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Morphology, Orthography, and Phonology in Reading Chinese Compound Words

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The interaction between morphological, orthographic, and phonological information in reading Chinese compound words was investigated in five sets of experiments, using both masked priming and visual-visual priming lexical decision tasks. Words sharing common morphemes were consistently found to facilitate each other, although the priming effects were modulated by spatial overlap of orthographic forms in masked priming. Priming effects were also found for words having homographic-homophonic characters, but the effect tended to be inhibitory when the SOA between primes and targets was long and when the competing morphemes corresponding to the characters were at the initial constituent position of primes and targets.

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Priming effects between words having homographic but non-homophonic characters were more inhibitory, compared with effects between words having homographic-homophonic characters. Words having orthographically different homophonic morphemes did not prime each other throughout the experiments. The results were discussed in terms of how lexical representations incorporate morphological structure and how morphological, orthographic, and phonological information interacts in constraining semantic activation of constituent

Further studies are needed to examine whether the arguments and the generic representation model proposed below for compound words can be applied to other types of polymorphemic words.

MORPHOLOGICAL AND PHONOLOGICAL PROCESSING IN CHINESE

In Mandarin Chinese, a morpheme usually corresponds to a syllable in spoken form and to a character in written form. Because the number of syllables used in the language is limited to about 1300 whereas the number of commonly used morphemes is over 5000, homophonic morphemes are the rule rather than the exception in the language.[1] However, such ambiguity rarely exists for written morphemes. With a few exceptions, each morpheme is written as a specific character, corresponding to a specific syllable. The homophonic morphemes, unlike their counterparts in English, may have no orthographic similarities at all. Occasionally, different morphemes may correspond to the same character, with the same or different pronunciations.

Morphemes used as constituents in compounds are usually words by themselves, although there are also bound morphemes in the language. There are also a few disyllabic monomorphemic words that are either descendants of Classic Chinese or loan words from other languages. The loan words follow the same phonotactic rules (e.g., having lexical tones) as other Chinese words and usually have fixed written forms. The phonological forms of compound words are usually the simple concatenations of the syllables corresponding to their constituent morphemes, although under certain circumstances the tone of one constituent can be altered due to the influence of the neighbouring tone. The orthographic forms of compound words or disyllabic, two-character monomorphemic words are always the concatenations of the orthographic forms (i.e., characters) of their constituents. In both orthographic and phonological forms, there are clear clues to the boundaries between constituents of Chinese two-character words.

The few previous studies on morphological processing in Chinese addressed the issue of how compound words are represented in the lexicon. Zhang and Peng (1992) found that both word and character (morpheme) frequencies affect lexical decision times to visually presented compounds. In auditory word recognition, Zhou and Marslen-Wilson

[1] Syllables with the same segmental elements but different tones are treated as different syllables. Tones are used to differentiate between lexical items. If tones are not counted, there are only about 400 syllables in Mandarin Chinese. The four tones are represented by numbers in parentheses in this paper.

(1994) observed similar word and morpheme frequency effects, together with a syllable frequency (i.e., cumulative frequency of homophonic morphemes) effect. These findings, however, led the authors to suggest different models of lexical representation. While Zhang and Peng (1992) maintained a decomposed lexical structure in which compound words are represented in terms of their constituent morphemes, Zhou and Marslen-Wilson (1994, 1995) proposed a multi-level representational model which distinguished a syllabic (phonological) layer, a morphemic layer, and a whole word layer. The morphological structure of compound words is represented or marked at all the levels, with constituent morphemes linking to whole word representations through excitatory connections, and homophonic morphemes linking to each other through inhibitory connections. A similar kind of structure was also suggested by Taft and Zhu (1995, 1997) to account for lexical processing in reading compound words.

In an auditory-auditory priming study, Zhou and Marslen-Wilson (1995) systematically manipulated morphological and phonological relations between primes and targets and the constituent positions of related morphemes in primes and targets. While consistent facilitatory priming effects were found for words sharing common morphemes, the priming effects between words having homophonic morphemes could be either inhibitory, facilitatory, or null, depending on the constituent positions of critical morphemes in primes and targets (see also Chen & Cutler, 1997). These positional priming effects between words having homophomic morphemes are difficult to explain in a lexical representation model with a single layer of morphemic representation. The multi-level morphological representation model, on the other hand, fits the data well. The complicated pattern of priming effects between words having homophonic morphemes was interpreted as the result of interactions between homophonic morphemes and between morpheme- and word-level representations in the time course of lexical activation.

However, the multi-level lexical representation model was not explicit about (a) what the nature of morphemic and whole word representations is and (b) whether it is necessary to arrange morpheme and word representations in a hierarchy. Zhou and Marslen-Wilson (1997) suggested that morpheme and whole-word representations in the multi-level representation model are semantic in nature. They are semantic representations corresponding to constituent morphemes and whole words. It follows that semantic representations for morphemes and whole words can be arranged at the same level, with phonological representations (i.e., syllables) connecting to both of them. It also follows that semantic representations of words and morphemes can be seen as composed of semantic features, with representations for words and representations for their constituent morphemes sharing some of their features, depending on semantic compositionality (transparency) of compound words (Zwitserlood, 1994).

The modified model can easily incorporate orthographic representations (Zhou & Marslen-Wilson, 1999c). It can be envisaged that there are orthographic representations for constituent morphemes that connect directly to their phonological and semantic representations, as well as to semantic representations of compound words containing these morphemes. Figure 1 illustrates prototypical orthographic (O), phonological (P), and semantic (S) representations and connections between them for a compound word (O1O2, such as *bathroom* or *butter y*). Both compound words and their constituents are represented at orthographic, phonological, and semantic levels. However, the representations for compound words are not independent from the representations for the constituent morphemes. At orthographic, phonological and semantic levels, the representations for compound words have much overlap with the representations for morphemes. In most cases, the orthographic and phonological representations of compound words are simply concatenations of the forms of their constituent morphemes. There are no separate representations at these levels for whole words. Similarly at the semantic

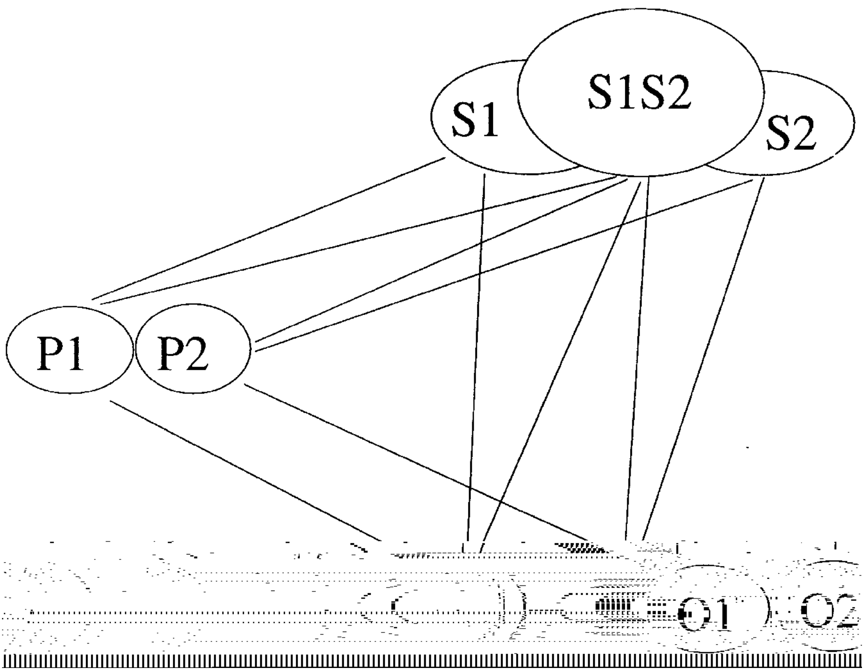

FIG. 1. A prototypical model of lexical representation of compound words.

level, compound words may share many semantic features with constituent morphemes. The degree of overlap reflects the semantic transparency of compound words. Representations at different levels are excitatorily connected, so that activation spreads bidirectionally between them.

Clearly, the schematic model illustrated in Fig. 1 assumes triangular relations between orthography, phonology, and semantics (Seidenberg & McClelland, 1989), where activation can spread either directly between two types of representations or indirectly via a third type of representation. In visual word recognition, access to semantics could be through direct links between orthographic and semantic representations and through activation of phonological representations. Moreover, this model assumes that the morphological structure of Chinese compound words is explicitly used to guide the mapping of visual input onto lexical representations. In projecting onto the lexicon, the visual input of a compound word is decomposed into smaller units, which activate orthographic (i.e., character) and phonological (i.e., syllable) representations of constituent morphemes, and semantic representations of both morphemes and the whole word. Morphological effects in lexical processing of compound words come from the interaction between form and meaning of constituent morphemes and the interaction between constituent morphemes and whole words. A more detailed discussion of this model and its possible implementation in connectionist framework can be found in Zhou and Marslen-Wilson (1999c).

The processing of constituent morphemes in reading compound words is related to the processing of single-character, monomorphemic words, which has been subject to a number of studies in recent years. These studies concentrate mainly on the role of phonology in visual word recognition. The critical questions addressed are whether phonology is mandatorily activated in visual word recognition and to what extent phonology constrains access to semantics. A majority of studies show that phonological information is automatically activated in reading single-character words, even when this activation is harmful to the completion of the experimental task required (Perfetti & Zhang, 1995; Zhou, 1997; Zhou & Marslen-Wilson, 1999, in press a; but see Chen et al., 1995). What is more contentious is the extent to which this phonological activation plays a role in constraining initial access to semantics.

