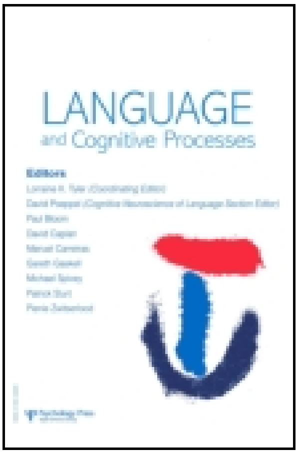

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Pseudohomophone effects in processing Chinese compound words

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The issue of how phonological information becomes available in reading Chinese and the role that it plays in lexical access was investigated for Chinese compound words, using pseudohomophone effects in lexical and phonological decision as a diagnostic tool. Pseudohomophones were created by replacing one or both constituents of two-character compound words with orthographically dissimilar homophonic characters. Experiment 1 found that mixed pseudohomophones sharing one constituent with their base words were more difficult to reject than control nonwords in lexical decision. Pure pseudohomophones sharing no constituents with their base words did not show this effect. Experiment 2 used mixed pseudohomophones and found an interaction between base word frequency and the frequency of constituent characters in determining pseudohomophone effects. Experiment 3 used a phonological decision task and found exceptionally poor performance for pure pseudohomophones. These results are interpreted in an interactive framework where the direct mapping from orthography to semantics is dominant and phonology plays a subsidiary role.

Keywords: Compound word; Phonological processing; Pseudohomophone effect; Reading Chinese.

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There are at least three crucial issues concerning the role of phonology in visual word recognition (e.g., Frost, 1998; Seidenberg & McClelland, 1989; Taft & van Graan, 1998): whether phonological information is automatically activated in initial lexical processing; what role phonology plays in mediating access to semantics; and how phonological information becomes available. In recent years, these issues have attracted many researchers to Chinese, because of its unique logographic writing system.

Does phonology function in the same way in reading Chinese as in reading alphabetic scripts? There is widespread agreement that phonological information in the mental lexicon is automatically activated, even in situations in which phonological activation is harmful or irrelevant to the completion of the experimental task (e.g., Leck, Weekes, & Chen, 1995; Perfetti & Zhang, 1995; Xu, Pollatsek, & Potter, 1999; Zhou & Marslen-Wilson, 2000a; but see Chen, Cheung, & Flores d'Arcais, 1995). There are different views, however, about whether phonology plays a strong role in driving or mediating semantic activation and how phonological information becomes available. On the one hand, there is a view that phonological information in reading Chinese, as in reading alphabetic scripts, is activated earlier than semantic information and that access to semantics depends predominantly on phonological activation (e.g., Perfetti & Tan, 1998; Perfetti, Tan, Zhang, & Georgi, 1995; Perfetti & Zhang, 1995; Tan, Hoosain, & Siok, 1996). This phonological activation is assumed to be due to a direct mapping from orthography to phonology. This phenomenon is universal across different orthographies 'because it depends, not on details of lexical access, but on a functional analysis of the role of phonology in word understanding' (Perfetti et al., 1995, p. 686). Unfortunately, the experiments supporting this argument are mostly not replicable (see, for example, Chen & Shu, 2001; Xie & Zhou, 2003). On the other hand, there is the view that access to semantics in skilled reading of Chinese is constrained by both phonology and orthography operating in interaction, and that phonology has no inherently privileged role over orthography in driving semantic activation (e.g., Chen & Shu, 2001; Zhou, Shu, Bi, & Shi, 1999b; Zhou & Marslen-Wilson, 1999, 2000a). Phonological information becomes available not only through direct links between orthography and phonology, but also through the spread of activation back from semantics to phonology (Zhou & Marslen-Wilson, 1997). On this view, both phonological and semantic activation in reading Chinese is the result of interactive processes involving orthography, phonology, and semantics.

In the research reported here, we bring new data to bear upon these issues, examining the processing of pseudohomophones based on Chinese two-character compounds.

PSEUDOHOMOPHONES IN ENGLISH AND CHINESE

Pseudohomophones are those nonwords (e.g., *brane*) that sound like real words but are written differently. It has been repeatedly found in alphabetic languages like English that pseudohomophones are named faster but are more difficult to reject in lexical decision than matched nonwords that do not sound like real words, such as *frane* (e.g., McCann & Besner, 1987; McCann, Besner, & Davelar, 1988; Rubenstein, Lewis, & Rubenstein, 1971; Seidenberg, Peterson, MacDonald, & Plaut, 1996; Taft & Russell, 1992). These pseudohomophone effects do not correlate with the frequency of base words (i.e., the real words from which the pseudohomophones are derived) in either naming or lexical decision (e.g., McCann & Besner, 1987; McCann et al., 1988), although different results concerning the base word frequency effects have been reported (Borowsky, Owen, & Masson, 2002; Taft & Russell, 1992).

The pseudohomophone effect in lexical decision is usually interpreted as indicating that the phonological representation of the base word is activated by the presence of a pseudohomophone and that this phonological activation spreads to the semantic representation of the base word. Thus, in reading alphabetic scripts, phonological information is argued to be automatically activated and this causes semantic activation of the corresponding words or morphemes in the lexicon (Frost, 1998; Lesch & Pollatsek, 1993; Lukatela & Turvey, 1991, 1994; van Orden, 1987; van Orden, Johnston, & Hale, 1988; van Orden & Goldinger, 1994). This semantic account is supported by pseudohomophone effects in semantic tasks. Van Orden et al. (1988) and Jared and Seidenberg (1991) found that participants were reluctant to reject pseudohomophones (e.g., *roze*) as inappropriate exemplars of pre-designated semantic categories (e.g., *flower*), suggesting activation of semantic properties of the base words (e.g., *rose*) by pseudohomophones. In priming experiments, Lukatela and Turvey (1991, 1994) found that pseudohomophones (e.g., *tode*) facilitated the processing of words (e.g., *frog*) that were semantically related to the base words (e.g., *toad*). These findings are consistent with a view that, whether phonological representations in the lexicon are word-specific (Besner, 1999; Besner, Twilley, McCann, & Seergobin, 1990; McCann & Besner, 1987) or distributed (Seidenberg & McClelland, 1989, 1999; Seidenberg et al., 1996), their activation by the presence of pseudohomophones automatically leads to activation of semantic representations of the base words. This semantic activation, possibly together with phonological activation, interferes with the participant's performance in semantic or lexical decision tasks.

