us by Ken and Jonathan Forster. As in Tan and Perfetti (1997), on each trial an eye fixation signal ("+") was first presented at the center of the screen for 1000 ms, followed by a prime which was presented for 129 ms. The target was presented immediately after the prime at the same location. It remained on the screen for 2 s or until participants responded to it, whichever was shorter. Naming latency was recorded from the onset of the target to the participant's vocalization, which trigged a voice key interfaced with a microphone and the computer. There was a 2-s interval between the disappearance of the target and the eye fixation signal for the next trial.

Before the formal test, each participant received 15 practice trials. As in Tan and Perfetti

[3] We did not use the 24-point font used by Tan & Perfetti (1997) because in our preliminary test our participants complained about the smallness of 24-point characters on the screen.

TABLE 2

Experiment 1: Mean Naming Latencies (ms) and Their Standard Deviations

	Semantic prime	Mediated prime	Control prime
Low density	559 (49)	580 (50)	570 (45)
Medium density	537 (45)	548 (47)	547 (53)
High density	567 (43)	572 (52)	582 (58)

(1997), primes here had no orthographic, phonological, or semantic similarities with their targets and the frequency of these characters were above 17 per million. Unlike Tan and Perfetti (1997), however, there were another five unrelated prime–target pairs that acted as dummy items before the critical tests.

Participants. Thirty-six participants were tested, 13 for test version 1, 11 for version 2, and 12 for version 3. All participants in this and the following experiments were undergraduate students at Beijing Normal University and were paid for their participation. They were native speakers of Mandarin Chinese.

Results

A total of 41 (2.5%) responses were excluded from analysis because of naming errors, the failure of the computer to register response times, or extraneous noise. Incorrect responses, stutters, and cases in which participants did not respond within 2 s of the presentation of targets were counted as naming errors. There were seven (1.3%) errors when targets were preceded by semantic primes, ten (1.9%) errors when they were preceded by mediated primes, and seven (1.3%) errors when they were preceded by control primes. Statistical analyses for error rates were not carried out in this and the following experiments because of the low error rates and many empty data points for items and participants. Mean naming latencies, based on correct responses and without trimming[4], were computed for participants and items and are reported in Table 2.

Analyses of variance (ANOVAs) were conducted for participants and items, respectively, with prime type and homophone density as between-participants factors. The main effect of homophone density was significant both by participants, $F1(2, 70) = 34.473$, $p < .001$, and by items, $F2(2, 42) = 4.354$, $p < .05$. Post hoc Newman–Keuls tests showed that the mean naming latency of targets in the medium density group (543 ms) was significantly shorter than the mean naming latencies of targets in the low (570 ms) and high (573 ms) density group. More importantly, the main effect of prime type was significant, $F1(2, 70) = 10.182$, $p < .001$, $F2(2, 84) = 4.351$, $p < .05$. Newman–Keuls tests showed that the mean naming latency for semantic primes (554 ms) was significantly faster ($p < .01$ by participants and $p < .05$ by items) than the latencies for mediated primes (567 ms) and control primes (566 ms), while the latter two did not differ from each other. The interaction between prime type and homophone density did not approach significance, $F1(4, 140) = 1.157$, $p > .1$, $F2(4, 84) = 1.168$, $p > .1$. Separate analyses involving only mediated and control primes confirmed that there was no overall priming effects for mediated primes, $F1 < 1$, $F2 < 1$, and no significant interaction between homophone density and prime type, $F1(2, 70) = 1.738$, $p > .1$; $F2(2, 42) = 2.349$, $p > .1$. Therefore, responses to target characters were significantly facilitated by their semantic associates but not by characters homophonic to these associates. Moreover, homophone density had no significant influence either on semantic priming effects or mediated priming effects.

Discussion

The pattern of priming effects in this experiment differed from that reported by Tan and Perfetti (1997), even though the same stimuli and experimental procedures were used. The differences between the two experiments were, first, the size of priming effects, and second, the influence of homophone density on the mediated priming. The overall semantic priming effect in this experiment (about 13 ms) was much

[4] Trimming data in different ways, such as replacing extreme responses, did not change the pattern of priming effects.

smaller than that (51 ms) in Tan and Perfetti (1997) in the comparable SOA condition[5].

More importantly, the present experiment, consistent with Zhou et al. (1999), did not find significant mediated priming effects for homophones that had no orthographic similarity with semantic primes. Tan and Perfetti (1997) reported that the size of mediated priming effects was affected by the homophone density of primes, with primes from larger homophone neighborhoods producing smaller priming effects. However, the data from the present replication indicated that, at least for the stimuli used, there are no significant facilitatory priming effects for the mediated homophone primes and no significant interaction between mediated priming and homophone density. The variation of the priming effects for the mediated primes in different homophone density groups, if anything, is in the opposite direction to what was reported by Tan and Perfetti (1997).

Why is there no mediated priming effect here? Does this mean that phonology plays no role in constraining semantic activation in reading Chinese? We suggest that access to semantics in reading Chinese is an interactive process in which both phonology and orthography can play significant roles. However, phonological effects on semantic activation are determined, to a large extent, by the computational efficiency of the links between orthography and phonology and between phonology and semantics. If phonological information is activated quickly, it may have more opportunity to influence semantic activation. This computational efficiency could be affected by a number of factors, such as reading skill, frequency, sublexical phonological regularity, and homophone density. Some of these factors may normally work against each other, reducing potential phonological effects of semantic activation. Although homophone density could influence phonological mediation on semantic activation, because of variations in the number of semantic representations corresponding to the same phonological form, other factors covarying with homophone density may cancel this potential density effect.

One factor that covaries with homophone density is cumulative syllable frequency, defined as the cumulative frequency of all homophonic characters or morphemes corresponding to a particular syllable. A higher cumulative syllable frequency usually means that there are more characters corresponding to this syllable and hence more competition between semantic representations corresponding to the syllable. On the other hand, a higher cumulative syllable frequency also means that the phonological activation, or the computation from orthography to phonology, should be faster. This in turn would increase the semantic activation of any characters corresponding to the phonological form. Thus, any homophone density effect is likely to be in conflict with cumulative syllable frequency effects. This may explain why we did not observe a homophone density effect in Zhou et al. (1999) and in Experiment 1, although it does not explain why Tan and Perfetti (1987) did find such an effect. Indeed, when we checked the cumulative frequencies for the mediated primes in this experiment, we found that their median frequencies were 309, 689, and 1473 per million, respectively, for the low, medium, and high homophone density groups. New experiments are needed which orthogonally vary homophone density and cumulative syllable frequency and examine their potential effects on semantic activation.

In the next experiment, however, we turned to another type of character for which phonology is computed very efficiently. These are complex (or compound) characters having homophonic sublexical phonetic radicals. If phonology plays a role in constraining semantic activation in reading Chinese, then phonological representations shared between such characters and semantic primes should be activated

[5] Tan and Perfetti (1997) did not pretest their stimuli for semantic relatedness. A few characters (e.g., 聊 liao[2]) represent more than one morpheme in Chinese, but Tan & Perfetti (1997) used their less frequent or obscure meanings. In our pretest for these stimuli, the semantic relatedness for some pairs (e.g., 聊 liao[2] and 少 shao[3]; 布 bu[4] and 段 duan[4]; 骄 jiao[1] and 烈 lie[4]; 犹 you[2] and 尚 shang[3]) fell below 4.0 on a 9-point scale (1 = unrelated and 9 = highly related). The average semantic relatedness for all pairs was 6.6, which was relatively low compared with the stimuli used in Experiments 2, 3, and 4.

efficiently by these characters, leading to significant mediated priming effects.