There is a prominent view that phonological activation not only occurs very early in visual character recognition, but also plays a predominant role in constraining access to semantics (Perfetti & Zhang, 1991, 1995; Perfetti & Tan, 1998). To extend this argument to the processing of the compound word, access to the semantic representations of the constituent morphemes and of the whole word could be assumed to be mainly mediated by the phonological activation of constituent syllables (and information about the co-occurrence of these syllables, see Zhou & Marslen-Wilson, 1999a). Direct access from orthography to semantics could play at most a minor role. One problem with this strong phonological view, however, is that most of the supporting experimental evidence, which is mainly based on the comparison of the relative time course of phonological and semantic activation in reading characters, proves to be difficult to replicate (see, for example, Chen & Shu, 1997; Zhou & Marslen-Wilson, in press a, b).

Zhou and Marslen-Wilson (in press a, b) promoted an interactive view according to which access to semantics in reading Chinese is constrained by both orthography and phonology operating in interaction with each other. Both direct computation from orthography to semantics and mediation through phonological activation and the interaction between the two routes play roles in the multiple constraint-satisfaction process of accessing semantics in skilled reading. Based on evidence from studies using different experimental paradigms tapping directly into semantic activation, including semantic categorisation (Chen et al., 1995; Leck et al., 1995; Sakuma, Sasanuma, Tatsumi, & Masaki, 1998; Wydell, Patterson, & Humphreys, 1993), semantic judgment (Xu, Pollatsek, & Potter, 1999; Zhou, Pollatsek, & Marslen-Wilson, 1999), and phonologically mediated semantic priming (Zhou, 1997; Zhou & Marslen-Wilson, in press b), Zhou and his colleagues further argued that it is orthography, rather than phonology, that plays a relatively more important role in determining semantic activation in reading Chinese.

In this study, we investigated whether this interactive view applies to visual recognition of two-character, two-syllable compound words. We used masked and visual-visual priming lexical decision tasks and manipulated systematically the morphological, orthographic, and phonological relations between primes and targets. The stimulus onset asynchrony (SOA) between primes and targets was also manipulated to track the time course of orthographic and phonological activation and their constraints on semantic activation. Masked and visual-visual priming and the SOA between primes and targets were manipulated as a between-subject factor, with each sub-experiment for each SOA condition.

The lexical decision task was used to focus participants more on semantic processing than processing of orthographic or phonological forms of compound words. The notion of wordhood can be ambiguous for some Chinese compound words. Subjects in this study were explicitly instructed that real words were those used in the language and had relatively fixed meanings while non-words were those not used in the language and had no fixed or commonly accepted meanings. Because nonwords were composed of meaningful characters, both words and nonwords could activate orthographic and phonological forms and indeed morphemic meanings of their constituent morphemes. Although theoretically the activation of co-occurrence information between constituent orthographic forms or syllables could be used to discriminate real words from nonword, such information by itself does not seem to be used efficiently in lexical decision (see Zhou & Marslen-Wilson, 1999a). Consequently lexical decision to compound words is biased towards the use of semantic information of whole words.

EXPERIMENT 1

Experiment 1 and the following Experiments 2 and 3 were essentially the visual version of the auditory-auditory priming experiments reported in Zhou and Marslen-Wilson (1995). In the present experiments, primes and targets either shared a common morpheme, or had homophonic-homographic morphemes, or had orthographically different homophonic morphemes. The crucial questions for these experiments were, firstly, whether morphological relations between primes and targets influence the processing of target compound words; secondly, whether morphological effects on lexical processing can be separated from the influences of orthographic and phonological forms of constituent morphemes, and thirdly, how orthographic and phonological processing of constituent morphemes interacts with morphological processing and with access to semantics of compound words.

Table 1 presents the design and sample stimuli of Experiment 1. A target word (e.g., 华贵 hua[2] gui[4], *luxurious*) was preceded by four types of primes. The first was a morphological prime (e.g., 华丽 hua[2] li[4], *magni cent*) which shared the initial constituent morpheme with the target. The shared morpheme exhibited the same orthographic and phonological form in the two compounds. The second type was a character prime (e.g., 华侨 hua[2] qiao[2], *overseas Chinese*) whose initial morpheme had the same orthographic and phonological forms with the initial morpheme of the target. However, the same character represented two different morphemes, i.e., having different morphemic meanings, in the prime and target (e.g., 华 means "magnificent" in 华贵 hua[2] gui[4], *luxurious*, and "Chinese" in 华侨 hua[2] qiao[2], *overseas Chinese*). The

TABLE 1
Design and Sample Stimuli for Experiment 1

MORPH	*CHAR*	*HOM*	*CON*	*TARGET*
华丽 hua(2) li(4) *magni cent*	华侨 hua(2) qiao(2) *overseas Chinese*	滑翔 hua(2) xiang(2) *glide*	完整 wan(2) zheng(3) *intact*	华贵 hua(2) gui(4) *luxurious*

initial morpheme of the third type of prime (e.g., 滑翔 hua[2] xiang[2], *glide*) was homophonic to the initial morpheme of the target. These homophonic morphemes, however, had different orthographic forms and different morphemic meanings. Finally, the same target was also preceded by a morphologically, semantically, orthographically and phonologically unrelated compound word (e.g., 完整 wan[2] zheng[3], *intact*).

There were at least two reasons for predicting a facilitatory priming effect between words sharing initial morphemes. Firstly, repeated access to morphemes shared between primes and targets, i.e., their orthographic and phonological forms and morphemic meaning, should facilitate the form and semantic activation of the targets. Secondly, primes and targets as wholes were semantically related as well, in the same way as words sharing no common morphemes (e.g., 医生 yi[1] sheng[1], *doctor*; and 护士 hu[4] shi[4], *nurse*). For words having homographic and homophonic morphemes (e.g., 华侨 hua(2) qiao(2), *overseas Chinese* and 华贵 hua(2) gui(4), *luxurious*), one would normally predict an inhibitory effect between them in visual-visual priming. The visual input of the critical character in a prime should activate two different morphemic meanings, one corresponding to the morpheme in the prime and one corresponding to the morpheme in the target. There should be competition between the activation of these morphemic meanings, with the one used in the prime taking the upper hand. When the target is presented, the critical morphemic meaning used in the prime is initially activated further. It takes time for the morphemic meaning used in the target to overcome this competition and to activate semantics of the whole word (Laudanna, Bedecker, & Caramazza, 1989, 1992; Zhou & Marslen-Wilson, 1995). On the other hand, it was not clear what kind of effects we would expect for masked priming. Words sharing orthographic properties tend to facilitate each other in this paradigm (e.g., Shen & Forster, this issue), but competition between morphemic meanings would reduce this facilitatory effect.

The prediction for the priming effect between words having orthographically different homophonic morphemes (e.g., 滑翔 hua[2] xiang[2], *glide*; and 华贵 hua[2] gui[4], *luxurious*) depends crucially on whether phonological mediation is the predominant route for accessing semantics. If phonology plays a predominant role in lexical processing of Chinese, we should expect to find a facilitatory effect in processing the compound target. At least at a short SOA, the processing of the initial morpheme of the prime should activate the semantic representation of the initial homophonic morpheme of the target. Because constituent morphemes share many semantic properties with the whole compounds, this morphemic semantic activation should lead to a facilitatory effect in lexical decision to the target. On the other hand, if phonological activation by itself has limited effects on semantic activation (Zhou, 1997; Zhou &

Marslen-Wilson, in press a, b), pre-activating a constituent syllable of the target may have no significant influence on lexical processing of the target.

Method

Design and Materials

Forty compound words were selected as targets, completed with the four types of primes illustrated in Table 1. The four priming conditions were labelled respectively as MORPH (for morphological priming), CHAR (for character priming), HOM (for homophonic or phonological priming), and CON (for control priming). Reaction times to targets in the CON condition provided baselines for measuring priming effects in other conditions. MORPH primes were not only morphologically but also semantically related to the target words, as indicated in a semantic relatedness judgement pretest. The average semantic relatedness between these words was 6.4 on a 9-point scale, where 1 represented "completely unrelated" and 9 "highly related". CHAR, HOM and CON primes were not semantically related to the targets. The average frequencies were 22, 23, 19, 20 per million respectively for the four types of primes. The average frequency of targets was 47 per million.

In addition to the critical word design, a nonword design was also created. Not only did the lexical decision task require nonword foils, but also the nonword stimuli could be organised to act as the counterpart of the word design and to provide additional information concerning the extensiveness of morphemic or form priming and strategic contribution to priming effects. The nonword design here mirrored the word design. In the BASE condition, a nonword target (i.e., 掩该 yan[3] gai[1]) was preceded by its base word (e.g., 掩盖 yan[3] gai[4], *conceal*) from which the nonword was derived. The creation of nonword targets were carried out by replacing the second constituents of BASE primes with characters sharing segmental templates or rhyming parts with the base characters. In the MORPH condition, the same nonword target was preceded by a compound word sharing the initial morpheme with the BASE prime (e.g., 掩护 yan[3] hu[4], *cover*). In the HOM condition, the initial morpheme of the prime (e.g., 演变 yan[3] bian[4], *evolve*) was homophonic to, but orthographically different from the initial morpheme of the BASE prime and nonword target. Finally, the nonword target was also preceded by an unrelated word (e.g., 填补 tian[2] bu[3], *ll*). Note, nonword targets here and other nonword fillers were all composed of meaningful morphemes.