The pseudohomophone effects are of interest from two perspectives in the context of the Chinese writing system. The first is that the nature of Chinese orthography allows us to completely dissociate the potential phonological and orthographic effects. An unresolved problem for pseudohomophone research in English is the possible contribution of orthographic properties of pseudohomophones to the phonological and semantic activation of their base words. Pseudohomophones in English and other alphabetic scripts are, with few exceptions, orthographically similar to their base words. These pseudohomophones are typically compared with control nonwords which are also orthographically similar to the base words. However, this may not be a fully adequate control since the test words share full phonological similarity as well as partial orthographic similarity with their base words, and this may lead to interactions which partially rely on these shared orthographic properties. In alphabetic scripts, therefore, given the phoneme-grapheme correspondences being intrinsic to their organisation, it is not feasible to evaluate pure phonological effects independently from possible orthographic contributions. The evidence that the phonological interference effect in semantic categorisation is modulated by the orthographic similarity between base words and homophones (e.g., Coltheart, Patterson, & Leahy, 1994; Jared & Seidenberg, 1991) only serves to strengthen the possibility that phonological similarity between base words and pseudohomophones is being confounded by orthographic similarity.

In Chinese, in contrast, it is possible to manipulate phonology and orthography independently and to create pseudohomophones that share essentially no orthographic properties with their base words. Given that a morpheme in Chinese usually corresponds to a spoken syllable and to a written character, but a syllable typically stands for a number of different morphemes which may have no orthographic elements in common, we can create pseudohomophones by replacing one or more constituents of compound words with orthographically dissimilar homophonic characters. Note that pseudohomophones cannot be created from single-character words in Chinese, because all homophonic characters are themselves existing words or morphemes, and pseudo-characters in Chinese have no definite phonological interpretations. However, working from compounds, such as the base word 严格 (yan[2] ge[2], *strict*),[1] we can create *pure* pseudohomophones such as 研革 (yan[2] ge[2]), where both replacement characters are homophonic with the constituents of the base word, but where neither has obvious orthographic overlap with the base characters they replace. In addition, we can create *mixed* pseudohomophones 严革 (yan[2] ge[2]) or 研格 (yan[2] ge[2]) where one constituent morpheme stays the same as in the base word, but where the other constituent is a homophonic character with no orthographic overlap. Manipulations of this type allow us to investigate, in a more orthographically controlled manner than is possible in alphabetic

[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.

scripts, to what extent semantic activation in pseudohomophone tasks is driven by phonological mediation alone.

This will allow us to address the ongoing debate about the role of phonology in lexical access in Chinese. If phonological mediation plays an obligatory, primary role in mapping from orthography onto semantics, then we predict very similar pseudohomophone interference effects for different types of pseudohomophones and to those found in English and related scripts. On alternative accounts where orthography plays a more direct role, we would predict much weaker effects for pure pseudohomophones.

REPRESENTATION OF CHINESE COMPOUND WORDS IN THE LEXICON

To interpret potential pseudohomophone effects in lexical or phonological decision, it is necessary to have a framework for how Chinese compound words are represented in the lexicon. Figure 1 presents such a framework, which was developed from studies on spoken and visual word recognition of Chinese compound words (Zhou & Marslen-Wilson, 1994, 1995, 2000b; Zhou, Marslen-Wilson, Taft, & Shu, 1999a). In this framework, compound words and their constituents are both represented at orthographic (O), phonological (P), and semantic (S) levels, which are connected directly to each other. However, the representations for compound words are not independent from the representations for their constituent morphemes.[2]

[2] It may be possible to realise this framework in a distributed, connectionist model, where orthographic, phonological, and semantic representations are viewed as activation patterns distributed over large numbers of simple processing unit (Rueckl, Mikolinski, Raven, Miner, & Mars, 1997; Seidenberg, 1987, 1989; Seidenberg & McClelland, 1989; Zhou & Marslen-Wilson, 2000b). There would be no need for explicit representation of morphological structure at either semantic or form levels. Lexical representations for compound words are 'whole-word' activation patterns at these levels. The morphological structure of compound words emerges from the dynamic interaction between semantic and form representations. At the orthographic and phonological levels, morphological structure may be cued by changes in transitional probability at morpheme boundaries. At the semantic level, semantic representations of both whole words and constituent morphemes are activated in parallel from their form representations, resulting in competition between the two sets of semantic features not shared between constituent morphemes and whole words. Patterns corresponding to constituent morphemes are well established through the acquisition and use of the monomorphemic words. In visual word recognition, although the mapping between orthography, phonology, and semantics establishes stable lexical activation at these levels for the whole words, the statistical regularities encoded within these levels and, more importantly, the interaction between different levels also establish in parallel sub-patterns corresponding to constituent morphemes, which are necessarily of higher frequency than compound words themselves.

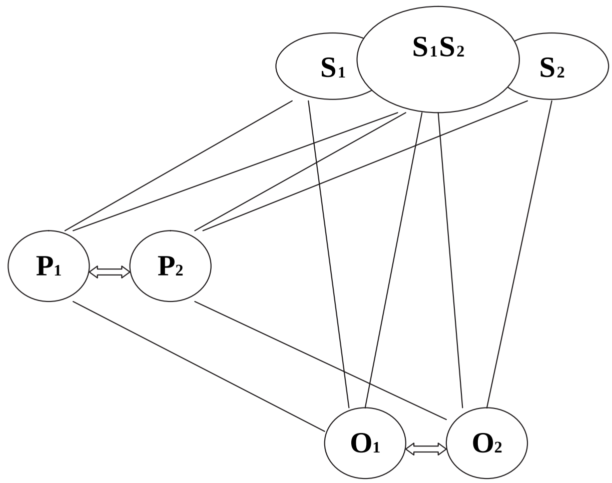

Figure 1. A framework for lexical representation of Chinese compound words.

At the semantic level, the representations of compound words and morphemes can be seen as composed of semantic features, with representations for compounds and representations for their constituent morphemes sharing common features. The semantic transparency (or semantic compositionality) of compound words is naturally embodied as the degree of semantic overlap between compounds and their constituent morphemes, with transparent compounds (e.g., *bathroom*, to use an English example) sharing many features with their constituents and opaque compounds (e.g., *blackmail*) sharing few features.

At the phonological and orthographic levels, since the spoken and written forms of Chinese compound words are mostly the simple concatenations of the forms of their constituent morphemes, orthographic and phonological representations of compounds can be represented as combinations of the form representations of their constituents, without postulating additional whole-word representations of compounds at these levels. These constituent form representations are linked through their co-occurrence in the language. The frequency properties of the whole words are captured through the strength of these links and through the resting level of the whole-word semantic representations.

In real-time processing of compounds, activation is assumed to spread automatically along the links between different types of representation. Semantic representations of both the whole word and constituent morphemes are activated in parallel from their form representations, resulting in competition between the two sets of semantic features not shared between constituent morphemes and whole words. However, activation of semantic representations of constituent morphemes also implies the partial activation of semantic representation of the whole word since they share some semantic features. Moreover, semantic activation of the whole word and constituent morphemes can feed back to the corresponding phonological and orthographic representations, increasing their activation levels.

In this framework, orthographic activation of constituent morphemes can spread directly to constituent and whole-word semantic representations without going through constituent phonological representations. This assumption is in conflict with the strong phonological view (e.g., Perfetti & Tan, 1998; Perfetti & Zhang, 1995; Perfetti et al., 1995; Tan et al., 1996), which would assume that phonological representations of individual morphemes are directly activated by orthography and that this phonological activation plays the predominant and universal role in driving semantic activation of the corresponding morphemes and the whole word.