EXPERIMENT 2

Modern Chinese characters can be broadly differentiated into two categories (Li, 1993), simple and complex, both of which are composed of strokes and arranged in squares of similar size. Simple characters (e.g., 义 yi[4], *righteousness*) are about 5% of the total characters in Modern Chinese. They are holistic visual patterns that cannot be divided meaningfully into sublexical units. Complex characters (e.g., 议, yi[4], *discuss*) constitute about 95% of all modern Chinese characters and most (over 80%) are composed of semantic and phonetic radicals (Li, 1993; Yin & Rohsenhow, 1994). Semantic radicals may indicate the semantic category of morphemes corresponding to the complex characters. Phonetic radicals may point to the pronunciations of whole characters, i.e., encoding phonological information at the subcharacter level, even though the majority of phonetic radicals are meaningful characters on their own. However, due to the evolution of the writing system, both functions are not complete, with exceptions and irregularities littered across the writing system.

As far as the phonological relations between complex characters and their phonetic radicals are concerned, less than one third of the complex characters are "regular," in the sense that they have exactly the same pronunciations as their phonetic radicals (e.g., Fan, Gao, & Ao, 1984; Li & Kang, 1993). Another third are "irregular," with their pronunciations completely different from those of their phonetic radicals. About another one third of complex characters have either the same segmental templates (but different lexical tones, which are used to differentiate lexical items in Chinese) or the same segmental rhyming parts or the same initial consonants as their phonetic radicals.

Previous research on complex characters has demonstrated that the mapping between orthography and phonology is influenced by the phonological regularity of the relationship between complex characters and their phonetic radicals (e.g., Hue, 1992; Peng, Yang, & Chen, 1994; Seidenberg, 1985; Zhou & Marslen-Wilson, 1999b). At least for low-frequency characters, regular characters (e.g., 清 qing[1], *clear*), which contain phonetic radicals having the same pronunciation (e.g., 青 qing[1], *blue*), are named faster than matched simple characters, which in turn, are named faster than irregular characters (e.g., 猜 cai[1], *guess*), which contain phonetic radicals having different pronunciations. In a primed naming task, Zhou and Marslen-Wilson (1998b) also found that, at least at short SOA's (57 ms), the homophone priming between complex characters (e.g., 清 qing[1], *clear*) and their targets (e.g., 轻 qing[1], *light*) was influenced by whether the phonetic radicals embedded in complex primes had the same pronunciation as the whole characters. More priming occurred for regular complex primes than for irregular complex primes, even though participants were not required to respond to the primes. Other studies (Fang, Horng, & Tzeng, 1986; Hue, 1992; Peng, et al., 1994) have found effects of the "consistency" of phonetic radicals, where consistency was defined according to whether *all* complex characters having a particular phonetic radical are pronounced in the same way as the radical. Regular-consistent characters were named faster than regular-inconsistent characters. Such regularity and consistency effects suggest that, in reading complex characters, phonetic radicals are decomposed from whole characters and used to access phonological (and semantic and orthographic) representations of their own as well as other characters containing these radicals. These cooperative and competitive interactions between different characters influence the naming latency of the complex character.

In Experiment 2, regular complex characters (e.g., 滤 lü[4], *filter*) which were homophonic with but not orthographically similar to semantic primes (e.g., 绿 lü[4], *green*) were used as homophonic mediated primes. The phonological representations of these characters should be activated more efficiently than those of simple or irregular characters, due to support from the sublexical phonological processing of their phonetic radicals (e.g., 虑 lü[4], *consider*). If phonology plays a significant role in semantic

TABLE 3

Experiment 2: Experimental Design and Sample Stimuli

	Semantic prime	Semantic control	Mediated prime	Mediated control	Target
			Low frequency group		
	绿	摸	滤	搂	青
Pinyin	lü(4)	mo(1)	lü(4)	lou(3)	qing(1)
Gloss	*green*	*touch*	*filter*	*hug*	*blue*
Frequency	477	482	17	17	464
Stroke	9.4	9.2	11	11	8.7
			High frequency group		
	瞧	漫	桥	烧	看
Pinyin	qiao(2)	man(4)	qiao(2)	shao(1)	kan(4)
Gloss	*look*	*overflow*	*bridge*	*burn*	*see*
Frequency	222	238	437	430	637
Stroke	9.6	9.7	8.7	9	8.6

activation, the phonological activation of regular characters should be able to activate the semantic representations of any morpheme, including the semantic prime, with the same phonological representation. This semantic activation should facilitate the processing of targets (e.g., 青 qing[1], *blue*) which share semantic properties with the semantic primes.

The converging phonological activation from whole characters and from their phonetic radicals (and other characters containing these radicals) may have different time courses for high- and low-frequency regular complex characters. Activation of phonological representations may take longer for low-frequency characters than for high-frequency characters. Consequently, it may take longer for the low-frequency mediated primes to activate the semantic representations of semantic primes than for the high-frequency mediated primes. To track the potentially different time courses of semantic activation and mediated priming, this experiment manipulated the frequency of the complex mediated primes and the SOA between primes and targets.

Method

Materials and design. The design and sample stimuli are presented in Table 3. Two groups of phonologically mediated primes were used, one of low frequency and another of high frequency. Both groups were regular characters, with the embedded phonetic radicals having the same pronunciations as the whole characters. Mediated primes and their phonetic radicals were homophonic to the semantic primes and were not semantically related to the target characters. There were 40 low frequency (below 36 per million) and 28 high frequency (above 200 per million) mediated primes, each homophonic to a semantic prime. Because semantic and mediated primes had relatively large differences in frequency, separate control primes were used for them, matching on a number of properties, including orthographic structure, frequency, and visual complexity (in terms of strokes per character). Control primes had no semantic, phonological, or orthographic relation with the target characters.

Table 3 summarizes the main properties of primes and targets. All the mediated primes had a left–right structure, mostly (65 out of 68) with the semantic radical on the left and the phonetic radical on right. The frequencies of their phonetic radicals as independent characters were also checked. They were 530 and 810 per million, respectively, for the low and high frequency mediated primes. Most of the semantic and control primes had a left–right structure although simple and complex characters with other structures were also used. The sublexical phonological regularity of these primes was not controlled, since there was no reason why this should influence semantic priming. The semantic relatedness between semantic primes and their targets was checked by asking 15 participants to judge, using a 9-point scale (1 = unrelated and 9 = highly related), how clearly the semantic primes and targets were related in meaning. The average scores were 8.0 (ranging from 6.1 to 8.9) for both low and high frequency conditions. Semantic primes and targets could be synonyms, antonyms, category coordinates, and so on. Some of the semantic pairs, as in related studies on English (e.g., Lesch & Pollatsek, 1993; Lukatela & Turvey, 1994), were also associatively related. Such variations, however, should not have significant influence on priming effects in the primed naming task (see Neely, 1991; Zhou & Marslen-Wilson, 1999a).

Besides the critical stimuli, there were 100 pairs of unrelated characters with a variety of orthographic structures acting as fillers. None of these characters had the same pronunciations as the critical characters. There were also 25 pairs of practice items, of which 10 pairs were related as critical stimuli. Primes were presented for either 57 ms or 200 ms. Because of the way we presented primes and targets (see below), the prime duration was equivalent to the SOA between primes and targets. Two sets of participants were tested, respectively, for the two conditions of prime duration (or SOA).

A Latin square design was used to assign the critical primes and their targets to four counterbalanced test versions. In each version, there were 17 primes for each of the four prime types, 10 for the high-frequency condition and 7 for the low-frequency condition. The same filler prime–target pairs were used in the four test versions. A pseudorandom ordering was used to arrange the stimuli in each version, so that, across test versions, the same target appeared in the same position in the testing sequence. The only difference between versions was that the primes for a particular critical word target were different. In each version, about 20% (34/168) of prime–target pairs were related either directly or through homophony between mediated and semantic primes.

Procedure. All stimuli were generated in a similar way as for the stimuli of Experiment 1, except that different fonts (*kaiti* and *songti*) were used for the primes and targets. Targets were 2.4 × 1.6 cm, and primes were slightly smaller. The presentation of the stimuli to participants and the recording of reaction times were again controlled by DMASTR. On each trial, a fixation signal ("+") was first presented at the center of the screen for 300 ms, followed by a 300 ms blank interval. A prime was then presented for either 57 or 200 ms, depending on the SOA, followed immediately by the target, which was presented for 400 ms. The prime and target were presented in the center of the screen, with the target overwriting the prime. There was a 3-s interval between the disappearance of the last target and the appearance of the next eye fixation point.