There were 40 nonword targets, each having the four types of primes. Fifty-four word-word pairs and 54 word-nonword pairs were also used as fillers in the experiment. The primes and targets in these pairs were neither semantically nor orthographically nor phonologically related. None of the syllables or characters in the filler primes and targets had been used in the critical primes and targets. Twenty prime-target practice pairs, which had the same compositions as formal test items, were also selected.

A Latin square design was used to assign critical primes and their targets to four counter-balanced test versions. In each version, there were ten primes from each of the four priming conditions for the critical word targets, and ten primes for each of the four priming conditions for the critical nonword targets. The same 108 filler prime-target pairs were used in the four test versions. A single pseudo-random order was used to arrange prime-target pairs, so that the same targets appeared at the same positions across the four test versions. The only difference between versions was that the primes for a particular critical word or nonword target were different. Not more than four consecutively presented targets were words or nonwords.

Procedure

All the stimuli were generated using a computer word processing program and captured as pictures on the screen by a snapshot program. Each word or nonword was excised and stored as an image file on a computer hard disk. Because primes and targets sometimes shared the same characters, they were created respectively in *kaiti* and *songti* fonts to avoid the abnormality of the shared characters being fixed on the computer screen in visual presentation. A target was about 3.4 × 5.4 cm in size and the prime was slightly smaller.

The presentation of stimuli to subjects and the recording of reaction times and response errors were controlled by the experimental software DMASTR, developed by Ken and Jonathan Forster. In visual-visual priming, an eye fixation signal ("+ ") was first presented at the centre of the screen for 300 ms, followed by a 300 ms blank interval. A prime was then presented either for 57 ms or for 200 ms, depending on the SOA, followed immediately by the corresponding target, which was presented for 400 ms. Both primes and targets were presented at the centre of the screen, with targets overwriting primes. In masked priming, a pattern mask, composed of lines and with a similar size to a compound word, were presented at the centre of screen for 300 ms, followed immediately by a prime, which was presented for 57 ms. The target was then presented for 400 ms. In this situation, subjects could not report the prime and most of them were not even aware of the presence of the prime. There was a 3-s interval between the disappearance of the last target and the appearance of the next eye fixation signal or the pattern mask.

Subjects were seated in a quiet room in groups of three or less, about 60 cm away from the screen. They were told to decide as quickly and as accurately as possible, by pressing "yes" and "no" buttons on the response boxes in front of them, whether each target was a real word or not. The dominant hand was used for the "yes" keys. Each subject saw first a list of 20 prime-target practice items. There was a break after practice and a break in the middle of the main test session. The first three pairs after each break were always fillers. The complete test session for each subject was less than 20 minutes.

Subjects

A total of 137 native speakers of Mandarin Chinese were tested, 52 in masked priming, 45 in visual-visual priming with SOA of 57 ms, and 40 in visual-visual priming with SOA of 200 ms. Each test version had roughly equal number of subjects. Subjects in masked priming and in visual-visual priming with SOA of 200 ms were either students or visiting scholars at universities in London while subjects in visual-visual priming with SOA of 57 ms were undergraduate students at Beijing Normal University. They all were paid for their participation.

Results

Three words in masked priming, four words in visual-visual priming with SOA of 57 ms, and two words in visual-visual priming with SOA of 200 ms were deleted from analyses because over 50% of responses to these items in one or more

TABLE 2
Mean Reaction Times (ms) and Error Percentages in Experiment 1

	MORPH	*CHAR*	*HOM*	*CON*
Masked	563 (5.1)	583 (9.1)	611 (10.1)	609 (8.1)
SOA 57 ms	575 (5.8)	595 (7.6)	628 (9.3)	618 (6.2)
SOA 200 ms	606 (3.7)	648 (7.1)	637 (6.8)	644 (7.1)

[$F_1(3,402) = 42.038$, $P < .001$, $F_2(3,105) = 16.63$, $P < .001$]. Post hoc Newman–Keuls tests showed that the mean reaction times for MORPH primes (580 ms) and CHAR primes (608 ms) were all significantly shorter ($P < .01$ or .05) than the times for HOM primes (625 ms) and CON primes (623 ms). Moreover, while the 28 ms difference between MORPH primes and CHAR primes was significant ($P < .01$), the 2 ms difference between HOM and CON primes was not ($P > .1$), indicating that words having orthographically different homophonic morphemes did not prime each other. The interaction between prime type and sub-experiment was

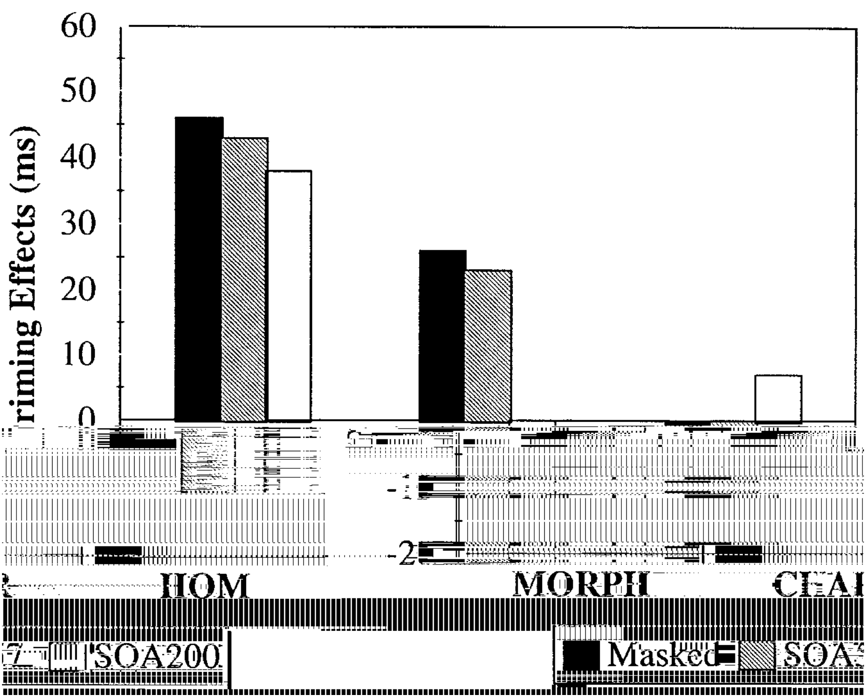

FIG. 2. Priming effects (ms) in Experiment 1.

significant by subjects [$F_1(6,402) = 2.99$, $P < .01$], and marginally significant by items [$F_1(6,210) = 2.08$, $.05 < P < .1$], suggesting that the patterns of priming effects were not uniform across sub-experiments. Figure 2 suggests that this interaction was mainly due to the change of priming direction of CHAR primes.

Detailed analyses of priming effects, as assessed against control priming conditions, were conducted respectively for MORPH, CHAR, and HOM primes. The main effect of morphological priming was highly significant [$F_1(1,134) = 80.73$, $P < .001$, $F_2(1,35) = 37.40$, $P < .001$]. This effect did not vary significantly across sub-experiments, as its interaction with sub-experiment was not significant [$F_1 < 1$, $F_2 < 1$]. The priming effect of CHAR primes was significant [$F_1(1,134) = 8.38$, $P < .01$, $F_2(1,35) = 4.29$, $P < .05$], and interacted with sub-experiment [$F_1(2,134) = 4.26$, $P < .05$, $F_2(2,70) = 2.52$, $.05 < P < .1$], indicating that CHAR primes did not produce the same pattern of priming effects across sub-experiments. In planned tests, the 26 ms facilitatory effect in masked priming was significant [$t_1(51) = 3.24$, $P < .01$, $t_2(35) = 3.46$, $P < .01$], as was the 23 ms effect in visual-visual priming with SOA of 57 ms [$t_1(44)$

1995). This effect can be interpreted as indicating that compound words are represented in the lexicon as individual morphemes and repeated access to the same morphemes induces the priming effect for target words. The model illustrated in Fig. 1, however, provides us with a more explicit way to account for the priming effect—in terms of activation of semantic (and form) properties of compound words and their constituent morphemes. In this semantic account, the activation of constituent orthographic representations of primes leads to the activation of semantic representations of both the whole words and the initial morphemes. The visual input of the initial characters of targets maps onto the same constituent orthographic and phonological representations, activating further the constituent semantic representations. Because semantic representations of target words share many properties with their constituent morphemes, the processing of target words is thus facilitated. Primes and targets could also share some semantic properties that were not shared with the critical constituent morphemes, and these shared properties contributed to the priming effect of MORPH primes as well.[3] We will try to tear apart the morphological priming effect from the "pure" semantic effect in later experiments.

The variation in priming effects between words having homographic-homophonic morphemes can also be accommodated by the semantic account of morphological priming. The activation of of HOM primes and targets were activated when the primes were presented.[4] However, this phonological activation by itself had little effect on the activation of morphemic semantic representations of the initial morphemes. The projection of visual input of the initial morphemes of targets onto the already activated morphemic phonological representations does not contribute much to the semantic activation of these initial morphemes and of the whole targets.

EXPERIMENT 2

Experiment 2 was essentially a replication of Experiment 1, but with the critical morphemes now at the second constituent position of both primes and targets. The purpose of this experiment was to collect converging evidence concerning morphological, orthographic and phonological processing of compound words. The empirical question was whether the pattern of priming effects in Experiment 1 was retained when the activation of critical morphemes in primes and target was more constrained by the processing of the initial morphemes of compound words.

In auditory-auditory priming, such a change of constituent position of critical morphemes in primes and targets resulted in different patterns of priming effects for words having homophonic morphemes (Chen & Cutler, 1997; Zhou & Marslen-Wilson, 1995)Ch between the first and second constituents. We therefore expect to observe a similar pattern of priming effects as in Experiment 1.