To consider the pseudohomophone effects in terms of the framework sketched in Figure 1, mixed pseudohomophones and pure pseudohomophones will behave differently in their mapping onto the semantic representations of base words. If orthographic input can activate corresponding semantic representations directly, and if phonological activation is driven both by direct mapping from orthography and by spread of activation from semantics, operating in an interactive manner (Zhou & Marslen-Wilson, 1999, 2000a; Zhou et al., 1999b), mixed pseudohomophones sharing morphemes with their base words are more likely to activate the semantic representations of the base constituents and the base compounds than pure pseudohomophones. For the pure pseudohomophones, only phonological information, derived from constituent syllabic representations, is available to activate the semantic representations of base constituents and base compounds. In fact, the orthographic input of pure pseudohomophones would activate the corresponding morphemic representations not used by the base words, creating interference with semantic activation of the latter. On the assumption that the role of phonological information in driving lexical access in Chinese reading is both weak and indirect, we would expect little or no interference for pure pseudohomophones in lexical decision.

The strong phonological view, in contrast, predicts no difference in pseudohomophone effects for mixed and pure pseudohomophones. In reading compound words, syllabic representations of constituent morphemes are activated by the input characters and this phonological activation is the primary (and perhaps the only) source of activation of the corresponding morphemic and the whole word semantic representations, resulting in the recognition of the input words. For pseudohomophones, the degree of phonological activation and its effects on the semantic activation of base words should be the same as in reading the base words. Only at a later stage of 'postlexical checking' can the orthographic information tell the decision system whether the orthographic input is a real word or not. Consequently the pattern of pseudohomophone effects should not be changed dramatically according to whether the pseudohomophones are mixed, sharing constituent morphemes with base words, or pure, composed of characters orthographically dissimilar to the base constituents, although the efficiency of postlexical checking may be influenced by the orthographic similarity between pseudohomophones and their base words. It may take more time to discriminate a mixed pseudohomophone than a pure pseudohomophone from a real word.

We conducted three experiments to investigate how phonological information becomes available and to what extent this information plays a role in driving semantic activation in processing Chinese compound words. Experiment 1 asked whether the appearance of pseudohomophone effects in lexical decision is influenced by activation and processing of individual morphemes, which may or may not be the constituent morphemes used in the base words. Experiment 2 looked at the potential interaction between base word frequency and constituent character frequency in determining phonological activation of base words and the pseudohomophone effects. Experiment 3 used a phonological decision task to explore the availability of orthographically derived phonological information and its impact upon the base word frequency effect.

EXPERIMENT 1

Experiment 1 investigated the potential pseudohomophone effects in lexical decision to Chinese disyllabic compound words and nonwords. We used pseudohomophones that shared either the first constituent ('Keep First' pseudohomophones), the second constituent ('Keep Second' pseudohomophones), or no constituent ('Change Both' pseudohomophones) with their base words. If direct mapping from orthography to phonology is sufficient to activate syllabic representations of the constituents of base words and the co-occurrence information associated with these constituents, and if activation of the semantic properties of base words is predominantly driven by this phonological activation, then all types of pseudohomophones should be more difficult to reject than the matched nonwords. If, on the other hand, phonological and/or semantic activation of base words is influenced to a significant extent by the activation of the constituent morphemes shared between pseudohomophones and base words, then we should expect to find stronger effects for mixed pseudohomophones than for pure pseudohomophones.

Note that lexical decision to compounds in Chinese, as in English, requires access to a level of lexical-semantic whole-word representations (see also Yates, Locker, & Simpson, 2003, for evidence that semantic activation is involved in processing pseudohomophones based on simple English words).

The decision, for example, that the sequence *horseshoe* is a word in English, while *horsetree* is not, can only be made on the basis of the recognition that a lexical entry exists for *horseshoe* but not for *horsetree*. The constituent stems in each case (*horse*, *shoe*, *tree*) are all existing words in the language. Similar criteria apply in Chinese, where readers can readily determine whether a given two-character pairing is an existing word in the language. Earlier research using the lexical decision task with Chinese compounds shows that these decisions can be made rapidly and accurately (e.g., Zhou & Marslen-Wilson, 1994, 1995; Zhou et al., 1999a).

Because effects for both pure and mixed pseudohomophones may be modulated by properties of the base compounds, it is necessary to control for salient properties such as frequency. In lexical decision to pseudohomophones in English, base word frequency effects are typically not found (McCann et al., 1988; but see Ziegler, Jacobs, & Kluppel, 2001 for a finding of a reversed base word frequency effect). In an earlier, unpublished study, however, we found that Chinese mixed pseudohomophones based on high frequency compound words were more difficult to reject than control nonwords, but pseudohomophones based on lower frequency words did not show this effect. This pattern was explained as due to frequency-based differences in the activation of base words. A problem with this study, however, was that the properties of the constituents of high and low frequency base words and the derived pseudohomophones were not fully matched. In this experiment, we controlled the stimuli more strictly, using only high frequency base words with high frequency constituent characters. The derived pseudohomophones also had high frequency constituents. Constituent syllabic activation of both mixed and pure pseudohomophones should be most effective for high frequency constituents. This should favour phonological mediation and the activation of semantic properties of base constituents and base words. The potential influence of character frequency on pseudohomophone effects was examined in more detail in Experiment 2.

Method

Design and materials

Seventy-eight high frequency words composed of high frequency characters were chosen as base words. All of these words, like most compound words in Chinese, were phonologically unambiguous, in the sense that no other compound words had the same phonological form. This means that the base words were always uniquely indexed by the phonological information specified by the constituent morphemes of the pseudohomophones. The mean frequency of the base words was 130 per million. The average character frequencies were 1030 per million for the first constituents and 1001 per million for the second constituents of these words. Examples of pseudohomophones and their controls derived from the base words are presented in Table 1.

Three types of pseudohomophones were differentiated according to whether the constituents of base words were replaced with orthographically dissimilar homophonic characters. Properties of the constituent morphemes of pseudohomophones (and the corresponding control nonwords) are summarised in Table 2. They were generally well matched across the three groups of stimuli, especially for the Keep Second and Change Both groups. The matched properties included the average character frequency (per million), visual complexity (in terms of the number of strokes per character), and the average 'productivity', which was indexed as the number of compound words that contained the characters as constituents or specifically as the last constituents. This measure correlated closely with character frequency (Institute of Language Teaching and Research, 1986).

