

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

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

FZW S' cgWfa', i ZW dSM' Yea_ WZ' Yi dffWM Zai Va kag
dMaY [lVS i ad/16 a kag geWag' Vfa 'aa] gb' Si adVXh_ kagd
_ WIS'VUfa' Sdk'ladVa kag geW W' Yl

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

phy to semantics. Only in this way can the two-step indirect access to semantics via phonology have an overall advantage over the direct route from orthography, so that the phonologically mediated route to semantics can dominate over the direct computation from orthography to meaning.

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

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

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BZa' a'a'k S' YgSWag' Ve
EW S' flé S' YgSW W' Y

BkafW S'fU_ Sbb' YTW W adZa xBzK
S' VbZa' a'a'k _ W' eZSf' SbZSfMU
i dff' Y'f' W' Y'efi fZ' YeSaw
bch' ag' UWel [Sdifa Zai fZMkafWbWwZM

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

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

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

Previous Studies

Perfetti and his colleagues used three experimental paradigms to investigate the relative time course of semantic and phonological activation in reading Chinese. The first paradigm was backward masking, in which a briefly exposed target was followed immedi-

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

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

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

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

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

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

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

However, the relations between orthography and meaning are arguably less arbitrary in Chinese than in alphabetic languages. This is because semantic radicals in complex characters may have the function of indicating the semantic category of the whole characters, although this function has been obscured for many

characters (D. Li, 1993; Yin & Rohsenow, 1994). There is evidence that this function helps the semantic activation of the whole characters (e.g., Feldman & Siok, 1999; Zhou & Marslen-Wilson, 1999b). Moreover, the fact that some characters have multiple, usually related, meanings does not necessarily imply that semantic activation of these characters is more difficult (see, e.g., Azuma & van Orden, 1997). Therefore, it can be argued that functional analyses of the Chinese writing system do not necessarily point to an earlier phonological than semantic activation in reading Chinese.

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

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

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

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

related meanings)

HlegS'zhlegS' _w' ebabw' fzwjwbw' Wf dSVUZSdUw/dSZMfZS' ZWQ' Yeag' Vefz
Bd' ['YlefZW]' VaefgVkgew,i ZWbVbabVwSVa' W adV'S VfZW dVZfSXWfZfz fZM
dSVS' afZWli adM i ZUZ [eVfZWdVfWadg' dSVfWz;XZVfi ai adV'SdVwSVfW fZW kag
SdVegbaeVfa TVSTVfa dSVfZVAA' Vi ad' _adVSe'kTMSgeVZWVf'f' adVZVbekag
'Suf'HSVfZ
>V[U'SVMe]a' _w' efZSf fZWbSd'Ubs' feySe ['fZWjwbw' Wfi Sefa VwVwVw ZWZVwS
i adV'eZWVSeleSdS'i adVad' afSdS'i adVz

Method U k #
O ‡

Design and stimuli. The design and sample stimuli are presented in

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

EA3 /'ɛf_ g'gea` eWSek` UZch` k'fi_ W` eZai
_ gUZf_ WZWV SeTW VV dSV` YfZWV` d'fi adV
S` VdSV` YfZWV` Vi adVž

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

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

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

Experiment 2

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

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

Method

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

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