Method

Design and Materials

The experimental design was very similar to the one illustrated in Table 1, except that the critical morphemes were at the second constituent position. A target word (e.g., 简易 jian[3] yi[4], *simple*, *unsophisticated*, in which 易 means “easy”) was preceded either by a word sharing the second constituent morpheme (e.g., 轻易 qing[1] yi[4], *easily*, *rashly*), by a word having a homographic-homophonic second constituent (e.g., 贸易 mao[4] yi[4], *trade*, in which 易 means “exchange”), by a word having an orthographically different homophonic second constituent (e.g. 压抑 ya[1] yi[4], *inhibit*, *constrained*), or by an unrelated word (e.g., 诬陷 wu[1] xian[4], *frame a case against*). There were 40 quartets of primes, which were matched on word frequency, with means of 14, 19, 16, and 18 per million respectively. The mean frequency of target words was 40 per million with SOA of 57 ms, and 44 in visual-visual priming with SOA of 200 ms. They were native speakers of Mandarin Chinese and were paid for their participation. Each test version of each sub-experiment had roughly equal numbers of subjects.

Results

In each sub-experiment, one target was deleted from the analyses because over half of subjects in one or more test versions made incorrect responses. One subject in masked priming was also excluded due to his high response error rate (over 30%). The mean reaction times and error percentages are reported in Table 3. Figure 3 also reports the priming effects for MORPH, CHAR and HOM primes, as assessed against their control primes.

Overall analyses were conducted, with prime type as a within-subject factor and sub-experiment as a between-subject factor. The main effect of prime type was highly significant [$F_1(3,426) = 62.81$, $P < .001$, $F_2(3,114) = 15.77$, $P < .001$]

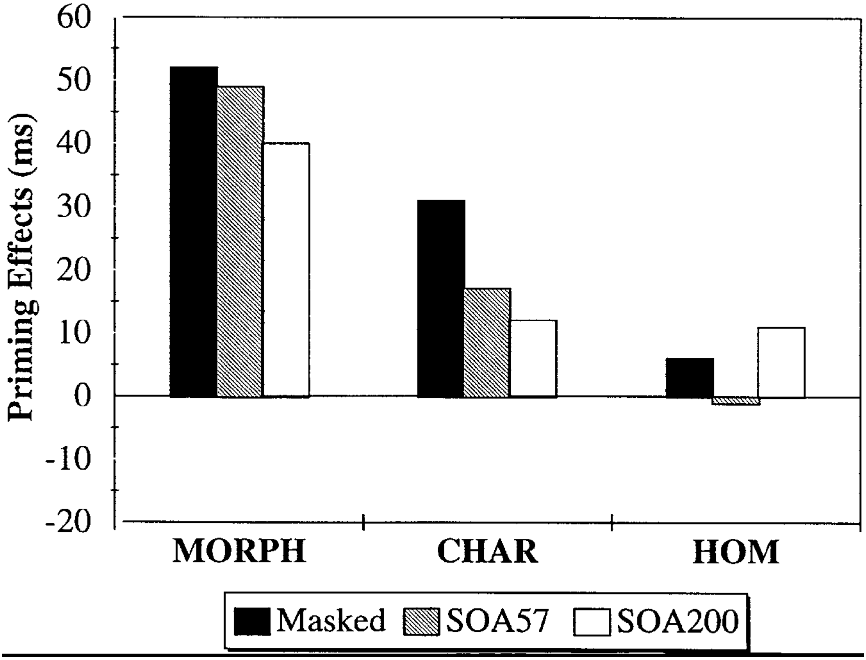

FIG. 3. Priming effects (ms) in Experiment 2.

was observed for CHAR primes. Here the priming effect was significant [$F_1(1,142) = 27.07$, $P < .001$, $F_2(1,38) = 4.30$, $P < .05$], but the interaction between priming effect and sub-experiment was not [$F_1(2,142) = 2.05$, $P > .1$, $F_2(2,76) = 1.21$, $P < .1$]. No significant priming effect was found for HOM primes [$F_1(1,142) = 2.82$, $.05 < P < .1$, $F_2 < 1$], nor any interaction with sub-experiment ($F_1 < 1$, $F_2 < 2$).

In the analyses of error rates, the main effect of prime type was significant [$F_1(3,426) = 7.463$, $P < .001$, $F_2(3,114) = 4.99$, $P < .01$]. Post hoc tests showed this effect was mainly due to the significant differences between MOR condition (2.5%) and other conditions (5.3% for CHAR, 5.1% for HOM, and 6.2% for CON). The differences between the latter three conditions were not significant ($P > .1$). The main effect of prime type did not interact with sub-experiment ($F_1 < 1$, $F_2 < 1$).

Discussion

Clearly, the pattern of priming effects was very similar to the one in Experiment 1. In both masked priming and visual-visual priming, words sharing common morphemes facilitated each other. Words having homographic-homophonic morphemes also facilitated each other, although this effect was slightly reduced as subjects had more time to process the CHAR primes. On the other hand, although words having orthographically different homophonic morphemes tended to facilitate each other in masked priming and in visual visual priming with the longer SOA, this effect was not significant.

The strong priming effect between words having common morphemes is consistent with the assumption that in reading Chinese compound words, the semantic representations of both whole words and their constituent morphemes are activated through constituent orthographic representations. The priming effect for CHAR primes suggests that both morphemic semantic representations corresponding to the critical characters were activated when the primes were presented. The absence of significant priming effects for words having orthographically different homophonic morphemes is consistent with the argument that phonology of constituent morphemes/syllables has little effects on semantic activation of compound words.

EXPERIMENT 3

In Experiments 1 and 2, critical morphemes in primes and targets were at the same constituent positions. One consequence of this was that the critical morphemes had the same spatial positions in the presentation of primes and targets.[5] In Experiment 3, we put the critical morphemes in primes and targets at differenth preceded by four types of primes: a MORPH prime (e.g., 宽容 kuan[1] and rong[2], *lenient*) which shared a common morpheme with the target; a CHAR prime (e.g., 笑容 xiao[4] rong[2], *smiling expression*, in which 容 means "appearance") which had a homographic-homophonic character with the target; a HOM prime (e.g., 繁荣 fan[2] rong[2]) whose second constituent was homophonic to, but orthographically different from the initial morpheme of the target; and an unrelated control prime. MORPH primes and targets were also semantically related, with an average point of 6.2 in the 9-point scale. The four types of primes were matched on frequence, with means of 14, 16, 14, and 16 per million respectively. The average frequency of targets was 30 per million.

As Experiments 1 and 2, there was also a nonword design, mirroring the word design. Nonword targets were preceded by BASE, MORPH, CHAR and CONT primes. Additional 55 word-word pairs and 55 word-nonword pairs were selected for use as fillers. Primes and targets here were neither orthographically, nor phonologically, nor semantically related. The creation of four test versions, preparation of stimuli, and test of subjects were conducted in the same way as Experiments 1 and 2.

Subjects

A total of 136 undergraduate students at Beijing Normal University were tested, 41 for masked priming, 55 for visual-visual priming with SOA of 57 ms, and 40 for visual-visual priming with SOA of 200 ms. They were native speakers of Mandarin Chinese and were not tested for Experiments 1 and 2.

Results

Three targets in masked priming, three in visual-visual priming with SOA of 57 ms, and two in visual-visual priming with SOA of 200 ms were deleted from the analyses because of excess error rates (over 50%) in one or more test versions. Mean reaction times and response error rates are reported in Table 4. Priming effects for MORPH, CHAR, and HOM primes, as assessed against control primes, are also plotted in Fig. 4.

In the overall analyses of reaction times, the main effect of prime type was highly significant [$F_1(3,399) = 42.387$, $P < .001$, $F_2(3,108) = 27.54$, $P < .001$]. Post hoc Newman-Keuls tests found that the mean reaction time for MORPH primes (569 ms) was significantly shorter than the times for CHAR, HOM, and CON primes ($P < .01$). Responses for CHAR primes (594 ms) was also significantly faster than responses for HOM primes (616 ms) and CON primes (612 ms),

TABLE 4
Mean Reaction Times (ms) and Error Percentages in Experiment 3

	MORPH	*CHAR*	*HOM*	*CON*
Masked	593 (2.2)	600 (5.8)	615 (9.5)	621 (8.0)
SOA 57 ms	564 (5.0)	596 (8.4)	623 (11.2)	614 (10.5)
SOA 200 ms	552 (2.1)	587 (7.9)	612 (7.6)	603 (5.8)

subjects [$F_1(6,399) = 2.283$, $P < .05$], and by items [$F_2(6,216) = 2.32$, $P < .05$].