The critical stimuli were assigned into six counter-balanced test versions. Each version had 39 pseudohomophones and 39 control nonwords, one third of them coming from each of the three groups. Pseudohomophones and control nonwords created from the same base words were split into different versions. In each version there were also 120 filler words and 42 filler nonwords. Nonword fillers were non-pseudohomophones, created by

TABLE 1
Experiment 1: Experimental design

	Pseudo		*Control*	
Keep First	严革	Yan[2] ge[2]	严围	yan[2] wei[2]
	行围	xing[2] wei[2]	行革	xing[2] ge[2]
Keep Second	研格	yan(2 ge[2]	研为	yan[2] wei[2]
	型为	xing[2] wei[2]	型格	xing[2] ge[2]
Change Both	研革	yan(2 ge[2]	研围	yan[2] wei[2]
	型围	xing[2] wei[2]	型革	xing[2] ge[2]

Note. Pseudohomophones in the table are derived from the high-frequency base words 严格 (yan[2] ge[2], *strict*) and 行为 (xing[2] wei[2], *behaviour*). The first characters in the 'Keep First' group are also the first characters of base words. The second characters in the 'Keep Second' group are also the second characters of base words. Pseudohomophones and the corresponding control nonwords in each group have the same sets of initial characters and the second characters. In other words, the control nonwords were created by re-combining the initial characters and the second characters of pseudohomophones in each group.

TABLE 2
Experiment 1: Properties of stimuli

	First Character			*Second Character*		
	Number of strokes	*Character frequency*	*Total productivity*	*Number of strokes*	*Character frequency*	*Total productivity*
Keep First	8.1	1030	58	7.8	1061	46
Keep Second	7.6	766	39	7.2	1001	63
Change Both	7.6	766	39	7.8	1061	46

Note. Total productivity refers to the average number of compound words that use the second characters as constituents irrespective of the constituent positions in compounds.

combining characters in a pseudo-random way. Syllables and characters used in the critical stimuli were not used in fillers. Another 10 words and 10 nonwords were chosen as practice items. Among them 6 were pseudohomophones, 2 to each category.

Procedure

Each word or nonword was generated in a computer program and stored on the hard disk as individual image files. These words or nonwords were in 48-point *songti* font. An item was about 2.4×3.8 cm in size and participants were seated about 60 cm from the screen. The presentation of stimuli to participants and the recording of reaction times and response errors in lexical decision were controlled by the experimental software DMASTR, which was made available to us by Ken and Jonathan Forster of the University of Arizona. In each trial, an eye fixation signal ('+') was first presented at the centre of the screen for 300 ms, followed by a 300-ms blank interval. A word or nonword was then presented for 400 ms for lexical decision. There was a 3-second interval between the disappearance of the last stimuli and the appearance of the next eye fixation point. The presentation of stimuli and the recording of reaction times were accurate to 1 ms.

Participants were tested in groups of three or less. They were asked to decide as quickly and as accurately as possible, by pressing 'yes' and 'no' buttons on the response boxes in front of them, whether the pair of characters seen on each trial was a real word or not. The dominant hand was used for the 'yes' keys. Each participant saw first a list of 20 practice items with similar compositions as the formal test. 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 fillers.

Participants

A total of 63 undergraduate students from Beijing Normal University were tested. They were native speakers of Mandarin Chinese and were paid for their participation. They had normal or corrected-to-normal vision.

Results

Three participants were dropped because of high error rates on critical stimuli (over 20%). This left 60 participants, 10 for each test version. Mean reaction times for each participant and each item were calculated, based on correct, untrimmed responses. Table 3 reports the mean reaction time and error percentage for each condition.

ANOVAs were conducted separately for RTs and error rates, with stimulus type (pseudohomophone vs. control) as a within-participant, within-item factor and stimulus group (Keep First vs. Keep Second vs. Change Both) as a within-participant, between-item factor. In the analyses of RTs, the main effect of stimulus type was found to be highly significant, $F_1(1, 59) = 29.461$, $p < .001$, $F_2(1, 232) = 15.453$, $p < .001$, indicating that pseudohomophones were overall more difficult to reject than control nonwords. The interaction between stimulus type and stimulus group was significant by participant, $F_1(2, 58) = 3.080$, $p < .05$, although not by item, $F_2(2, 232) = 1.903$, $p > .1$. Planned comparisons between pseudohomophones and control nonwords revealed significant effects for the Keep First group, $t_1(1, 59) = 4.045$, $p < .001$, $t_2(77) = 3.198$, $p < .01$, and for the Keep Second group, $t_1(1, 59) = 3.514$, $p < .001$, $t_2(77) = 2.472$, $p < .05$. However, the 8 ms difference in the Change Both group was not significant, $t_1(59) = 1.389$, $p > .1$, $t_2 < 1$. The main effect of stimulus group was significant, $F_1(2, 118) = 19.342$, $p < .001$, $F_2(2, 231) = 5.699$, $p < .01$, suggesting that the mean reaction times for the three categories of stimuli were different from each other. Newman–Keuls post hoc tests showed that stimuli in the Change Both group (658 ms) were responded to significantly faster ($p < .05$) than the stimuli in the Keep Second group (680 ms) and the stimuli in the Keep First group (693 ms). The latter two differed significantly by participant ($p < .05$) but not by item ($p > .1$).

TABLE 3
Experiment 1: Mean reaction times (ms) and error percentages (in parentheses)

	Pseudo	*Control*	*Effect*
Keep First	710 (6.7)	677 (4.2)	−33
Keep Second	692 (5.9)	667 (2.7)	−25
Change Both	662 (3.8)	654 (3.2)	−8

Response error rates were analysed in the same way. The main effect of stimulus type was significant, $F_1(1, 59) = 12.782$, $p < .001$, $F_2(1, 231) = 8.464$, $p < .01$, indicating that responses to pseudohomophones were overall more error-prone than to control nonwords. Planned comparisons between pseudohomophones and control nonwords showed significant differences for the Keep First group, $t_1(59) = 2.240$, $p < .05$, $t_2(77) = 1.884$, $.05 < p < .1$, and for the Keep Second group, $t_1(59) = 2.601$, $p < .05$, $t_2(77) = 2.297$, $p < .05$. Again, the difference in the Change Both group did not reach significance, $t_1 < 1$, $t_2 < 1$. The main effect of stimulus group was significant by participant, $F_1(2, 118) = 4.301$, $p < .05$, but not by item, $F_1(2, 231) = 1.897$, $p > .1$. There were more errors to stimuli in the Keep First group (5.9%) than to stimuli in the Keep Second group (4.6%) and to stimuli in the Change Both group (3.8%), consistent with the pattern in reaction times.

Discussion

The results provide a striking contrast between the significant interference effects observed for the mixed pseudohomophones (Keep First, Keep Second), which share the initial or final characters with their base words, and the absence of a significant effect for the pure pseudohomophones (Change Both). The null effect for pure pseudohomophones was replicated in several other experiments not reported here. Thus these results are inconsistent with a strong phonological mediation view, where access to lexical representations is either wholly or predominantly driven by phonological information elicited by the orthographic input. Although constituents of pure pseudohomophones presumably activate phonological representations (i.e., syllables) corresponding to the constituents of base words and this phonological activation may mediate or influence semantic activation of these constituents and base words, such phonological constraints have no significant impact upon semantic activation without the support of appropriate orthographic activation and direct orthographic access (Zhou & Marslen-Wilson, 1999; Zhou et al., 1999b). Activation of the base word purely through a phonological route seems either to be weak or non-existent, or to operate on a too slow time-course to affect the lexical decision response. The orthographic input of the pseudohomophones could not activate the orthographic representation for the base words in the lexicon, and the activation of the corresponding morphemic meanings may interfere with the semantic activation of base words. Information from orthographic and semantic processing would be sufficient for the decision system to say 'no' to the pure pseudohomophones before the potential phonological mediation for the whole words could impact upon lexical decision. We will return to the latter point in the Discussion of Experiment 3.