Participants were tested individually in a quiet room. They were seated about 60 cm away from a computer screen and were asked to read out the second word of a trial into the microphone in front of them. The naming errors were recorded by hand by an experimenter on scoring sheets. Each participant saw first a list of 25 prime–target practice items. There was a break after practice and a break in the middle of the main test session. The first three item pairs after each break were always filler pairs. The complete test session for each participant was about 15 min.

Participants. A total of 84 participants were tested, 40 for the SOA of 57 ms and 44 for the SOA of 200 ms.

Results

One participant in the 200 ms SOA group had to be excluded from the analyses because the voice key failed to register over 10% of her responses. There were 1.1 and 3.8% missing data points, respectively, in the 57 and 200 ms SOA groups, either because of the failure of the voice key to register naming latencies, the triggering of the voice key by extraneous noise, or

TABLE 4

Experiment 2: Mean Naming Latencies (ms) and Their Standard Deviations

	Semantic prime	Semantic control	Mediated prime	Mediated control
SOA 57 ms				
Low frequency	570 (43)	580 (40)	582 (49)	584 (50)
High frequency	562 (47)	583 (65)	567 (49)	584 (52)
SOA 200 ms				
Low frequency	547 (39)	564 (54)	561 (41)	571 (51)
High frequency	549 (49)	572 (47)	558 (41)	562 (42)

because of participants' mispronunciations. Naming errors were not entered into statistical analyses but were categorized. There were a total of 54 (0.96%) naming errors in both SOA conditions. Mean naming latencies, based on correct responses and without trimming, were computed for each participant and each item, and the overall mean latencies for each condition are presented in Table 4.

Overall ANOVAs were first conducted for participants and items, with prime type (primed vs control), type of relation between primes and targets (semantic vs mediated), and frequency group (low vs high) as three within-participant factors and prime duration (SOA) as a between-participant factor. The main effect of prime type was highly significant both by participants, $F1(1, 81) = 48.85$, $p < .001$, and by items, $F2(1, 66) = 12.76$, $p < .001$, indicating that responses to targets were faster when they were preceded by related critical primes than by unrelated control primes. The main effect of relation type was also significant, $F1(1, 81) = 4.49$, $p < .05$, $F2(1, 66) = 6.04$, $p < .05$, indicating that responses to targets were faster when they were preceded by semantic primes and their control primes than by mediated primes and their control primes. More importantly, the interaction between prime type and relation type was significant by participants, $F1(1, 81) = 4.67$, $p < .05$, and marginally significant by items, $F2(1, 66) = 2.79$, $.05 < p < .1$, suggesting that the priming effects for semantic primes were larger than the priming effects for mediated primes, as assessed against their respective control primes. Detailed analyses of semantic and mediated priming effects were then warranted. No other main effects or interactions reached significance, although the main effect of prime duration was significant by items, $F2(1, 66) = 52.75$, $p < .001$, but not by participants, $F1(1, 81) = 2.292$, $p > .1$.

In the separate analyses of semantic and mediated priming, priming effects were collapsed across SOA and frequency group since there were no significant interactions of prime type or relation type with these two factors. The 17-ms overall semantic priming effect was significant, $F1(1, 83) = 37.26$, $p < .001$, $F2(1, 68) = 10.991$, $p < .005$. More importantly, the 8-ms overall mediated priming effects also reached significance, $F1(1, 83) = 9.08$, $p < .005$, $F2(1, 68) = 5.23$, $p < .05$, indicating that responses to targets were facilitated by regular characters homophonic to semantic primes.

Discussion

The pattern of priming effects for mediated primes here was different from Experiment 1 and from our earlier results (Zhou et al., 1999), which did not show significant priming effects for mediated primes. A crucial difference between this experiment and the previous experiments is that regular complex characters were used to increase the efficiency of phonological activation and to maximize its potential influence on semantic activation. The sublexical phonological processing of phonetic radicals embedded in the regular mediated primes supported the phonological activation of the whole character, and this phonological activation was able to influence the semantic activation of other characters, including semantic primes, corresponding to the phonological forms. In previous experiments, however, phonological activation for mediated primes was less efficient because these primes, in general, were not regular characters. For example, only three mediated primes in Experiment 1 and in Tan and Perfetti (1997) had phonetic radicals pronounced in the same way as the whole characters. There was not much support and possibly even competition from sublexical phonological processing. Phonological constraints on semantic activation may have been overshadowed by the more efficient constraints from orthography.

The results indicate that there is a complex relationship between phonological activation and semantic activation in reading Chinese. A simple overlap in the overall phonological form associated with a given character is clearly not sufficient to significantly activate the semantic properties associated with this form. This seems to rule out a straightforward phonological mediation story for Chinese. Nonetheless, at least for a minority of complex characters (the estimated 30% classified as regular), a small (8 ms) but reliable mediated priming effect is obtained. We interpret this effect in terms of an interactive model, where priming may spread from orthography to phonology to semantics under processing circumstances in which the orthography–phonology relationship is strong and rapidly computed, but where the primary route to semantics may be via a direct link from orthography and where phonology does not play an obligatory mediating role.

To develop this view further, we need to look more closely at the relationship between phonological and orthographic effects in mediated priming tasks, and the extent to which they are interdependent. This is the subject of the next two experiments. Experiment 3 examined the effects of orthographic similarity between a prime and a target both on its own and when the prime and target are also homophones. Previous research suggests strong effects of orthographic overlap, with homophone interference effects in semantic categorization being observed for characters or compound words sharing orthographic similarities with category exemplars, but not for homophones having no orthographic similarity with exemplars (e.g., Chen et al., 1995; Leck et al., 1995; Sakuma et al., 1998). However, the weakness with this evidence is that the orthographic contribution is inferred from the reduction of phonological effects in the absence of appropriate orthographic information. More direct evidence is needed, where orthographic information by itself supports semantic activation.

EXPERIMENT 3

We asked three questions in this experiment: (a) whether orthographic similarity between homophone mediated primes and semantic primes plays a role in determining the phonologically mediated semantic priming effect; (b) whether orthographic similarity by itself can produce significant mediated priming effects; and (c) whether there are significant differences between priming effects for orthographically similar homophone mediated primes and for orthographically similar nonhomophone mediated primes. Orthographic similarity was defined as left–right structured complex characters sharing their right parts (i.e., phonetic radicals). These radicals were mostly not homophonic to the whole characters containing them.

Characters (e.g., 杜 du[4], a family name) that were both homophonic with and orthographically similar to semantic primes (e.g., 肚 du[4], *belly*) were used as homophone mediated primes (see Table 5). Characters (e.g., 社 she[4], *society*) that were orthographically similar but not homophonic to semantic primes were used as orthographically mediated primes, in addition to unrelated control primes (e.g., 忧 you[1], *anxiety*). Given our assumption that orthography directly projects to semantics, we expect to find significant priming effects in naming semantic targets (e.g., 胃 wei[4], *stomach*) not only for the homophone mediated primes, but also for the orthographically mediated primes. Moreover, the contrast between homophone mediated primes and orthographically mediated primes will shed light on the relative contributions of phonology and orthography in access to semantics. The sublexical phonological regularity for the mediated homo-

TABLE 5

Experiment 3: Experimental Design and Sample Stimuli

	Semantic prime	Homophone mediated prime	Orthographically mediated prime	Control prime	Target
	肚	杜	社	依	胃
Pinyin	du(4)	du(4)	she(4)	yi(1)	wei(4)
Gloss	*belly*	*name*	*society*	*follow*	*stomach*
Frequency	174	126	331	132	376
Stroke	9.5	9.9	9.4	9.5	8.9

phonic and orthographic primes was not systematically varied since this would cause too much difficulty in selecting stimuli.