Separate analyses were conducted for priming effects for MORPH, CHAR, and HOM primes across sub-experiments. For MORPH primes, the main prime effect was highly significant [$F_1(1,133) = 91.54$, $P > .001$, $F_2(1,36) = 50.71$, $P < .001$]. The interaction between priming effect and sub-experiment was marginally significant [$F_1(2,133) = 2.43$, $.05 < P < .1$, $F_2(2,72) = 2.54$, $.05 < P < .1$], indicating that the MORPH priming effect

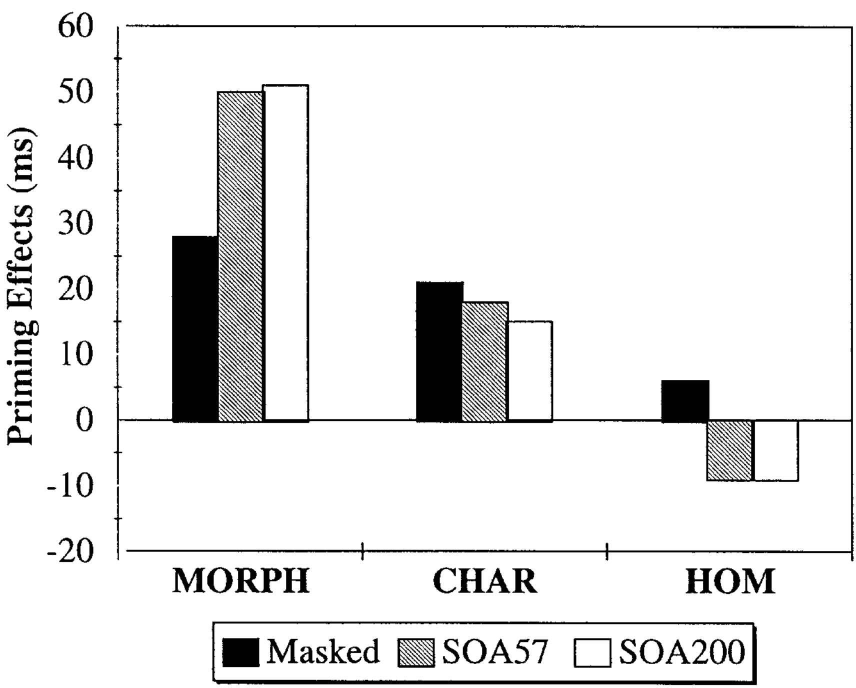

FIG. 4. Priming effects (ms) in Experiment 3.

was smaller in masked priming than in visual-visual priming (see Fig. 4). For CHAR primes, the priming effect was significant [$F_1(1,133) = 15.23$, $P < .001$, $F_2(1,36) = 9.07$, $P < .001$], but not the interaction between priming effect and sub-experiment ($F_1 < 1$, $F_2 < 1$). No significant priming effect was found for HOM primes ($F_1 < 1$, $F_2 < 1$). The interaction between this effect and sub-experiment was not significant either, [$F_1(2,133) = 1.04$, $P > .1$, $F_2(2, 72) = 1.30$, $P > .1$].

The analyses of error rates found a significant main effect of prime type [$F_1(3,399) = 13.90$, $P < .001$, $F_2(3,108) = 3.08$, $P < .05$]. Post hoc tests showed that this effect was mainly due to the differences between MORPH primes and the other three types of primes ($P < .01$ or .05). There were no significant differences between the later three types of primes ($P > .1$). The interaction between prime type and sub-experiment was significant by items [$F_2(6,216) = 2.99$, $P < .01$], but not by subjects ($F_1 < 1$).

Discussion

The pattern of priming effects was similar to the ones in Experiments 1 and 2, although the MORPH priming effect was reduced in masked priming. This reduction indicates that the priming effects between words sharing morphemes were not simply due to repeated access to morphemic semantic representations through character forms and the consequent semantic activation of whole words. This semantic activation is also influenced significantly by the orthographic relationship between critical morphemes in masked priming. Although the importance of orthographic form is masked priming has long been recognised (Forster & Davis, 1991; Forster, Davis, Schoknecht, & Carter, 1987), this experiment suggests that the spatial overlap of orthographic forms also plays an important role in determining morphological priming. Significant priming effects for CHAR primes throughout the three sub-experiments indicated that, even though the processing of the initial morphemes of the primes serves as a strong contextual constraint on the semantic activation of the second constituent, this does not seem to suppress the alternative semantic activation of the critical morphemes in the targets (Zhou & Marslen-Wilson, 1995). The non-significant priming effects for HOM primes demonstrated again the weakness of "pure" phonology in constraining semantic activation.

EXPERIMENT 4

The pattern of priming effects between words having homographic-homophonic characters in Experiments 1, 2, and 3 suggested parallel access to semantic representations of homophonic morphemes through common orthographic forms. The semantic representations of alternative morphemes may compete with each other in the time course of activation. It follows that if a character corresponding to a morpheme in the prime does not have a corresponding competitive morpheme in the target, there should be no competition between alternative morphemic semantic representations. Consequently processing of the target should not be hampered by morphemic competition, even though it contains the critical character used by the prime. The priming effect for the CHAR prime should therefore be larger than what was found in the previous experiments.

One way to have characters representing no competing morphemes in targets is to use two-character monomorphemic words (e.g., 沙发 sha[1] fa[1], *sofa*). In such words, characters are used mainly for the purpose of representing the sound of the word, even though syllables in these words use only specific characters (from sets of homophones). On the other hand, most of the characters used in monomorphemic words are also used as morphemes in isolation and in compound words (e.g. 沙 sha[1], means "sand" and 发 fa[1] means "hair" or "develop" in isolation). These monomorphemic words can therefore be taken as semantically opaque compound words. If similar patterns of priming effects are obtained for such monomorphemic words as for compound words in previous experiments, it could be argued that semantically transparent and opaque compound words are represented in essentially the same way in the lexicon.

Another purpose of Experiment 4 was to investigate further the role of phonology in processing compound words. Although "pure" phonological overlap between homophonic morphemes having no orthographic similarity does not have significant effects on lexical decision to compound targets, phonological information may have nevertheless played a role in producing the priming effects between words having homographic-homophonic morphemes. In other words, the priming effects for CHAR primes in Experiments 1, 2, and 3 were not solely based on orthographic overlap between primes and targets. Phonological information carried by the homographic characters may interact with orthographic information and this interaction constrains semantic activation of homographic morphemes and compound words (for further argument and evidence, see Zhou & Marslen-Wilson, 1999a, in press b).

Experiment 4 used compound words that had homographic, but not homophonic morphemes (e.g., 重复 chong[2] fu[4], *repeat*; 重量 zhong[4] liang[4], *weight*, where 重 can be chong[2], *repeat*, or zhong[4], *heavy*). If the pattern of priming effects between such words is different from the one between words having homographic-homophonic morphemes in Experiment 1 (e.g., 华侨 hua[2] qiao[2], *overseas Chinese* and 华贵 hua[2] gui[4], *luxurious*, where 华 hua[2] is either *Chinese* or *magni cent*), we may conclude that phonological information of constituent morphemes interacts with orthographic information in constraining semantic activation of morphemes and compound words.

Method

Design and materials

There were two sets of critical target words. In Experiment 4A, all the targets were two-character monomorphemic words, such as 沙发 (sha[1] fa[1], *sofa*). Each target was preceded by a compound word (CHAR prime, 沙滩 sha[1] tan[1], *sandy beach*) which had the same initial character as the target. The same target was also preceded by a word (HOM prime, 杀害 sha[1] hai[4], *kill*) whose initial morpheme was homophonic to but orthographically different from the initial character of the target. This target was also preceded by an unrelated control prime (请求 qing[3] qiu[2], *request*). This design was very similar to the one in Experiment 1, except that the target words here were monomorphemic words. Because of restrictions in finding appropriate stimuli, there were only 18 monomorphemic targets. The average frequences of the three types of primes and of the targets were 13, 15, 13, and 13 per million respectively.

In Experiment 4B, both primes and targets were compound words, where the initial morphemes of the CHAR primes (e.g., 重复 chong[2] fu[4], *repeat*) shared the orthographic form with the initial morphemes of targets (e.g., 重量 zhong[4] liang[4], *weight*). However, the homographic morphemes had different pronunciations in primes and targets. Because Experiment 4B was run in conjunction with Experiment 4A, two types of control primes were used to create balanced test versions. For one type, the initial constituents of control primes (e.g., 崇高 chong[2] gao[1], *lofty, high*) were homophonic to the

Experiments 4A and 4B were run concurrently as a single experiment. The procedures of creating test versions, preparing stimuli, and testing subjects were the same as Experiment 1. Because the patterns of priming effects in masked priming and in visual-visual priming with SOA of 57 ms were essentially the same in Experiments 1, 2, and 3, we did not test subjects for visual-visual priming with the SOA of 57 ms in this and the following Experiment 5.

Subjects

Sixty-three subjects in London were tested, 30 in visual priming and 33 in masked priming. Many of them had participated in Experiment 1. However, there was an interval of at least three months between the two experiments. Another 71 subjects were tested in Beijing in a replication of this experiment, with 36 in masked priming and 35 in visual-visual priming. These subjects were undergraduate students at Beijing Normal University and were not tested in the previous experiments.

Results

Because essentially the same patterns of priming effects were found for subjects in London and in Beijing, the analyses reported here were based only on the London data.[6] Mean reaction times and error percentages are reported in Table 5. Separate analyses were conducted for monomorphemic targets and phonologically altered (non-homophonic homographic) targets.

TABLE 5
Mean Reaction Times (ms) and Error Percentages in Experiment 4

	Experiment 4A			*Experiment 4B*		
	CHAR	*HOM*	*CON*	*CHAR*	*CON1*	*CON2*
Masked	648 (4.0)	684 (7.6)	694 (4.5)	680 (6.6)	693 (6.1)	689 (3.5)
SOA 200 ms	652 (3.8)	671 (2.2)	664 (3.9)	683 (4.9)	661 (7.2)	655 (5.6)

[6] For Beijing subjects, the mean reaction times in responding to monomorphemic targets (Experiment 4A) were 625, 675, and 680 ms respectively for CHAR, HOM, and CON primes in masked priming, and were 662, 679, and 687 ms in visual-visual priming. The mean reaction times in responding to targets of Experiment 4B were 669, 673, and 671 ms respectively for CHAR, CON1, and CON2 primes in masked priming, and were 696, 665, and 652 ms in visual-visual priming.