The absence of a significant effect for pure pseudohomophones conversely suggests the importance of orthography in Chinese lexical access. It is likely that the interference effect in the mixed conditions is mediated by the orthographically driven access of the morpheme shared between the mixed pseudohomophones and their base words. When a pair of characters like 严革 (yan[2] ge[2]) is presented, where the initial constituent is the same morpheme as the initial constituent in the base word 严格 (yan[2] ge[2], *strict*), this will trigger lexical access of the constituent characters, each of which is a word or morpheme in its own right. Under the view we described earlier of the representation of compounds in Chinese, this will lead to partial activation of the base word, thereby tending to slow down the lexical decision that a nonword is present. Although phonological information may play a role in this access process (i.e., by interacting with the orthographically driven processes), it is apparently quite subsidiary to the direct orthographic route.

EXPERIMENT 2

The purpose of this experiment was to investigate whether pseudohomophone effects in lexical decision are influenced by frequency and productivity of (the shared) constituent characters of pseudohomophones and whether a base word frequency effect can be found for pseudohomophones under certain circumstances. We used four types of base words: low and high frequency words with high frequency characters, and low and high frequency words with low frequency characters. Mixed pseudohomophones were created by retaining the initial characters of these base words but replacing the second characters with orthographically dissimilar homophonic characters. Both phonological mediation from syllabic representation of the initial and second morphemes and direct orthographic access for the shared initial morphemes should be influenced by character frequency, with higher frequency constituents producing more effective semantic activation of base constituents and base words. This should hold for the pseudohomophones irrespective of the frequency of the base word. In addition, if semantic activation is influenced by whole-word frequency, then this should produce further interactions. Pseudohomophones with low base word frequency but high character frequency (Low-High) should be more difficult to reject than their control nonwords, while pseudohomophones with low base word frequency and low character frequency (Low-Low) should show little effect. However, when base word frequency is high, we may see stronger effects for the pseudohomophones with low frequency characters (High-Low). By the same token, effects should be strongest for the High-High combination.

Method

Participants

Thirty participants were tested, 15 in each version. They were undergraduate students at Peking University and were paid for their participation.

Design and stimuli

Four groups of base words were selected, with 40 compound words for each of the four combinations of base word frequency and constituent character (High-High, High-Low, Low-Low, Low-High). The properties of these base words are listed in Table 4.

Pseudohomophones were derived from these base words by replacing the second constituents of base words with homophonic characters having no orthographic similarities to the base constituents. The properties of the second constituents in the pseudohomophones followed closely the properties of the replaced characters (see Table 5). Control nonwords were created by re-pairing the initial characters with the second characters of pseudohomophones in the same group, so that pseudohomophones and control nonwords in each group had exactly the same sets of initial and final characters.

The pseudohomophones and their control nonwords in each group were split into two counter-balanced test versions. Each version contained 80 pseudohomophones and 80 control nonwords, 20 each from the four groups. There were also 200 real word and 40 nonword fillers. Thus each version had 400 items, half of them requiring 'yes' responses and the other half 'no' responses.

The preparation of stimuli and testing of the participants were conducted in the same way as in Experiment 1, with the exception that a different experimental control software, called DMDX (an updated vesion of DMASTR) was used. This did not materially affect the running of the experiment

Results

Mean reaction times, based on untrimmed correct responses, were computed for participants and items. These, together with error rates, are reported in Table 6.

Three-way ANOVAs were used to analyse the RT data, with three within-participant factors, stimulus type (pseudohomophone, control nonword), base word frequency (High, Low), and character frequency (High, Low). There was a main effect of stimulus type ($F_1(1, 29) = 18.389$, $p < .001$, $F_2(1, 156) = 11.072$, $p < .01$), indicating that pseudohomophones

TABLE 4
Experiment 2: Properties of base words

	Base word			*Word freq.*	*First character*		*Second character*	
					Character frequency	*Total productivity*	*Character frequency*	*Total productivity*
High-High	条件	tiao[2] jian[4]	*condition*	202	1706	89	1313	70
High-Low	介绍	jie[4] shao[4]	*introduce*	55	106	16	99	14
Low-High	会员	hui[4] yuan[2]	*member*	7	1869	84	2170	82
Low-Low	销毁	xiao[1] hui[3]	*destroy*	3	129	25	85	18

TABLE 5
Experiment 2: Properties of stimuli

	Pseudohomophone		*Number of stroke*	*Character frequency*	*Total productivity*	*Last productivity*
High-High	条建	tiao[3] jian[4]	7.9	898	53	37
High-Low	介哨	jie[4] shao[4]	9.6	78	12	8
Low-High	会原	hui[4] yuan[2]	7.2	909	48	25
Low-Low	销悔	xiao[1] hui[3]	9.9	66	13	9

Note. Numbers listed in the table refer to the properties of the second characters of pseudohomophones and control nonwords.

were in general more difficult to reject than control nonwords. The main effect of base word frequency was not significant, $F_1 < 1$, $F_2 < 1$. The main effect of character frequency, however, was significant, $F_1(1, 29) = 15.421$, $p < .001$, $F_2(1, 156) = 5.380$, $p < .05$, indicating that pseudohomophones and control nonwords having high frequency constituent characters were more difficult to reject than pseudohomophones and controls having low frequency characters. The interaction between stimulus type and character frequency was significant by participant, $F_1(1, 29) = 11.138$, $p < .01$, although not by items, $F_2(1, 156) = 1.829$, $p > .1$, suggesting that pseudohomophone effects were larger for stimuli with high frequency constituent characters than for stimuli with low frequency constituent characters. Planned tests found that pseudohomophones in the High-High, High-Low, and Low-High groups were more difficult to reject than nonword controls: for High-High, $t_1(29) = 4.393$, $p < .001$, $t_2(39) = 2.415$, $p < .05$; for High-Low, $t_1(29) = 2.690$, $p < .05$, $t_2(39) = 1.795$, $.05 < p < .1$; for Low-High, $t_1(29) = 3.645$, $p < .01$, $t_2(39) = 2.703$, $p < .05$. However, there was no effect for the Low-Low group, $t_1 < 1$, $t_2 < 1$.