Method

Materials and design. The experimental design and the sample stimuli are presented in Table 5. Forty triplets of semantic, homophone mediated, and orthographically mediated primes (e.g., 肚 du[4], *stomach*, 杜 du[4], a family name, and 社 she[4], *society*) were selected. All of these characters were of left–right structure, with a semantic radical on the left and a phonetic radical on the right. A triplet of primes shared the same phonetic radicals (e.g., 土 tu[3], *soil*), most (35 out of 40) of which were pronounceable characters by themselves and had their own meanings. The other five triplets of primes shared the right parts which, due to historical reasons, were not characters by themselves (e.g., the right parts of 择 ze[2], *select;* 泽 ze[2], *pond;* and 译 yi[4], *translate*) and were hence unpronounceable. Among the 35 triplets of primes containing pronounceable phonetic radicals, 11 homophonic mediated primes (and the corresponding semantic primes) were regular characters, i.e., having exactly the same pronunciations as their phonetic radicals. Another 19 homophonic mediated primes (and semantic primes) had partial phonological overlap with their phonetic radicals, e.g., sharing the initial consonants or rhymes. The potential priming effects for these primes could be supported further by this sublexical phonological overlap with the whole characters.

For the mediated orthographic primes, five were homophonic to their phonetic radicals (but not to the semantic primes containing the same radicals). Another 13 had partial phonological overlap with their phonetic radicals. Although all the orthographic primes had different pronunciations from the semantic primes, 15 of them did share the initial consonants or rhymes with the semantic primes. The potential contribution to the priming effects of orthographic primes from the partial phonological overlap between orthographic and semantic primes and between orthographic primes and their phonetic radicals will be discussed later.

The mean frequencies of the primes are presented in Table 5. The higher mean frequency for orthographic mediated primes was mainly due to two orthographic primes having much higher frequencies than the rest. The visual complexity of primes was measured by the number of strokes per character, matched across prime types. Control primes were chosen to match the critical primes in terms of orthographic structure, frequency, and visual complexity. Target characters were of various different orthographic structures, with an average frequency of 376 per million and an average number of strokes of 8.9 per character. Targets shared no phonological or orthographic similarities with their primes or the sublexical parts of these primes. In a semantic relatedness judgment test in which 15 participants were asked to judge how clearly the semantic primes and targets were related in meaning, the average score was 7.7 in a 9-point scale (1 = unrelated and 9 = highly related).

Ninety pairs of unrelated characters were

TABLE 6

Experiment 3: Mean Naming Latencies (ms) and Their Standard Deviations

	Semantic prime	Homophone mediated prime	Orthographically mediated prime	Control prime
SOA 57 ms	595 (46)	569 (40)	577 (45)	582 (52)
SOA 100 ms	571 (45)	589 (53)	592 (63)	599 (58)
SOA 200 ms	547 (43)	560 (40)	561 (41)	564 (39)

used as fillers. None of these characters had the same pronunciation as the critical stimuli. There were also 25 pairs of practice items, of which 10 pairs were related in similar ways to critical stimuli. Primes were presented for 57, 100, or 200 ms, creating three SOA conditions. The prime duration (SOA) was treated as a between-participant factor.

A Latin square design was used to assign the critical primes and their targets to four counter-balanced test versions. In each version, there were 10 primes from each of the four priming conditions. The same filler prime–target pairs were used in the four test versions. A pseudo-random ordering was used to arrange the stimuli in each version, so that, across the test versions, the same target appeared in the same position in the testing sequence. In each version, about 23% (30/130) of the prime–target pairs were related either directly or through the phonological and/or orthographic similarity between mediated primes and semantic primes.

Procedure. The procedure was the same as in Experiment 2.

Participants. A total of 124 participants were tested, 40 each at SOA's of 57 and 100 ms, and 44 at the SOA of 200 ms. They had not been tested in the previous experiment.

Results

At the SOA of 57 ms, 57 (3.5%) data points were excluded from analysis due to participants' naming errors, extraneous noise, or the failure of the voice key to register participants' responses. Among these, 23 (1.4%) were naming errors, distributed equally among the four priming conditions. At the SOA of 100 ms, there were 40 (2.5%) missing data points, of which 16 were naming errors. At the SOA of 200 ms, there were 21 (1.3%) missing data points, of which 13 were naming errors. Mean naming latencies, based on correct responses and without trimming, were computed for each SOA and are reported in Table 6.

Overall ANOVAs with prime type as a within-participant factor and prime duration as a between-participant factor were conducted for participant and item means. The main effect of prime duration was significant, $F1(2, 121) = 4.280$, $p < .05$, $F2(2, 78) = 7.248$, $p < .01$, with faster naming latencies at SOA 200 ms. More importantly, the main effect of prime type was highly significant, $F1(3, 363) = 21.914$, $p < .001$, $F2(3, 117) = 12.987$, $p < .001$. Post hoc Newman–Keuls tests showed that the mean naming latency for semantic primes (562 ms) was significantly shorter ($p < .01$) than the latencies for homophone mediated primes (575 ms), orthographic primes (578 ms), and unrelated control primes (586 ms). Homophonic mediated primes were significantly faster than control primes ($p < .01$ by participants and $p < .05$ by items) but did not differ from the orthographic mediated primes ($p > .1$). Targets were also named significantly faster when they were preceded by orthographic primes than by control primes ($p < .05$ by participant and $.05 < p < .1$ by item). The interaction between prime type and prime duration did not reach significance, $F1(6, 363) = 1.089$, $p > .1$, $F2 < 1$, although it appeared that mediated and orthographic priming effects dropped off over SOA's.

Discussion

The results showed that the semantic properties of semantic primes were activated by mediated primes that were homophonic with and/or orthographically similar to them. The finding of a significant priming effect for the mediated orthographic primes, in contrast with the null effect in English (e.g., Lukatela & Turvey, 1994), is consistent with the view that in reading Chinese, orthography can directly influence semantic activation. The presence of an orthographic prime activates partially the semantic representations of any characters, including the semantic prime, sharing orthographic properties with the orthographic prime. This mediated activation of the semantic prime facilitates naming of a target sharing semantic properties with the prime.

The comparison between priming effects for orthographic mediated primes and for orthographically similar homophonic mediated primes also argues for a strong role of orthography in constraining semantic activation. The homophonic mediated primes did not show a significantly larger priming effect than the orthographic primes (11 vs 8 ms), while orthographic primes did show significant priming effect compared with unrelated controls. This finding is consistent with earlier semantic categorization studies of Chinese, where orthographically similar homophones did not differ significantly from orthographically similar nonhomophone foils, but where orthographically similar nonhomophone foils differed from controls (Leck et al., 1995; Sukuma et al., 1998). Although the priming effects for homophone mediated primes in this experiment may reflect both their homophony and their orthographic similarity to semantic primes, it is likely that orthographic similarity played the more important role, given that homophone mediated primes sharing no orthographic similarity with semantic primes and having no sublexical phonological support did not show strong priming effects (Experiment 1 and Zhou et al., 1999) and given that nonhomophonic orthographic primes did have a significant effect on naming targets.

Before moving on to Experiment 4, however, we need to consider an alternative account of the orthographic priming effects. This account, consistent with a strong phonological view of semantic activation, could argue that the significant effect for orthographic primes was due to decomposition and sublexical processing of phonetic radicals embedded in orthographic primes. Phonetic radicals (e.g., 土 tu(3), *soil*) would be decomposed from the orthographic primes (e.g., 社 she[4], *society*) and used to activate phonological representations of any characters containing these radicals, including the semantic primes (e.g., 肚 du[4], *stomach*). This phonological activation could lead to the semantic activation of the semantic primes, facilitating the processing of the subsequently presented targets (e.g., 胃 wei[4], *stomach*).