Experiment 4A

The overall analyses were conducted with prime type as a within-subject factor and sub-experiment as a between-subject factor. The main effect of prime type was significant by subjects but not by items [$F_1(2,122) = 3.51$, $P < .05$, [$F_2(2,34) = 1.07$, $P > .1$], and similarly for the interaction between prime type and sub-experiment [$F_1(2,122) = 3.74$, $P < .05$, [$F_2(2,34) = 2.30$, $P > .1$]. The item tests were not as powerful as subject tests, as there were only 18 targets in total.

Separate analyses were conducted for masked priming and the visual-visual priming with SOA of 200 ms. In masked priming, the main effect of prime type was significant by subjects, [$F_1(2,64) = 7.28$, $P < .005$], and marginally significant by items [$F_2(2,34) = 3.09$, $.05 < P < .1$]. Post hoc Newman-Keuls tests showed that responses to targets were significantly faster for CHAR primes than for HOM or CON primes ($P < .01$ by subjects and $.05 < P < .1$ by items). However, the difference between HOM and CON condition was not significant ($P > .1$). The analyses of error rates did not produce significant results. In visual-visual priming, the main effect of prime type was not significant in either reaction times or error rates ($F_1 < 1$, $F_2 < .1$).

Experiment 4B

In the overall analyses of reaction times, the main effect of prime type was not significant ($F_1 < 1$, $F_2 < .1$). The interaction between prime type and SOA was significant by subjects [$F_1(2,122) = 3.86$, $P < .05$], although not by items ($F_2 < 1$). This indicated that the pattern of priming effects in masked priming was not the same as the pattern in visual-visual priming. Separate analyses found no significant main effect of prime type in masked priming ($F_1 < 1$, $F_2 < 1$). But this main effect was significant in visual-visual priming [$F_1(2,58) = 5.36$, $P < .01$, $F_2(2,34) = 2.61$, $.05 < P < .1$]. Post hoc tests showed that responses to targets for CHAR prime were slower than responses for the two types of control primes ($P < .05$ by subjects and $.05 < P < .1$ by items). No differences were found between the two types of control primes. The analyses of error rates did not reveal any effects significant.

Discussion

The pattern of priming effects in Experiment 4A was generally similar to that in Experiment 1, even though different types of two-character words were used as targets. The null effect between words having orthographically different homophonic morphemes replicated Experiments 1, 2, and 3. In both masked and visual-visual priming, however, the priming effects between words sharing homophonic characters, were larger than the effects for compound targets in Experiment 1: the effects for monomorphemic targets increased by 15 ms in masked priming and by 20 ms in visual-visual priming (see Fig. 5). We discuss the implications of these findings later.

The pattern of priming effects for compound words having initial homographic but non-homophonic morphemes (Experiment 4B) was clearly different from the pattern for compound words having initial homographic-homophonic morphemes (Experiment 1). In masked priming, no significant effect was found here while a significant facilitatory effect was found in Experiment 1. In visual-visual priming, an inhibitory effect was found here whereas no significant effect was found in Experiment 1 (see Fig. 6). These differences suggest that phonological information carried by homographic characters has a significant influence on the processing of these characters and compound words containing these characters. This phonological effect, contrasting with the null effect between words having orthographically different homophonic morphemes, indicate that phonological activation, when it interacts with activation of appropriate orthographic information, could have significant

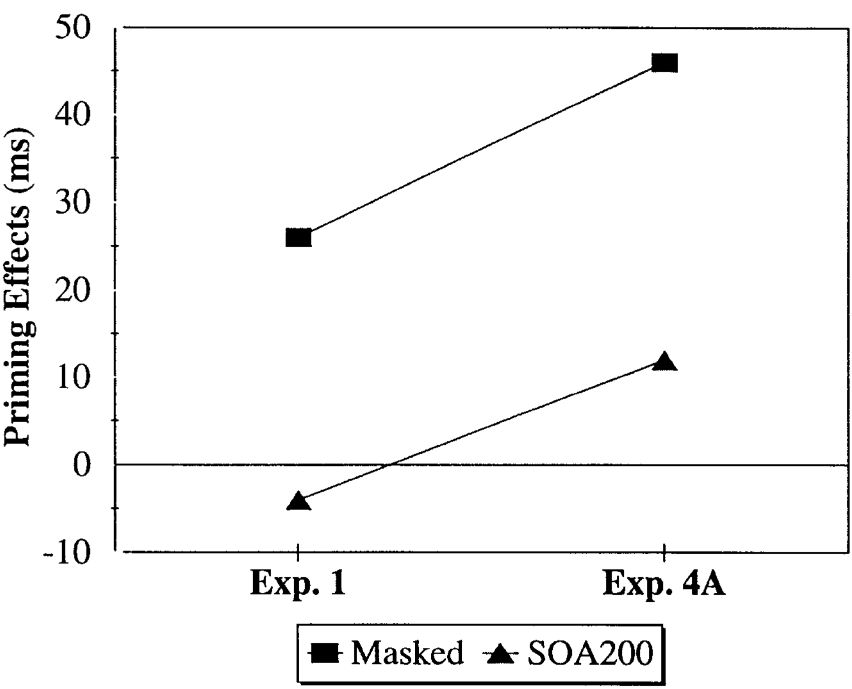

FIG. 5. Priming effects (ms) for CHAR primes in Experiments 1 and 4A.

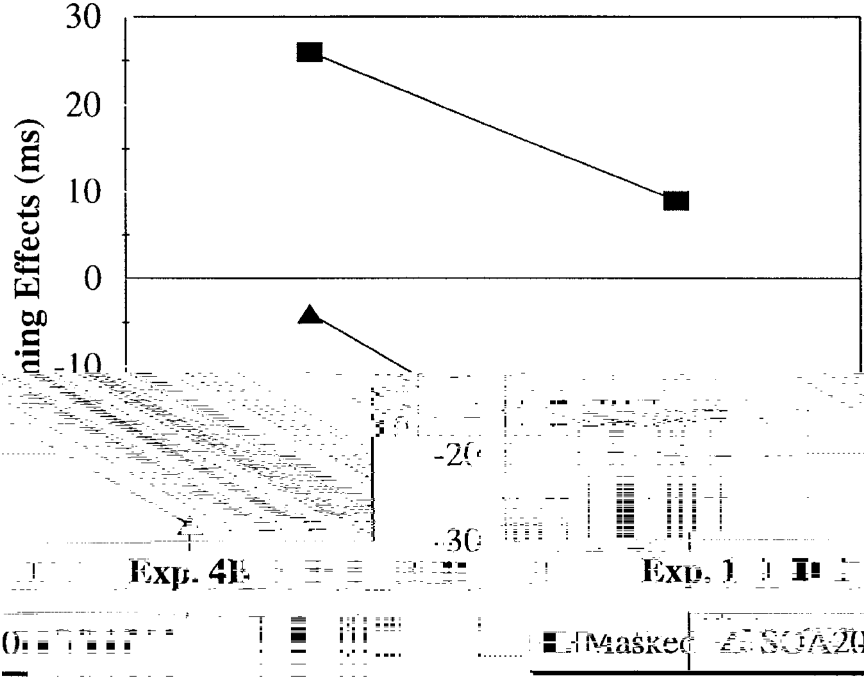

FIG. 6. Priming effects (ms) for CHAR primes in Experiments 1 and 4B.

influences on semantic activation of constituent morphemes and compound words.[7] In the General Discussion we discuss how the model sketched in Fig. 1 handles these findings.

EXPERIMENT 5

The purpose of this experiment was to examine whether the apparent morphological priming effects between words having common morphemes

[7] Because the mean reaction times in Experiment 4B were about 50ms longer than the times in Experiment 1, one might argue that the more inhibitory effects for targets having non-homophonic homographic characters than for targets having homophonic-homographic characters were not due to the interaction between orthographic and phonological information carried by the homographic characters, but due to the slower reaction times themselves. More phonological information was allowed to come into play when responses were slowed down. It should be noted, however, that the null priming effects between words having orthographically different homophonic morphemes did not change according to the speed of responses (see Tables 1 and 5). Moreover, representing priming effects in terms of the proportion of mean reaction times in control conditions does not change the general pattern of the comparison between experiments.

in Experiments 1, 2, and 3 could be reduced to "pure" semantic priming. As discussed earlier, morphologically related words (e.g., 医院 yi[1] yuan[4], *hospital*; 医生 yi[1] sheng[1], *doctor*) are mostly semantically related as well, like words that are not morphologically related (e.g., 护士 hu[4] shi[4], *nurse*; 医生 yi(1) sheng[1], *doctor*). The previous experiments suggested that priming effects between words sharing common morphemes were the joint effects of "pure" semantic priming, due to the general overlap of semantic properties between primes and targets, and morphemic semantic priming, due to repeated access to morphemic semantic properties that may be or may be not used by the whole words. In masked priming, the orthographic and spatial overlap of the shared morphemes also contributed to the priming effects. In this experiment, we compared directly morphological priming effects with "pure" semantic priming effects. A target word (e.g., 医生 yi[1] sheng[1], *doctor*) was preceded by either a word sharing a common morpheme (医院 yi[1] yuan[4], *hospital*) or by a word only semantically related (护士 hu[4] shi[4], *nurse*). If the two types of paired words are equally semantically related, as indexed in semantic relatedness tests, it can be assumed that the two types of primes have the same extent of overlap of semantic properites with the targets. We expected to observe larger priming effects for morphologically related words than for semantically related words.