The analyses of error rate found a similar pattern, with a significant main effect of stimulus type, $F_1(1, 29) = 8.295$, $p < .01$, $F_2(1, 156) = 7.901$, $p < .01$,

TABLE 6
Experiment 2: Mean reaction times (ms) and error percentages (in parentheses)

	Pseudo	*Control*	*Effect*
High-High	684 (6.3)	654 (4.1)	−30
High-Low	671 (5.8)	649 (1.9)	−22
Low-High	688 (9.8)	660 (7.0)	−28
Low-Low	648 (2.5)	650 (2.2)	2

and a marginal three-way interaction between stimulus type, character frequency, and word frequency, $F_1(1, 29) = 4.615$, $p < .05$, $F_2(1, 156) = 1.723$, $p > .1$. This interaction indicated that the difference between pseudohomophones and controls in the Low-Low group was significantly smaller than the differences in other stimulus groups. Planned tests did not find a significant difference between pseudohomophones and control nonwords in the Low-Low group.

Discussion

This experiment revealed a clear pattern of pseudohomophone effects. Mixed pseudohomophones were more difficult to reject than control nonwords in lexical decision if the base words were of high frequency, whether the constituent character frequencies were high or low. Mixed pseudohomophones based on low frequency words, however, may or may not show a pseudohomophone effect, depending on the frequency of constituent characters. If the characters were of high frequency, a significant effect was observed. If the characters were of low frequency, pseudohomophones were no more difficult to reject than control nonwords.

Therefore, there is an interaction between the whole-word frequency of base words and the character frequency of constituents of base words and pseudohomophones. As we suggested earlier, word frequency can be embodied in the resting level of the semantic representations of whole words and/or in the strength of links between syllabic representations and between orthographic representations. Because semantic representations of higher frequency base words have higher resting levels, they need only minimal spread of activation from orthography (and possibly also from phonology) for them to be activated to a crucial level. In this situation, the frequency of constituent morphemes is not critical. If base words are of low frequency, their semantic representations have low resting levels and it may take time for them to be activated to the crucial level. The frequency of constituent characters, which represents the efficiency of direct orthographic access (and spread of phonological activation) to the semantic level, thus has more opportunities to play a role in determining the pseudohomophone effect. Note, however, it is the character frequency of the shared morphemes between pseudohomophones and base words, or more specifically the direct orthographic access for these morphemes, not the frequency of the other orthographically dissimilar constituents, that plays the dominant role in determining the semantic activation of base words and the pseudohomophone effect. Recall that there was no significant pseudohomophone effect for pure pseudohomophones in Experiment 1 even though both of their constituents were of high character frequency.

The generally slower reaction times and higher error rates in response to pseudohomophones and control nonwords composed of high frequency characters demonstrates again that lexical decision to Chinese compound nonwords is influenced by properties of individual constituents. In processing compound words and nonwords, constituent morphemes are decomposed and used to access their own representations as well as the representations of whole-words (Taft, Liu, & Zhu, 1999; Zhou & Marslen-Wilson, 1994, 1995, 2000b; Zhou et al., 1999a). For pseudohomophones and nonwords composed of high frequency characters, the activation of constituent morphemes (i.e., their orthographic, phonological, and semantic properties) sends positive signals to the lexical decision system, making it more difficult to say 'no'.

EXPERIMENT 3

Experiment 3 was conducted to provide converging evidence concerning the activation of phonological information associated with base words in an experimental task tapping more directly into phonology. Although the naming task is a good candidate for this purpose, it cannot be used effectively for compound words or pseudo-homophones. The vocalisation of pseudohomophones or other types of compound nonwords can be made on the basis of their initial characters alone. This would undercut any effects based on properties of whole words (Zhou et al., 1999b). Consequently, the task we used here was 'phonological decision' (e.g., McCann et al., 1988; Taft & Russell, 1992), in which participants were asked to judge whether an item they saw sounded like a real word. Responses to pseudohomophones in this task should be 'yes'. If phonological representations of base words are activated by pseudohomophones in this task, we should expect a frequency effect in which responses to pseudohomophones based on high frequency words are faster than responses to pseudohomophones based on low frequency words. Other things being equal, the activation of co-occurrence information between the constituents of compound words could be influenced by the whole-word frequency, with higher frequency words being activated faster by pseudohomophones. We used both mixed and pure pseudohomophones created from the same pairs of high and low frequency based words sharing the initial characters (e.g., 直接, zhi[2] jie[1], *direct*; 直觉, zhi[2] jue[2], *intuition*; see Table 7). While the mixed pseudohomophones kept the first characters (i.e., 'Keep First'; 直阶, zhi[2] jie[1]), the pure pseudohomophones replaced both characters of the base words with orthographically dissimilar homophonic characters (i.e., 'Change Both'; 职阶, zhi[2] jie[1]).

TABLE 7
Experiment 3: Properties of base words and critical stimuli.

				Character frequency	*Number of strokes*	*Total productivity*	*Last productivity*
Base	High	直接	zhi[2] jie[1]	698	8.0	47	25
	Low	直觉	zhi[2] jue[2]	567	8.1	37	19
Pseudo	High	直阶	zhi[2] jie[1]	545	9.3	29	14
	Low	直决	zhi[2] jue[2]	542	9.5	28	14

Note. Properties listed in the table were all of the second characters of the base words or pseudohomophones. Productivity refers to the average number of compound words that contain the second characters. Total = the number of compounds that use the second characters as constituents irrespective of their positions in compounds. Last = the number of compounds that use the second character as their last constituents.

Method

Design and stimuli

Sixty pairs of high frequency and low frequency two-character compound words sharing the initial characters were selected as base words (Table 7). The average word frequencies were 116 and 4 per million respectively for the two groups of base words. In selecting these words, we ensured that the second characters in the high and low frequency groups were as closely matched as possible on a number of standard properties, even though these characters were not presented to participants. The matched properties included the average character frequency (per million), visual complexity (in terms of the number of strokes per character), and the average 'productivity', which was indexed as the number of compound words that contained the characters as constituents or as the last constituents. The average frequency of the initial characters of base words, pseudohomophones and control nonwords was 704 per million and the average productivity of these characters was 53 per character.

The Keep First pseudohomophones were created by replacing the second characters of base words with homophonic characters that were orthographically dissimilar to the replaced characters. These new second characters in the pseudohomophones were matched on the relevant properties for the high base frequency and low base frequency groups. These properties included character frequency, visual complexity, and productivity (Table 7). The word class of the base constituents and the characters in pseudohomophones were not systematically manipulated. The Change Both pseudohomophones were created by replacing further the first constituents of the Keep First pseudohomophones with orthographically dissimilar homophonic characters. The average frequency of the initial characters of the Change Both pseudohomophones was 360 per million and the average productivity was 29 per character.

The two types of pseudohomophones were tested separately. In each sub-experiment, the critical stimuli were assigned, using a Latin square design, into two counter-balanced test versions for each sub-experiment. In each version, there were 30 pseudohomophones of high base frequency and 30 of low base frequency. Members of the same pairs of stimuli sharing the initial characters were split into different versions. Forty filler words were added into each test version. These pseudohomophones and filler words all required 'yes' responses in phonological decision. Another 100 nonwords that required 'no' responses were created in the same way as the nonword fillers used in other experiments.