The problem with this alternative account is that the sublexical processing of phonetic radicals embedded in orthographic primes in this experiment could not strongly activate the phonological representations of the semantic primes. When orthographic primes (e.g., 社 she[4], *society*) were presented, the most highly activated phonological representations should be the ones corresponding to the primes themselves. These representations were, in general, not related to the representations of the phonetic radicals (e.g., 土 tu[3], *soil*) or to the representations of the semantic primes (e.g., 肚 du[4], *stomach*). The phonological representations of phonetic radicals were, in general, not strongly related to the representations of semantic primes either. In fact, if there was strong phonologically mediated semantic activation in this experiment, it should be the semantic representations corresponding to the phonological forms of the orthographic primes that were activated, not the semantic representations corresponding to the phonological forms of the semantic primes.

EXPERIMENT 4

Experiment 2 demonstrated that a significant phonologically mediated priming effect could be observed when phonological representations are highly activated due to the support of sublexical phonological processing. Experiment 3 demonstrated further that orthographic similarity between mediated and semantic primes contributes to the priming effect. In Experiment 4, we combine the manipulations of both sublexical phonological processing and orthographic similarity to maximize the chance of obtaining mediated semantic priming effects. If semantic activation is jointly constrained by the computation from orthography to meaning, the computation from orthography to phonology to meaning, and the interaction between these two processes, we should be able to observe a strong mediated priming effect in this combined manipulation.

A mediated prime in this experiment was a phonologically regular complex character (e.g., 钩 gou[1], *hook*) whose phonetic radical (e.g., 勾 gou[1], *tick*) was pronounced in the same way as the whole character. Moreover, most or all other characters having this phonetic radical (e.g., 构 gou[4], *construct;* 购 gou[4], *purchase*), including the semantic prime (e.g., 沟 gou[1], *trench*), were also pronounced in this way (ignoring tonal differences). In other words, the mediated primes were phonologically both regular and consistent in relation to their phonetic radicals. Previous research has found that, at least for low-frequency characters, regular-consistent characters were named faster than matched regular-inconsistent characters and irregular-inconsistent or simple characters (e.g., Hue, 1992; Peng et al., 1994), suggesting that phonological activation of the present mediated primes could be very efficient. This efficient phonological activation by itself should be able to activate strongly all semantic representations corresponding to the phonological form, as illustrated in Experiment 2. Moreover, the mediated primes (e.g., 钩 gou[1], *hook*) were also orthographically similar to the semantic primes (e.g., 沟 gou[1], *trench*). Given the findings of Experiment 3, this orthographic similarity should also allow the mediated primes to strongly influence the semantic activation of semantic primes (and target characters). Furthermore, mostly low-frequency mediated primes were used to slow down the computation from orthography to semantics for the whole characters and hence the semantic activation of these primes themselves. If semantic activation in reading Chinese is a multiple constraint–satisfaction process, we should observe stronger mediated priming than in any of the three earlier experiments.

TABLE 7

Experiment 4: Experimental Design and Sample Stimuli

	Semantic prime	Mediated prime	Control prime	Target
	沟	钩	绘	渠
Pinyin	gou(1)	gou(1)	hui(4)	qu(2)
Gloss	*trench*	*hook*	*paint*	*ditch*
Frequency	77	76	78	244
Stroke	11	11	11	9.3

Method

Materials and design. Table 7 presents the design and sample stimuli of the experiment. Twenty-four regular-consistent characters (e.g., 钩 gou[1], *hook*) were selected as mediated primes and 24 other characters (e.g., 沟 gou[1], *trench*) having the same phonetic radicals were chosen as semantic primes. Targets (e.g., 渠 qu[2], *ditch*) were semantically related to the semantic primes but not to the mediated primes. Among the 24 semantic prime–target pairs, eight shared semantic radicals, which may support semantic priming of targets (see Feldman & Siok, 1999 and Zhou & Marslen-Wilson, 1999b). Unrelated control primes were selected to match the semantic and mediated primes on orthographic structure, frequency, and visual complexity. Phonologically different orthographic primes were impossible to set up because, by definition, all characters having the same phonetic radicals as those in the mediated and semantic primes were pronounced in the same way as these primes. There is no other obvious and explicit way to define orthographic similarity between two (complex) characters.

All primes had a left–right structure, and the mean semantic relatedness between semantic primes and targets was 7.3 on a 9-point scale. Further details of the stimuli are given in Table 7.

Sixty pairs of unrelated characters were used as fillers. None of them had the same pronunciations as the critical items. The critical stimuli were split into three test versions in a counterbalanced way. Fillers were then added into each version and testing sequences were created in

TABLE 8

Experiment 4: Mean Naming Latencies (ms) and Their Standard Deviations

	Semantic prime	Mediated prime	Control prime
SOA 57 ms	579 (46)	584 (49)	600 (53)
SOA 200 ms	558 (41)	558 (38)	570 (44)

the same way as the previous experiments. Primes were presented for 57 or 200 ms, depending on the SOA between primes and targets.

Procedure. The equipment and procedure were the same as in Experiments 2 and 3.

Participants. A total of 63 participants took part in the experiment, 33 at the 57 ms SOA and 30 at the 200 ms SOA. They had not been tested in the previous experiments.

Results. One participant at the SOA of 57 ms had to be dropped because the voice key failed to register many (over 10%) of her responses. There were 4.8 and 4.4% missing data points, respectively, in the 57 and 200 ms SOA groups, because of the failure of the voice key to register naming latencies, the false trigger of the voice key by extraneous noise, or participants' mispronunciations. There were 19 (2.5%) naming errors in total. Mean naming latencies were computed for each participant and each item, and the mean latencies for each condition are presented in Table 8.

Overall ANOVAs were conducted for participants and items, with prime type as a within-participant factor and prime duration as a between-participant factor. There was a significant main effect of prime duration, $F1(2, 60) = 4.738$, $p < .05$, $F2(1, 23) = 36.649$, $p < .001$, indicating that the mean naming latencies were shorter at the SOA of 200 ms. More importantly, there was a significant main effect of prime type, $F1(2, 120) = 8.045$, $p < .001$; $F2(2, 46) = 5.651$. $p < .01$. Post hoc Newman–Keuls tests showed that the mean naming latencies for semantic primes (569 ms) and for mediated primes (571 ms) were significantly shorter ($p < .01$) than the latency for control primes (585 ms). However, the difference between semantic and mediated primes was not significant ($p > .1$), nor was there an interaction between prime type and SOA ($F1 < 1$, $F2 < 1$).

Discussion

The pattern of priming effects in this experiment is different from the previous three experiments here and from Zhou et al. (1999). In particular, equally strong facilitatory effects were found, at short and long SOA's, for both semantic and mediated primes. This strong effect for mediated primes is the evident consequence of combining orthographic similarity with the presence of phonologically regular and consistent phonetic radicals. In Experiments 2 and 3, where either orthographic similarity or regular phonetic radicals were present, but not both simultaneously, the homophonic mediated primes produced significantly smaller effects than the semantic primes. This outcome, as we will discuss below, is consistent with a complex, interactive model of the relations between orthography, phonology, and semantics, and inconsistent with a model where the primary route from orthography to semantics is phonologically mediated.

GENERAL DISCUSSION

The main purpose of the present research was to investigate the extent to which access to semantics in reading Chinese is constrained by phonological and orthographic activation. We used a phonologically mediated semantic priming technique in which targets were preceded not only by semantically related characters, but also by characters that were homophonic and/or orthographically similar to the semantic primes. The findings from the four sets of experiments can be summarized as follows. Experiment 1 failed to replicate Tan and Perfetti (1997), in which the mediated primes were homophonic to but orthographically different from semantic primes. No significant phonologically mediated priming effects on the processing of targets were found and homophone density by itself did not have a strong influence on mediated priming and semantic activation. Experiment 2 used complex characters containing regular phonetic radicals as mediated primes, which were also orthographically different from the semantic primes. Both high- and low-frequency regular mediated primes facilitated the processing of targets at short (57 ms) and long (200 ms) SOA's, although this phonologically mediated priming effect was significantly less than the direct semantic priming effect. Experiment 3 used homophonic characters that shared phonetic radicals with semantic primes as homophonic mediated primes and characters that shared phonetic radicals with semantic primes but were not homophonic to them as orthographic primes. Equal and significant facilitatory priming effects were observed for the two types of primes, although the effects were significantly smaller than the direct semantic priming effect. In Experiment 4, the mediated primes and semantic primes shared the same phonetic radicals, which were pronounced in the same way in all characters containing these radicals. At both the short and long SOA's, these phonologically and orthographically mediated primes facilitated the processing of targets to the same extent as the semantic primes.