Method

Design and materials

Each target word was paired with three types of primes. In MORPH condition, a prime and its target had the same initial morpheme, which was written and pronounced in the same way in the prime and target. The same target was also preceded by a semantically related compound word in the SEM condition. The SEM prime and target shared no morphemes and no phonological and orthographic similarities. Meanings of the constituent morphemes in the prime and target were not related either. In the control priming (CON) condition, the target was also paired with a morphologically, semantically, orthographically, and phonologically unrelated word.

Forty-five target words and their MORPH and SEM primes were selected from a pool of potential stimuli, which underwent a semantic relatedness pretest. Thirty subjects were asked to judge the semantic relatedness between primes and targets on a 9-point scale, with 1 representing "completely unrelated" and 9 "very related". The primes and targets were split into two versions so that half MORPH primes and half SEM primes were in one version. Subjects were also split into two groups so that they never saw the same targets twice. For the selected set of stimuli, the average point of semantic relatedness to targets was 7.9 for

MORPH primes and 7.8 for SEM primes. The average word frequencies were 18 and 28 per million respectively for the two types of primes. The mean frequency of control primes was 23 per million.

To prevent subjects from using response strategies based on orthographic overlap between MORPH primes and targets, the experiment included 10 word-nonword pairs that shared their initial characters. These nonword targets were derived from real words that shared the initial morphemes with the primes. There were also 45 word-word pairs and 80 word-nonword pairs that were not morphologically, semantically, orthographically, or phonologically related. These pairs acted as fillers to reduce the proportion of critically related items in a test version. The creation of test versions, preparation of stimuli and tests of subjects were carried out in the same ways as previous experiments. As in Experiment 4, only masked priming and visual-visual priming with SOA of 200 ms were conducted.

Subjects

Sixty-two undergraduate students at Beijing Normal University were paid to participate in the experiment. Thirty-two of them were tested for visual-visual priming and 30 for masked priming. They were native speakers of Mandarin Chinese and were not tested for the previous experiments or for the semantic relatedness pretests.

Results

One subject and two items in masked priming were deleted from analyses because of high error rates. Mean reaction times, based on correct, untrimmed response times, and response error rates are reported in Table 6.

TABLE 6
Mean Reaction Times and Error Percentages of Experiment 5

	MORPH	*SEM*	*CON*
Masked	530 (1.9)	566 (3.2)	583 (5.0)
SOA 200 ms	536 (1.6)	548 (2.2)	580 (4.0)

Overall analyses were conducted for reaction times and error rates with prime type as a within-subject factor and sub-experiment as a between-subject factor In the analyses of reaction times, the main effect of prime type was highly significant [$F_1(2,118) = 47.41$, $P < .001$, [$F_2(2,84) = 27.85$, $P < .001$], indicating that targets were responded to faster when they were preceded by MORPH and SEM primes than by unrelated control primes. Post hoc Newman-Keuls tests showed that the mean reaction times to targets were significantly shorter ($P < .01$) for morphological primes (533 ms) than for semantic prime (557 ms) or control primes (582 ms). The difference between semantic and control primes was also significant ($P < .01$). The interaction between prime type and sub-experiment was significant by subjects [$F_1(2,118) = 4.32$, $P < .05$, although not by items [$F_2(1,84) = 1.09$, $P > .1$].

Planned tests were conducted to compare morphological and semantic priming effects. In masked priming, the 36 ms difference between MORPH primes and SEM primes was significant [$t_1(28) = 5.99$, $P < .001$, $t_2(42) = 3.30$, $P < .01$]. Moreover, the 17 ms semantic priming effect, as assessed against control primes, was also significant [$t_1(28) = 2.23$, $P < .05$, $t_2(42) = 2.65$, $P < .05$]. In visual-visual priming, the difference between MORPH primes and SEM primes (12 ms) was in the same direction as in masked priming, although it did not reach statistical significance [$t_1(31) = 1.19$, $P > .1$, $t_2(42) = 1.72$, $.05 < P < .01$]. The 32 ms semantic priming effect, against control primes, was highly significant [$t_1(31) = 5.96$, $P < .001$, $t_2(42) = 4.22$, $P < .001$].

The analyses of error rates found only a significant main effect of prime type [$F_1(2,118) = 5.14$, $P < .01$, $F_2(2,84) = 5.12$, $P < .01$]. Post hoc tests showed that while the error rates in both MORPH and SEM conditions were significantly lower than the rate in the control condition ($P < .05$ or .01), the difference between morphological priming and semantic priming was not significant ($P > .1$). No other effects were significant.

Discussion

The message from the experiment is clear. There is in general more than “pure” semantic priming between words sharing common morphemes. The additional priming effect, based on morphemic processing in reading compounds, is most obvious in masked priming. It can be argued that repeated access to form and semantic representations of critical morphemes in primes and targets leads to higher activation of semantic representations of target words. Although MORPH primes and SEM primes were well matched in their semantic relatedness to targets and, presumably, in the degree of semantic overlap between primes and targets, repeated activation of morphemic form and semantic properties not shared between SEM primes and targets led to larger priming effects for MORPH primes. The larger priming effect in masked priming was likely orthographic and phonological characteristics of the Chinese language and its writing system.[8] At the semantic level, both compound words and their constituent morphemes have representations composed of semantic features, with much overlap between whole-word and morpheme semantic representations. The degree of semantic overlap between whole words and constituent morphemes reflects the semantic transparency of the compounds (Zhou & Marslen-Wilson, 1999c; Zwitserlood, 1994). The initial morphological (or orthographic) decomposition in mapping visual input onto the lexicon and the activation of orthographic, phonological, and semantic representations of constituent morphemes are part of the processes of activating the semantic and form properties of compound words. The interactions between form and semantic processing of constituent morphemes and between processing of constituent morphemes and whole words result in the observed morphological effects in lexical processing.

The morphological priming effects between words sharing morphemes, summarised across experiments in Fig. 7, are joint effects of semantic priming based on general semantic overlap between primes and targets, semantic priming based on morphemic meanings, and form priming based on orthographic and phonological activation. However, the effects from different sources are not necessarily additive, but interactive in forming morphological priming. The form-based priming effects can be elevated by the masked priming technique (see Forster & Davis, 1991; Forster et al., 1987). The contribution of form priming to morphological priming can be clearly identified in Experiments 3 and 5. In Experiment 5, morphologically related words produced significantly larger priming effects than "pure" semantically related words in masked priming, although the advantage was reduced in visual-visual priming. In Experiment 3, the shift of spatial position of critical morphemes reduced the morphological priming effect in masked priming, compared with the effects in

[8] For Chinese two-character words, one might argue that this boundary marking is not morphological but orthographic and phonological, since representations for two-character monomorphemic words are probably also marked in the same way. However, there are only a small amount of such two-character monomorphemic words and many of them can be treated as semantically opaque compounds anyway. Thus in Chinese, calling this boundary marking "morphological" or "form-based" does not make much difference. For other languages like English, however, this boundary marking of polymorphemic words could be either explicit, as in many traditional theories of morphological processing (Taft & Forster, 1975, 1976), or implicit, as in connectionist theories of morphological processing (Rueckl, Mikolinski, Raven, Miner, & Mars, 1997; Seidenberg & McClelland, 1989; Zhou & Marslen-Wilson, 1999c). Whether boundaries between constituent morphemes are explicitly marked and whether this boundary marking is "morphological" or "formed-based" are fundamental to the issue of how morphological structure is represented in the lexicon (Rueckl et al., 1997; Zhou & Marslen-Wilson, 1999c).

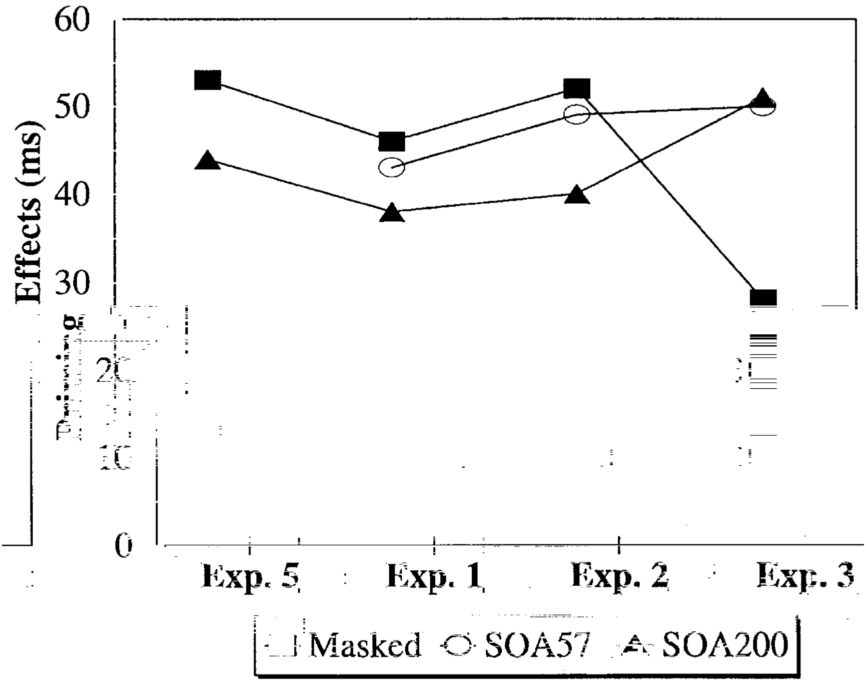

FIG. 7. Priming effects (ms) for MORPH primes in Experiments 1, 2, 3, and 5.