Participants

Thirty-six participants were tested for the Keep First stimuli, 18 for each version. Another 47 participants were tested for the Change Both stimuli, 19 for one version and 28 for the other version. These participants were undergraduates at Beijing Normal University and were not tested for the previous experiments.

Results

The phonological decision task proved to be much more difficult than the lexical decision task. For the Keep First stimuli, three participants in one test version were discarded because their overall response error rates to all critical items were high (over 30%). Three pairs of pseudohomophones were also excluded because participants made too many (over 60%) errors to one of these pairs. If the 50% error rate cut-off line was adopted, 6 more pairs would be lost. However, the pattern of effects did not change whether 3 or 9 (out of 60) pairs of pseudohomophones were excluded. For the Change Both stimuli, 11 participants were particularly error-prone in phonological decision. The remaining participants also made a high percentage of incorrect responses. The mean reaction times and error rates, with and without these participants, are reported in Table 8, together with the means for the Keep First stimuli.

Responses to mixed pseudohomophones of high base frequency were about 43 ms faster than responses to pseudohomophones of low base frequency. This difference was significant both by participant, $F_1(1, 32) = 12.833$, $p < .01$, and by item, $F_2(1, 56) = 6.122$, $p < .05$. The difference between error rates was also significant, $F_1(1, 32) = 7.481$, $p < .05$, $F_2(1, 56) = 3.545$,

TABLE 8
Experiment 3: Mean reaction times (ms) and error percentages (in parentheses)

Keep First		*Change Both (with all participants)*		*Change Both (without worst participants)*	
High	*Low*	*High*	*Low*	*High*	*Low*
837 (20.5)	880 (25.4)	1249 (45.3)	1258 (47.4)	1221 (36.8)	1226 (41.6)

$.05 < p < .1$, with fewer errors to pseudohomophones of high base frequency than to pseudohomophones of low base frequency.

For pure pseudohomophones, it can be seen in the table that participants took painfully longer to decide whether these stimuli sounded like real words. The error rates approached the chance level. Even after 11 of the worst participants were discarded, the error rates were still around 40% and mean RTs remained at about 1200 ms.

Discussion

The base frequency effect in phonological decision to mixed pseudohomophones demonstrates that phonological representations of base words can be activated by the orthographic input, consistent with the pseudohomophone effects observed in the last two lexical decision experiments. This phonological activation includes not only the activation of constituent syllables of base words, but also the co-occurrence information associated with these constituents. Given that mixed pseudohomophones based on high and low frequency words had the same initial characters and had well-matched second characters, the frequency effect in phonological decision must come from the co-occurrence information. As we discussed previously, the base word frequency can be taken as a measure of the strength of links between constituent syllables. The higher the base word frequency, the easier the activation of the co-occurrence information.

The base frequency effect for mixed pseudohomophones in phonological decision contrasted with the absence of such an effect in lexical decision to the same set of stimuli (not reported here) and the absence of this effect in Experiment 2, suggesting that the phonological decision and lexical decision tasks tap into different aspects of lexical processing. The phonological decision task taps into phonological activation of constituent syllables and their co-occurrence information, even though this activation is influenced greatly by orthographic and semantic processing of the shared constituent morphemes (given the extreme difficulties with pure pseudohomophones). The lexical decision task, as we discussed earlier, instead taps more into semantic rather than phonological activation of base words. As long as the shared morphemes between pseudohomophones and base words are of sufficiently high frequency, semantic properties of base words can be efficiently activated through direct orthographic access (and through phonological mediation of syllabic representations), compensating for the low resting level of semantic representations of low frequency words and leaving no space for a base word frequency effect in lexical decision. If the shared morphemes are of low frequency, however, a base word frequency would be revealed.

Why is lexical decision to pseudohomophones and compound words relatively easy to carry out while phonological decision is so difficult? Although this question merits further investigation, we suggest that activation of semantic properties of constituents and/or whole words directly from visual input (and from phonological mediation) is very efficient for compound words and pseudohomophones. This semantic activation forms a stable, coherent pattern, which allows lexical decision to be made quickly. Without support of appropriate orthographic information, the activation of phonological information, however, was less stable, especially for the co-occurrence information associated with syllabic representations. For pure pseudohomophones, decision based on phonological activation is susceptible to interference from orthographic activation corresponding to individual input characters, and from semantic activation corresponding to the constituent morphemes used in the pseudohomophones. Such fragmentary orthographic and semantic activation do not form coherent patterns for the whole orthographic input, making the ‘yes’ responses extremely difficult. Without this interference, as for spoken words, there would be no particular difficulties with phonological decision (c.f., Zhou & Marslen-Wilson, 1994, 1995).

GENERAL DISCUSSION

The main purpose of this study was to investigate the activation of phonological information and its interaction with other aspects of lexical processing in reading Chinese compound words. Three experiments were reported to explore pseudohomophone effects in lexical and phonological decision. Pseudohomophones were created by replacing one or both constituents of compound words with orthographically dissimilar homophonic characters. Experiment 1 observed a significant interference effect for mixed pseudohomophones and the absence of this effect for pure pseudohomophones in lexical decision. Experiment 2 demonstrated that the pseudohomophone effect in lexical decision interacts with the frequency of the shared constituents of mixed pseudohomophones. While pseudohomophones based on high frequency words with high or low frequency characters and pseudohomophones based on low frequency words with high frequency characters were more difficult to reject than control nonwords, pseudohomophones based on low frequency words with low frequency characters did not show a significant effect. Experiment 3 found that phonological decision to pure pseudohomophones was extremely difficult to perform, but phonological decision to mixed pseudohomophones was easier. A significant base word frequency effect was observed for mixed pseudohomophones.

These data provide important evidence concerning the cross-script generality of pseudohomophone effects in lexical processing, as well as about phonological, orthographic, and morphological processing in reading Chinese compound words. They demonstrate (a) the contribution of orthography to pseudohomophone effects across different scripts; and (b) semantic activation as multiple constraint-satisfaction processes. In the following paragraphs, we discuss these points in relation to findings from this and some other relevant studies.

Orthographic contribution to pseudohomophone effects

At the beginning of this paper, we pointed out that studies using pseudohomophone effects as a tool to investigate phonological processing in reading English and other alphabetic scripts have tended to neglect the possible contribution of orthography to phonological and semantic activation in reading. Homophony in alphabetic scripts is intrinsically interwoven with orthographic similarity, so that pseudohomophones in English are also orthographically similar to their base words. Although researchers have tried to evaluate the contribution of orthography to pseudohomophone effects (or, in general, to phonological effects in lexical processing) by using orthographic controls, this approach, and the reasoning behind it, cannot exclude the possibility that the effects of phonological and orthographic properties of pseudohomophones on the activation of their base words might be interactive, rather than additive. That is, pseudohomophone effects may appear only when the pseudohomophones have the right orthographic properties, and the method of subtraction does not give us pure phonological effects. The differential effects for mixed and pure pseudohomophones in logographic Chinese, which allows a complete separation between phonology and orthography, and the extreme difficulties in phonological decision to pure pseudohomophones, indicates that, without appropriate orthographic properties, mere phonological overlap between pseudohomophones and their base words does not activate the base words strongly. It is normally the interaction between orthography and phonology, rather than a predominant phonological mediation, that drives semantic activation in lexical processing of Chinese (Zhou & Marslen-Wilson, 1999, 2000a; Zhou et al., 1999b).