These results allow us to draw two important and related conclusions. First, they help us specify the conditions under which phonological factors play a role in the mapping from the orthographic form of a Chinese character to its underlying semantic representation. Simple homophony between two characters or between two bisyllabic compounds (Zhou et al., 1999) is not sufficient on its own to generate significant phonologically mediated priming. Instead, in this research, we only saw significant effects for a minority of Chinese word-forms—the approximately 30% of the complex characters where the pronunciation of the whole form is the same as the pronunciation of the phonetic radical contained within the character. Effects as strong as those found for English—where mediated priming is statistically indistinguishable from direct semantic priming (e.g., Lukatela & Turvey, 1994)—were only found for a still smaller subset of the complex characters, where the relationship between the pronunciation of the whole character and of the phonetic radical is not only regular but also consistent and where the mediated prime and the semantic prime are orthographically similar.

The results suggest that phonologically mediated access for Chinese, where orthographic activation affects semantic representations via the intermediate activation of phonological representations, cannot be the predominant or default mechanism for linking orthographic form to lexical semantic representation. There is little doubt that phonology is activated early and obligatorily in reading Chinese characters (e.g., Perfetti & Zhang, 1995; Zhou & Marslen-Wilson, 1999a). It is also clear that under specific circumstances phonological factors can drive semantic activation for skilled readers. It is, however, much more plausible to view phonological and orthographic factors as functioning in an interactive framework to determine the mapping from character to lexical meaning. Orthographic factors play at least as strong a role, if not stronger, than purely phonological factors in access to semantics. Our second conclusion, therefore, is that access to semantics in reading Chinese is a multiple constraint–satisfaction process in which both orthographic and phonological activation and the interaction between them play important roles.

One source of evidence for interactive access to semantics is that it was the interaction between orthography and phonology that placed the strongest constraints on semantic activation in reading Chinese. Although the priming effects for homophonic mediated primes in Experiment 3 could be accounted for just by the orthographic similarity between mediated and semantic primes, the priming effects for the homophone mediated primes in Experiment 4, which were statistically equivalent to the direct semantic priming effects, cannot be reduced to orthographically mediated semantic priming. Given that the priming effects for orthographic and homophone mediated primes in Experiment 3 were significantly smaller than the direct semantic priming effects, the extra effects in Experiment 4 can be attributed to phonological mediation: the strong phonological activation of the homophone mediated primes, due to the support from the sublexical processing of regular and consistent phonetic radicals, interacted with orthographic activation and led to strong and long-lasting mediated priming effects. Indeed, sublexical processing of regular phonetic radicals was sufficient to make the orthographically different homophone mediated primes, which would normally exhibit no significant mediated priming (Experiment 1 and Zhou et al., in press), produce a significant phonologically mediated priming effect (Experiment 2).

Further evidence for the interaction between orthography and phonology in constraining semantic activation comes from other experiments on Chinese. Zhou and Marslen-Wilson (1998a) found that pseudohomophones that were created by replacing both constituents of compound words with homophonic characters were no more difficult to reject than control nonwords in lexical decision. However, pseudohomophones that were created by replacing only one constituent of compounds with homophonic characters were more difficult to reject than matched control nonwords. The pseudohomophone effect was also modulated by the character frequency of the constituents shared between pseudohomophones and base words. This result suggests that the phonological (and semantic activation) of base words by pseudohomophones depends crucially on the interaction between the phonological form of the whole word and the morphological processing (i.e., the orthographic, phonological, and semantic activation) of the common morphemes shared between pseudohomophones and base words. Similar patterns were also found in the semantic categorization task (e.g., Leck et al., 1997; Sakuma et al., 1998; Wydell et al., 1993) and in morphological priming between compound words (Zhou et al., 1995). Sakuma et al. (1998), for example, found a homophone interference effect for homophones sharing one character with category exemplars but not for homophones sharing no characters with exemplars. These data suggest that the semantic activation of base words was not simply mediated by phonological activation. It was the interaction between phonology and orthography (and morphology) that determined semantic activation.

Interactive processes in semantic activation also involve feedback from semantic activation to orthographic and phonological activation. Using a semantically mediated phonological priming technique, Zhou and Marslen-Wilson (1997) found that, in both English and Chinese, the presence of a semantic prime (e.g., *war*) not only facilitated the naming of its target (e.g., *peace*), but also the word homophonic to this target (e.g., *piece*) (see O'Seaghdha and Marin, 1997 for related findings). Moreover, the amount of priming varied according to whether homophone targets were also orthographically similar to semantic targets, with orthographically similar homophone targets producing larger effects. An inhibitory priming effect can also be found for Chinese characters that were orthographically similar to but phonologically different from the semantic targets. This pattern of priming effects suggested that the semantic activation of targets, due to the presence of semantic primes, spreads to the orthographic and phonological representations of these targets, which were shared in part by other words homophonic and/or orthographically similar to the targets.

UNIVERSALS OF LEXICAL PROCESSING ACROSS DIFFERENT ORTHOGRAPHIES

Having argued that orthographic and phonological information interact in access to semantics in reading Chinese and that orthography plays at least as strong a role as phonology in this process, we now turn to the comparison between orthographic and phonological activation in reading Chinese and in reading alphabetic scripts. We believe that, although the data from this study are somewhat different from those in English, where phonology is argued to play a predominant role in constraining semantic activation (e.g., Fleming, 1993; Lesch & Pollatsek, 1993; Lukatela & Turvey, 1994), they all point to the same underlying fundamental architecture (e.g., Seidenberg & McClelland, 1989; Plaut et al., 1996). The applications of the same underlying mechanisms to different orthographies may produce different patterns of data due to the influence of language-specific properties that determine the efficiency of the computational link between orthography, phonology, and semantics.

In Chinese, the relations between orthography and phonology are more arbitrary than in alphabetic scripts. Orthographically similar simple characters are mostly pronounced in different ways while orthographically different simple characters may have similar pronunciations. For complex characters, although about one third of them have the same pronunciations as their phonetic radicals, this is far from consistent. Moreover, orthographically different characters may have the same pronunciations while orthographically different characters may have similar pronunciations. There is little "feedback consistency" between phonology and orthography (Stone, Vanhoy, & van Orden, 1997; Ziegler, Motant, & Jacobs, 1997). Such arbitrariness makes the computation from orthography to phonology much less efficient in Chinese than in alphabetic scripts. The widespread homophony between characters also induces competition between semantic patterns corresponding to the same phonological form. These features make it less likely that visual–phonology correlations in Chinese take the primary role in organizing the lexical processing system (c.f., van Orden & Goldinger, 1994; van Orden et al., 1997).

The relations between orthography and semantics in Chinese are less arbitrary than in alphabetic scripts. This is because semantic radicals in complex characters may indicate the semantic category of the morphemes, even though this function has been obscured for many characters. Experimental studies suggested that the information provided by semantic radicals is used in the lexical processing of whole characters (e.g., Feldman & Siok, 1999; Zhou & Marslen-Wilson, 1999b).