Experiments 1 and 2 and with the effects for the same words in visual-visual priming in Experiment 3. The contribution of the form processing of shared morphemes in masked priming may take the form of either activating constituent semantic representations more quickly or sending positive signals directly to the lexical decision mechanisms.

Character priming and access to semantics of constituent morphemes

Although the priming effects between words having homographic morphemes may be attributed to orthographically based activation of the target words, the variation in priming effects across experiments (Figs 5, 6, and 8) indicates that more detailed analyses of the processes involved in producing the effects are needed. The model sketched in Fig. 1 provides a good account for the results. This account, based on semantic and form activation of constituent morphemes, attributes the priming effects to parallel semantic activation of the homographic constituent morphemes and to interaction between semantic activation of constituent morphemes and whole words.

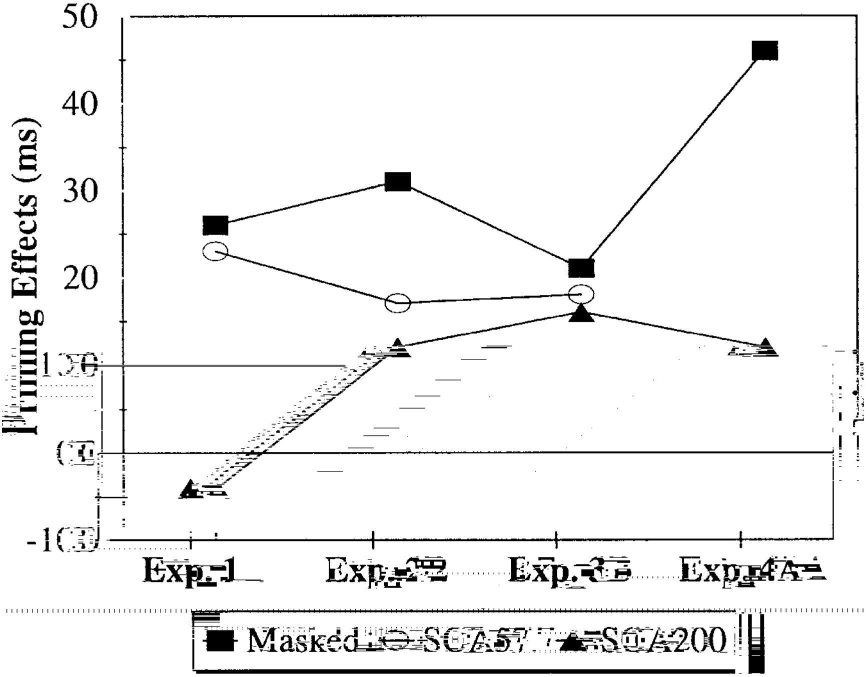

FIG. 8. Priming effects (ms) for CHAR primes in Experiments 1, 2, 3, and 4A.

The presentation of the critical morphemes in the primes activates the orthographic and phonological representations of these morphemes. Semantic representations of these morphemes are also activated, mainly through direct computation from orthography to semantics (see Zhou, 1997; Zhou & Marslen-Wilson, in press b). The alternative semantic representations of homographic morphemes are also activated, leading to facilitation in the recognition of target words. Semantic representations of homographic-homophonic morphemes also compete with each other and their activation interacts with semantic activation of whole words. As the SOA increases, this competition becomes stronger and the magnitude of priming effects decreases. Figure 8 summarises the priming effects at different SOAs across experiments 1 to 4.

The morphemic semantic competition is influenced by interaction between morphemic and whole-word semantic activation, which is in turn influenced by constituent positions of critical characters in primes and targets (see also Zhou & Marslen-Wilson, 1995). Because of a tendency to left-to-right processing in reading Chinese, the competition is stronger when the critical characters are at the initial constituent position. At the second constituent position, however, the competition is weaker, due to the contextual constraint from the processing of the initial morphemes. The processing of the initial morphemes activates the semantic representations of whole words. This semantic activation serves as contextual constraint in interpreting the ambiguous second character and there is less competition between the critical morphemes in these words and the semantic activation of the alternative morphemes. The negative priming effects between words having initial homographic-homophonic morphemes (Experiment 1) can be accommodated by the assumption that the visual input of the initial characters of targets are initially used to support further semantic activation of the critical morphemes in primes. Only when the second constituent of the target enters into semantic processing does the semantic representation of the initial critical character in the target become activated, due to interaction with semantic activation of the whole words.[9]

This semantic account of character priming is supported further by the comparison of priming effects between Experiments 1 and 4A (Figure 5). Because the critical characters do not represent alternative morphemes in monomorphemic words, competition between semantic interpretations of initial homographic morphemes is minimised. Consequently, the processing of monomorphemic targets is more likely to be facilitated by character primes than the processing of compound targets.

Phonology in reading Chinese compound words

In neither masked nor visual-visual priming did we observe significant priming effects between words having homophonic but non-homographic morphemes. This result suggests either that phonological information about constituent morphemes is not activated or that morphemic phonological activation by itself has no significant influence on semantic activation of morphemes and whole words.

[9] The significant inhibitory priming effect between Italian inflected words having homographic (and homophonic) stems (Laudanna et al., 1989, 1992) can be accounted for in the same way. The fact that inhibitory effects were not significant for Chinese compounds or for Italian derived words may be due to the degree of semantic contribution from homographic morphemes to whole words. Semantic properties of inflected words are mostly specified by semantic properties of their stems, while semantic properties of compound words and derived words are determined to a less extent by semantic properties of individual constituents or stems. Semantic competition between homographic morphemes thus exerts a larger influence on the processing of inflected words than on the processing of compounds or derived words.

There is evidence that the phonological properties of single-character words or morphemes are automatically activated in reading Chinese (e.g., Perfetti & Zhang, 1995, Zhou, 1997; Zhou & Marslen-Wilson, in press a). There is also evidence that phonological properties of constituent morphemes of compound words are activated, subject to task demands (see Footnote 4). Data from other studies support the proposition of automatic phonological activation of constituent morphemes in reading compound words. Zhou and Marslen-Wilson (1999) found that pseudo-homophones created from compound words by replacing one constituent with orthographically dissimilar homophonic characters were more difficult to reject in lexical decision than matched control nonwords (see also Sakuma et al., 1988 for a similar finding for Japanese kanji compounds in a semantic categorisation task). Since lexical decision to pseudohomophones can be made on the basis of orthographic information, this phonologically based pseudohomophone effect can only indicate the automatic activation of phonological information, which interferes with the lexical decision response, either directly or through semantic activation.

Given these and other results, the null effect of phonological overlap between primes and targets in the current series of experiments can only be interpreted as suggesting that, although phonology of constituent morphemes is automatically activated in reading, it does not in general play a significant role in constraining the semantic activation of constituent morphemes and whole words. This conclusion is consistent with the finding that orthographically dissimilar homophonic compounds (e.g. 清净 jie[2] jing[4], *hygienic; 捷径 jie[2] jing[4], shortcut*) do not significantly prime each other in lexical decision (Zhou, 1997; Zhou & Marslen-Wilson, in press a).

However, phonological information does play a significant role in constraining semantic activation when it interacts with appropriate orthographic information (Zhou & Marslen-Wilson, in press b). In this study, this point is clear from the comparison of priming effects between words having homographic characters, which were either homophonic or not (see Fig. 6). These priming effects decreased by about 30 ms in both masked and visual-visual priming when the critical characters were changed from homophonic to non-homophonic. This decrease of priming effects indicates that phonological information of constituent morphemes is automatically activated and this phonological activation influences semantic activation of constituent morphemes and compounds and hence lexical decision to compounds.

There are two possible ways for phonological activation to influence the CHAR priming effects. One is that morphemic semantic activation is constrained both by direct computation from orthography and by phonological mediation. These two routes to semantics operate in interaction with direct access plays a dominant role (Zhou, 1997; Zhou & Marslen-Wilson, in press a, b). The morphemic semantic competition between homographic but not homophonic morphemes is stronger than the competition between homographic-homophonic morphemes. The former types of homographic morphemes compete not only at the semantic level, but also at the phonological level. This phonological competition, acting in conjunction with direct visual access to morphemic semantics, intensifies semantic competition, leading to more negative priming. Another way to account for the phonological effect is to assume that the lexical decision task is sensitive to phonological activation as well as to semantic activation. If semantic activation leads the lexical decision mechanisms to make positive responses but the activation in the phonological system leads the mechanisms to make negative responses, the conflict delays lexical decision. This is the case for the inhibitory priming effects between words having homographic but non-homophonic characters (Experiment 4B). After the recognition of a CHAR prime (e.g., 重复 chong[2] fu[4], *repeat*), the phonological representation of the critical character (e.g., 重 chong[2]) is highly activated. When the target (e.g., 重量 zhong[4] liang[4], *weight*) is presented, the phonological representation of "chong(2)" is initially activated further while the phonological representation of "zhong[4]" is either not activated or inhibited. The combination of "chong[2]" with the second morpheme of the target (i.e., liang[4]) forms a nonword at the phonological level. This will inform the lexical decision mechanisms to make a "no" response, delaying the recognition of target words.

To summarise, this research demonstrates that morphological, orthographic, and phonological information interact with each other in the lexical processing of Chinese compound words. Morphological processing is exhibited through interaction between orthographic, phonological, and semantic processing of constituent morphemes and through interaction between semantic activation of morphemes and whole words. Semantic activation of constituent morphemes is constrained by both orthographic and phonological activation although phonology by itself has no significant influences on morphemic semantic activation. The prototypical representation model sketched in Fig. 1 captures the fundamental relations between morphology, semantics, orthography, and phonology in reading Chinese compound words and provides perhaps a new way to think of morphological processing.

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