The pseudohomophone effects for mixed pseudohomophones in Experiments 1 and 2 reflect the interaction between direct orthographic access to semantic properties of base morphemes and base words for the shared morphemes and phonological mediation through activation of constituent syllabic representations. The contrast between pseudohomophone effects for mixed and pure pseudohomophones suggest that this interaction relies predominantly on the contribution of direct orthographic access. Without direct orthographic access, there would be no additional spread of activation from syllabic representations to semantic representations and no activation of the co-occurrence information associated with these syllabic representations, as demonstrated by the absence of significant effects for pure pseudohomophones in lexical and phonological decision.

One might locate the orthographic influence on pseudohomophone effects to a post-semantic orthographic checking process, rather than to the process of accessing semantics. Thus semantic representations of base words can be activated, through phonological mediation, by both mixed and pure pseudohomophones. However, the orthographic checking process allows the pure pseudohomophones to be quickly rejected, resulting in null pseudohomophone effects. But it takes more time to discern pseudohomophones sharing morphemes with base words. While we have no definite data to contradict this account since it does not offer independent predications that can be tested (Jared & Seidenberg, 1991), we suggest that this account is awkward in accommodating the interaction between word frequency and constituent frequency (Experiment 2). It also has difficulties in accounting for the performance in the phonological decision task with pure and mixed pseudohomophones (Experiment 3). Presumably there is no need to conduct post-semantic orthographic checking in making phonological decision, and yet the participants behaved very differently with pure and mixed pseudohomophones. Moreover, orthographic effects on semantic activation have also been observed for single-character words in a phonologically mediated semantic priming paradigm with a naming task (Zhou & Marslen-Wilson, 1999). Again, it seems that no postlexical checking is needed for this task.

Although it is difficult to generalise the present conclusion about Chinese to English or other scripts given the differences between Chinese and English pseudohomophones, including script and compoundhood, it is conceivable that pseudohomophones used in most English studies are generally more like the mixed rather than the pure pseudohomophones in this study. Consequently, it is possible that pseudohomophone effects observed for English (e.g., McCann & Besner, 1987; McCann et al., 1988; Seidenberg et al., 1996; Taft & Russell, 1992), as for Chinese, depend crucially on the activation of orthographic properties shared between pseudohomophones and their base words. This suggestion is consistent with the finding that, in English, the homophone interference effect in semantic categorisation varies according to the orthographic similarity between homophones and category exemplars, with orthographically less similar homophones producing less interference (Coltheart et al., 1994; Jared & Seidenberg, 1991). Such orthographic modulation of the (pseudo)homophone effect was also reported in other studies on Chinese (e.g., Leck et al., 1995) and Japanese (e.g., Sakuma, Sasanuma, Tatsumi, & Masaki, 1988; Wydell, Patterson, & Humphreys, 1993)

Semantic activation as interactive processes

A fundamental issue in the study of visual lexical processing is the question to what extent semantic activation is constrained by phonological and orthographic processing. Data from the present study suggest that semantic activation is a result of multiple constraint-satisfaction processes in which both direct computation from orthography to semantics and indirect processes through phonological mediation interacts in real time. As we argued earlier, the lexical decision task for Chinese compound words is sensitive to semantic activation. The non-significant effect for pure pseudohomophones demonstrates that phonological activation on its own does not trigger or is too slow to affect semantic activation of base compound words. However, when phonological activation interacts with orthographic processing of appropriate morphemes, it does influence significantly semantic activation of base words. This point is further supported by the effect of character frequency of shared constituent morphemes in Experiment 2.

The relative weakness of pure phonology and the interaction between phonology and orthography in constraining semantic activation in reading Chinese has been demonstrated in studies of single-character words (e.g., Zhou & Marslen-Wilson, 1999, 2000a). The effect of phonological information on semantic activation of single-character words is mostly seen when the task is relatively difficult, such as the 'no' response in semantic categorisation (e.g., Leck et al., 1995) or semantic relatedness judgement (e.g., Xu et al., 1999), or when phonological activation is extremely efficient due to the support of sublexical processing (e.g., Zhou & Marslen-Wilson, 1999). Indeed, the relative weakness of phonology is also supported by a number of studies on Chinese or Japanese Kanji compound words, even though these studies did not go into details of how the processing of individual constituents is conducted and how orthographic information drives semantic activation of constituent morphemes and whole words. Zhou and Marslen-Wilson (2000a) and Zhou et al. (1999b) found that homophonic compound words sharing no orthographic similarities (e.g., 洁净, jie[2] jing[4], *clean*; 捷径, jie[2] jing[4], *shortcut*) do not significantly prime each other in lexical decision. We also observed no homophone interference effect for compound words (e.g., 捷径, jie[2] jing[4], *shortcut* and 卫生 wei[4] sheng[1], *hygienic*, which is semantically related to the homophone 洁净, jie[2] jing[4], *clean*) in semantic judgement task. Similarly, Zhou et al. (1999a) found no priming effects between compound words having orthographically dissimilar homophonic morphemes (e.g., 滑翔 hua[2] xiang[2], *glide*; and 华贵 hua[2] gui[4], *luxurious*) in either masked priming or visual-visual priming lexical decision. In semantic categorisation, Sakuma et al. (1988) found no homophone interference effects for homophonic Kanji compound words sharing no characters with category exemplars.

However, when homophones share characters or have orthographic similarities with base words or category exemplars, strong phonological effects are observed in semantic tasks or semantic designs. Wydell et al. (1993) and Sakuma et al. (1988), for example, found a homophone interference effect for homophones sharing one character with category exemplars in semantic categorisation for Japanese Kanji. Zhou et al. (1999a) found that compound words having homographic characters (e.g., 华侨 hua[2] qiao[2], *overseas Chinese*; 华贵 hua[2] gui[4], *luxurious*, where 华 means 'Chinese' in the first word and 'magnificent' in the second word) prime each other in lexical decision and the priming effect varies according to whether the homographic morphemes are also homophonic. In the present study, we found that pure pseudohomophones did not create interference in lexical decision, but mixed pseudohomophones sharing morphemes with base words were more difficult to reject than controls. Compared with previous studies on Chinese or Japanese Kanji compound words, the present study took advantage of the experimental designs for pseudohomophones and provided a detailed link between the processes involved in the activation of individual morphemes and the interaction between phonology and orthography (and morphology) in driving semantic activation of compound words.

To summarise, using pseudohomophone effects as a diagnostic tool, this study demonstrated that phonological overlap without appropriate orthographic support does not produce significant pseudohomophone effects in logographic Chinese, and that orthographic information may play a dominant role in the interactive processes driving semantic activation in reading Chinese.

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