In connectionist frameworks (e.g., Plaut et al., 1996), these mapping consistencies between orthography, phonology, and semantics lead to differences in how orthography and phonology participate in the interactive access to semantics in Chinese as opposed to other scripts. These differences should be viewed as complementary, rather than contradictory, to the argument for a predominant role of phonological mediation in reading English (e.g., Frost, 1998; Lesch & Pollatsek, 1993; Lukatela & Turvey, 1994; van Orden, 1987; van Orden et al., 1990; van Orden et al., 1997; van Orden & Goldinger, 1994). Indeed, one may argue that the contribution of orthographic information to phonological effects in various experiments (e.g., Lesch & Pollatsek, 1993; Lukatela & Turvey, 1994; van Orden, 1987) has not been properly appreciated (see Footnote 2) and that the direct route from orthography to semantics may play a significant role in reading alphabetic words as well (e.g., Coltheart et al., 1994; Jared & Seidenberg, 1991; Taft & van Graan, 1998). Access to semantics in reading both alphabetic and logographic scripts is an interactive process in which different types of knowledge, including orthographic information, come into play. The relatively regular relations and hence computational efficiency of the mapping between orthography and phonology lead to the strong role of phonology in constraining semantic activation in reading alphabetic scripts. In Chinese, in contrast, we believe that phonology has no inherently privileged role over orthography in constraining semantic activation.

APPENDIX

In Experiment 2, the first 40 rows of characters form the low frequency group while the rest form the high frequency group.

Experiment 2

	Semantic prime	Semantic control	Mediated prime	Mediated control	Target
1	倍 bei(4)	摸 mo(1)	狈 bei(4)	鸥 ou(1)	半 ban(4)
2	饼 bing(3)	敏 min(3)	柄 bing(3)	祥 xiang(2)	汤 tang(1)
3	长 chang(2)	回 hui(2)	偿 chang(2)	弥 mi(2)	短 duan(3)
4	巢 chao(2)	葵 kui(2)	嘲 chao(2)	嫩 nen(4)	窝 wo(1)
5	灯 deng(1)	权 quan(2)	蹬 deng(1)	佩 pei(4)	光 guang(1)
6	弟 di(4)	变 bian(4)	缔 di(4)	颈 jing(3)	姐 jie(3)
7	点 dian(3)	老 lao(3)	碘 dian(3)	琥 hu(3)	线 xian(4)
8	殿 dian(4)	颇 po(1)	惦 dian(4)	躯 qu(1)	宫 gong(1)
9	肚 du(4)	沟 gou(1)	镀 du(4)	陵 ling(2)	胃 wei(4)
10	断 duan(4)	胜 sheng(4)	缎 duan(4)	啼 ti(2)	裂 lie(4)
11	封 feng(1)	烟 yan(1)	枫 feng(1)	绚 xuan(4)	闭 bi(4)
12	高 gao(1)	两 liang(3)	糕 gao(1)	谦 qian(1)	低 di(1)
13	公 gong(1)	条 tiao(2)	躬 gong(1)	搂 lou(3)	私 si(1)
14	壶 hu(2)	昂 ang(2)	蝴 hu(2)	滔 tao(1)	瓶 ping(2)
15	汇 hui(4)	俗 su(2)	绘 hui(4)	邻 lin(2)	合 he(2)
16	建 jian(4)	政 zheng(4)	舰 jian(4)	辣 la(4)	筑 zhu(4)
17	懒 lan(3)	柳 liu(3)	缆 lan(3)	澎 peng(2)	勤 qin(2)
18	路 lu(4)	眼 yan(3)	碌 lu(4)	赔 pei(2)	道 dao(4)
19	绿 lü(4)	减 jian(3)	滤 lü(4)	嘹 liao(2)	青 qing(1)
20	明 ming(2)	听 ting(1)	铭 ming(2)	郎 lang(2)	暗 an(4)
21	奇 qi(2)	窗 chuang(1)	棋 qi(2)	饶 rao(2)	怪 guai(4)
22	深 shen(1)	晚 wan(3)	绅 shen(1)	泄 xie(4)	厚 hou(4)
23	失 shi(1)	虫 chong(2)	狮 shi(1)	诵 song(4)	丢 diu(1)
24	童 tong(2)	康 kang(1)	桐 tong(2)	俊 jun(4)	孩 hai(2)
25	西 xi(1)	百 bai(3)	熄 xi(1)	腮 sai(1)	东 dong(1)
26	兄 xiong(1)	尺 chi(3)	汹 xiong(1)	烤 kao(3)	哥 ge(1)
27	袖 xiu(4)	拔 ba(2)	绣 xiu(4)	潭 tan(2)	领 ling(3)
28	移 yi(2)	败 bai(4)	姨 yi(2)	描 miao(2)	动 dong(4)
29	纸 zhi(3)	跳 tiao(4)	址 zhi(3)	陌 mo(4)	笔 bi(3)
30	猪 zhu(1)	漫 man(4)	株 zhu(1)	碍 ai(4)	羊 yang(2)
31	煮 zhu(3)	惹 re(3)	拄 zhu(3)	帕 pa(4)	炒 chao(3)
32	难 nan(2)	特 te(4)	喃 nan(2)	锣 luo(2)	易 yi(4)

APPENDIX—*Continued*

	Semantic prime	Semantic control	Mediated prime	Mediated control	Target
33	飞 fei(1)	究 jiu(1)	绯 fei(1)	伦 lun(2)	跑 pao(3)
34	煤 mei(2)	吹 chui(1)	楣 mei(2)	镐 gao(3)	炭 tan(4)
35	秋 qiu(1)	耐 nai(4)	蚯 qiu(1)	蚪 dou(3)	春 chun(1)
36	步 bu(4)	或 huo(4)	怖 bu(4)	谱 pu(3)	走 zou(3)
37	琴 qin(2)	柔 rou(2)	擒 qin(2)	胯 kua(4)	音 yin(1)
38	聚 ju(4)	雷 lei(2)	俱 ju(4)	裙 qun(2)	散 san(4)
39	糖 tang(2)	揭 jie(1)	膛 tang(2)	缠 chan(2)	甜 tian(2)
40	真 zhen(1)	革 ge(2)	侦 zhen(1)	胖 pang(4)	假 jia(3)
41	裁 cai(2)	融 rong(2)	材 cai(2)	沙 sha(1)	缝 feng(2)
42	橙 cheng(2)	袒 tan(3)	城 cheng(2)	睡 shui(4)	梨 li(2)
43	蛋 dan(4)	宽 kuan(1)	但 dan(4)	如 ru(2)	卵 luan(3)
44	缸 gang(1)	赖 lai(4)	刚 gang(1)	验 yan(4)	盆 pen(2)
45	割 ge(1)	操 cao(1)	歌 ge(1)	射 she(4)	切 qie(1)
46	河 he(2)	强 qiang(2)	和 he(2)	到 dao(4)	山 shan(1)
47	击 ji(1)	包 bao(1)	机 ji(1)	理 li(3)	敲 qiao(1)
48	急 ji(2)	席 xi(2)	级 ji(2)	制 zhi(4)	快 kuai(4)
49	晶 jing(1)	奖 jiang(3)	惊 jing(1)	温 wen(1)	亮 liang(4)
50	瓶 ping(2)	款 kuan(3)	评 ping(2)	枪 qiang(1)	罐 guan(4)
51	弃 qi(4)	庆 qing(4)	汽 qi(4)	细 xi(4)	扔 reng(1)
52	瞧 qiao(2)	练 lian(4)	桥 qiao(2)	始 shi(3)	看 kan(4)
53	轻 qing(1)	确 que(4)	清 qing(1)	保 bao(3)	重 zhong(4)
54	囚 qiu(2)	闲 xian(2)	球 qiu(2)	脑 nao(3)	牢 lao(2)
55	室 shi(4)	念 nian(4)	试 shi(4)	摇 yao(2)	屋 wu(1)
56	诉 su(4)	推 tui(1)	速 su(4)	派 pai(4)	说 shuo(1)
57	尾 wei(3)	晨 chen(2)	伟 wei(3)	除 chu(2)	头 tou(2)
58	阳 yang(2)	般 ban(1)	洋 yang(2)	烧 shao(1)	阴 yin(1)
59	异 yi(4)	盾 dun(4)	议 yi(4)	阵 zhen(4)	同 tong(2)
60	游 you(2)	棉 mian(2)	油 you(2)	神 shen(2)	走 zou(3)
61	圆 yuan(2)	矛 mao(2)	源 yuan(2)	伤 shang(1)	方 fang(1)
62	知 zhi(1)	给 gei(3)	织 zhi(1)	拉 la(1)	懂 dong(3)
63	终 zhong(1)	维 wei(2)	钟 zhong(1)	选 xuan(3)	止 zhi(3)
64	医 yi(1)	首 shou(3)	依 yi(1)	挥 hui(1)	药 yao(4)
65	智 zhi(4)	歪 wai(1)	致 zhi(4)	侵 qin(1)	愚 yu(2)
66	侄 zhi(2)	诺 nuo(4)	值 zhi(2)	泥 ni(2)	叔 shu(1)
67	庭 ting(2)	狂 kuang(2)	停 ting(2)	冷 leng(3)	院 yuan(4)
68	劣 lie(4)	瓦 wa(3)	烈 lie(4)	熟 shu(2)	优 you(1)

APPENDIX—*Continued*

Experiment 3

	Semantic prime	Mediated prime	Orthographic prime	Control prime	Target
1	绸 chou(2)	稠 chou(2)	凋 diao(1)	泣 qi(4)	丝 si(1)
2	肚 du(4)	杜 du(4)	社 she(4)	驮 tuo(2)	胃 wei(4)
3	福 fu(2)	幅 fu(2)	逼 bi(1)	滑 hua(2)	灾 zai(1)
4	航 hang(2)	杭 hang(2)	抗 kang(4)	诊 zhen(3)	海 hai(3)
5	俭 jian(3)	检 jian(3)	脸 lian(3)	依 yi(1)	勤 qin(2)
6	洁 jie(2)	结 jie(2)	桔 ju(2)	线 xian(4)	脏 zang(1)
7	惊 jing(1)	鲸 jing(1)	凉 liang(2)	糟 zao(1)	吓 xia(4)
8	快 kuai(4)	块 kuai(4)	决 jue(2)	统 tong(3)	慢 man(4)
9	蜡 la(4)	腊 la(4)	惜 xi(1)	洼 wa(1)	烛 zhu(2)
10	桥 qiao(2)	侨 qiao(2)	骄 jiao(1)	琐 suo(3)	河 he(2)
11	愉 yu(2)	榆 yu(2)	偷 tou(1)	硕 shuo(4)	乐 le(4)
12	伴 ban(4)	拌 ban(4)	胖 pang(4)	赖 lai(4)	朋 peng(2)
13	伯 bo(2)	泊 bo(2)	怕 pa(4)	棉 mian(2)	叔 shu(1)
14	侧 ce(4)	测 ce(4)	铡 zha(2)	救 jiu(4)	旁 pang(2)
15	吵 chao(3)	炒 chao(3)	沙 sha(1)	躬 gong(1)	闹 nao(4)
16	锤 chui(2)	捶 chui(2)	唾 tuo(4)	拇 mu(3)	斧 fu(3)
17	盯 ding(1)	叮 ding(1)	灯 deng(1)	忧 you(1)	看 kan(4)
18	读 du(2)	犊 du(2)	续 xu(4)	涩 se(4)	念 nian(4)
19	根 gen(1)	跟 gen(1)	银 yin(2)	性 xing(4)	叶 ye(4)
20	红 hong(2)	虹 hong(2)	江 jiang(1)	呻 shen(1)	蓝 lan(2)
21	绞 jiao(3)	饺 jiao(3)	校 xiao(4)	柿 shi(4)	拧 ning(3)
22	俊 jun(4)	峻 jun(4)	酸 suan(1)	缕 lü(3)	美 mei(3)
23	铃 ling(2)	玲 ling(2)	冷 leng(3)	捏 nie(1)	哨 shao(4)
24	妹 mei(4)	昧 mei(4)	味 wei(4)	弥 mi(2)	弟 di(4)
25	晴 qing(2)	情 qing(2)	猜 cai(1)	知 zhi(1)	雨 yu(3)
26	驱 qu(1)	躯 qu(1)	呕 ou(3)	陋 lou(4)	赶 gan(3)
27	搜 sou(1)	馊 sou(1)	嫂 sao(3)	腕 wan(4)	寻 xun(2)
28	桃 tao(2)	逃 tao(2)	挑 tiao(1)	炉 lu(2)	梨 li(2)
29	蹄 ti(2)	啼 ti(2)	缔 di(4)	怯 qie(4)	爪 zhao(3)
30	铜 tong(2)	桐 tong(2)	洞 dong(4)	隙 xi(4)	金 jin(1)
31	途 tu(2)	涂 tu(2)	徐 xu(2)	肥 fei(2)	路 lu(4)
32	峡 xia(2)	狭 xia(2)	陕 shan(3)	彼 bi(3)	谷 gu(3)
33	详 xiang(2)	祥 xiang(2)	样 yang(4)	陌 mo(4)	略 lue(4)
34	烟 yan(1)	胭 yan(1)	姻 yin(1)	僧 seng(1)	雾 wu(4)

APPENDIX—*Continued*

	Semantic prime	Mediated prime	Orthographic prime	Control prime	Target
35	秧 yang(1)	殃 yang(1)	映 ying(4)	诵 song(4)	苗 miao(2)
36	椅 yi(3)	倚 yi(3)	骑 qi(2)	佩 pei(4)	凳 deng(4)
37	油 you(2)	铀 you(2)	袖 xiu(4)	惦 dian(4)	盐 yan(2)
38	择 ze(2)	泽 ze(2)	译 yi(4)	酥 su(1)	选 xuan(3)
39	住 zhu(4)	柱 zhu(4)	往 wang(3)	招 zhao(1)	居 ju(1)
40	阻 zu(3)	祖 zu(3)	姐 jie(4)	针 zhen(1)	拦 lan(2)

Experiment 4

	Semantic prime	Mediated prime	Control prime	Target
1	擂 lei(2)	镭 lei(2)	楣 mei(2)	敲 qiao(1)
2	谱 pu(3)	镨 pu(3)	碘 dian(3)	曲 qu(3)
3	韧 ren(4)	纫 ren(4)	缤 bin(1)	坚 jian(1)
4	停 ting(2)	婷 ting(2)	枫 feng(1)	止 zhi(3)
5	擒 qin(2)	噙 qin(2)	滤 lü(4)	捉 zhuo(1)
6	浓 nong(2)	脓 nong(2)	铭 ming(2)	稀 xi(1)
7	揽 lan(3)	缆 lan(3)	蚯 qiu(1)	抱 bao(4)
8	喂 wei(4)	偎 wei(4)	啡 fei(1)	饲 si(1)
9	猩 xing(1)	腥 xing(1)	糕 gao(1)	猴 hou(2)
10	像 xiang(4)	橡 xiang(4)	喃 nan(2)	画 hua(4)
11	沟 gou(1)	钩 gou(1)	熄 xi(1)	渠 qu(2)
12	唱 chang(4)	倡 chang(4)	侦 zhen(1)	舞 wu(3)
13	拦 lan(2)	栏 lan(2)	绘 hui(4)	阻 zu(3)
14	缎 duan(4)	锻 duan(4)	傲 ao(4)	布 bu(4)
15	糖 tang(2)	塘 tang(2)	眯 mi(1)	甜 tian(2)
16	钢 gang(1)	纲 gang(1)	抖 dou(3)	铁 tie(3)
17	嫁 jia(4)	稼 jia(4)	璃 li(3)	娶 qu(3)
18	杖 zhang(4)	仗 zhang(4)	胸 xiong(1)	棍 gun(4)
19	湖 hu(2)	糊 hu(2)	躲 duo(3)	江 jiang(1)
20	购 gou(4)	构 gou(4)	证 zheng(4)	买 mai(3)
21	唤 huan(4)	换 huan(4)	源 yuan(2)	叫 jiao(4)
22	授 shou(4)	绶 shou(4)	梆 bang(1)	教 jiao(1)
23	拭 shi(4)	试 shi(4)	汽 qi(4)	擦 ca(1)
24	锯 ju(4)	据 ju(4)	钟 zhong(1)	砍 kan(3)

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