
Reading and Writing: An Interdisciplinary Journal **10:** 165–200, 1998.
C.K. Leong & K. Tamaoka (eds.), Cognitive Processing of the Chinese and the Japanese Languages, pp. [11–46]

Phonological codes as early sources of constraint in Chinese word identification: A review of current discoveries and theoretical accounts

LI-HAI TAN & CHARLES A. PERFETTI
Learning Research and Development Center, University of Pittsburgh, USA

Abstract. A written Chinese character has a more direct connection with its meaning than a written word in English does. Moreover, because there is no unit in the writing system that encodes single phonemes, grapheme-phoneme mappings are impossible. These unique features have led some researchers to speculate that phonological processing does not occur in visual identification of Chinese words or that meaning is activated earlier than phonology. This hypothesis, however, has been challenged by more recent discoveries that suggest that phonology in Chinese, just as in English, is central to the visual recognition system. The present paper reviews the literature on phonological codes as early sources of constraint in Chinese word identification and considers the specific aspects of phonological and orthographic processing in Chinese that may differ from those in English. It emphasizes that early phonological processes and phonological mediation are two different questions in the identification-with-phonology hypothesis. 'Mediation' and 'prelexical phonology', two very important concepts in the literature on phonological computation in reading English, are both misleading in Chinese.

Key words: Phonological processing, Semantic processing in Chinese, Phonological mediation, Prelexical phonology, Chinese character recognition, Visual recognition, Reading Chinese

Introduction

Two decades ago Tzeng, Hung and Wang (1977) reported their seminal experiments on phonological processing in Chinese reading. With a grammaticality judgment task (Experiment 2) they found that decision time was longer for sentences with phonemically similar characters than for sentences with phonemically dissimilar characters. This result, contrary to some researchers' speculation that reading in Chinese does not involve phonological reading (e.g., Baron & Strawson 1976; Smith 1985; Wang 1973), suggested that phonology plays an as important role in reading Chinese sentences as in reading English sentences. Tzeng et al.'s conclusion has spawned a lively controversy over the generality of phonological activation. Subsequent studies have extended to the character level (e.g., M. J. Chen, Yung & Ng 1988; Cheng & Shih 1988; Hoosain 1981; Hoosain & Osgood 1983; Kao & Cheng

1981; Peng, Guo & S. Zhang 1985; Perfetti & S. Zhang 1991; Tan & Peng 1991; Tzeng & Hung 1978; H. Zhang & Shu 1989; W. Zhang & Feng 1992), while substantiating Tzeng et al.'s hypothesis at the sentence and memory phases of language processing (e.g., Treiman, Baron & Luk 1981; Xu 1991; Yik 1978; S. Zhang & Perfetti 1993). Until the early 1990s the general consensus as to phonological processing in visual character identification has been that phonology plays no role in recognition, or that character meaning is accessed prior to phonology (for reviews, see Hoosain 1991; Hung & Tzeng 1981). This view has been labeled the *identification-without-phonology hypothesis* or *meaning-before-phonology hypothesis* (see Perfetti & S. Zhang 1995a).

The identification-without-phonology position, however, has been challenged by more recent studies (e.g., Cheng & Shih 1988; Hung, Tzeng & Tzeng 1992; Perfetti & S. Zhang 1991; Tan & Peng 1991). Emerging evidence has led researchers to propose an *identification-with-phonology hypothesis* that assumes that phonological codes provide early sources of constraint in recognizing characters. On this view, phonology in Chinese, just as in English, is central to the recognition system (Perfetti, S. Zhang & Berent 1992).

In the following sections, we review current discoveries in support of the identification-with-phonology hypothesis, and summarize the theoretical assumptions of this hypothesis that have been postulated in recent publications (e.g., Perfetti & Tan 1998a, b; Perfetti & S. Zhang 1995a; Tan, Hoosain & Peng 1995; Tan, Hoosain & Siok 1996; Tan & Perfetti 1997a). We begin with a brief description of some important features of the Chinese writing system, which constitute a basis for the traditional view that phonology is 'silent' in character recognition. In the second section we review the basic assumptions of the identification-with-phonology hypothesis. Following the summary of theoretical assumptions, we consider theoretical grounds responsible for this point of view and discuss recent evidence that suggests the ubiquity of phonological processing in Chinese word identification. In Section 5 we focus on the important distinction between early phonological processes and phonological 'mediation'. Finally, we discuss some aspects of phonological processing in Chinese that may differ from those in English.

1. The Chinese writing system and the identification-without-phonology hypothesis

Written Chinese is usually referred to as a morphemic (e.g., Leong 1973) or morphosyllabic (e.g., DeFrancis 1989; Mattingly 1992) system, in which a character, as a basic, monosyllabic writing unit, maps onto a morpheme

rather than a phoneme in the spoken language. In Chinese, words coincide with morphemes (i.e., characters), although a morpheme often combines with other morphemes to form bimorphemic words. In this paper we use words and characters interchangeably.[1]

The morphemic nature of Chinese writing has resulted in a close connection between graphic form and meaning, as reflected by the following two aspects. First, it has been argued that Chinese characters, especially simple characters (i.e., pictographs and self-explanatory characters) that are pictographic in origin, are directly encodable as abstract or even concrete images that are themselves representations of meanings. This is called the *direct-image hypothesis* (for a review, see Liu 1995). On this account, a character's graphic form vividly signals its meaning (Wang 1973). A second aspect reflecting the close form-meaning associations stems from the high transparency of sub-character units' meaning to compound characters' meaning. Compound characters usually comprise two semantic components (i.e., associative compounds) or one semantic component and one phonetic component (i.e., phonetic compounds). Previous research has suggested that semantic portions usually hint at the meaning of whole characters. For example, Fan (1986) and Jin (1985) evaluated the semantic cueing function of 糸 (*silk* or *fabric*) and 扌(*action, hand*), demonstrating that more than 80% of compound characters have their meanings indicated by these semantic portions.

Thus, for simple characters, the graphic form-meaning relations are highly transparent at the character level, due to their pictorial origins. With associative or phonetic compounds, form-meaning connections are quite strong in the sub-character level, despite the variability of a semantic component's meaning transparency across compound characters (Feldman & Siok 1997; Tan et al. 1995).

The graphic form-phonological form relations are defined over the character to syllable level. Although about 85 percent of present-day characters are phonetic compounds containing a phonetic component that can give information about the pronunciation of the compound (Perfetti & Tan 1998b; Zhu 1988), estimates of the validity of this information reveal that only 38 percent of phonetic components are helpful (Y. Zhou 1978).[2] Moreover, it is never the case in Chinese that a phonetic component maps onto a subsyllabic phonological representation in the way that a letter maps onto a substring of a word's phonological form in an alphabetic system. In *beech*, the *b* corresponds to /b/, and the latter is a segment of the word. In 理 (/li3/,[3] *reason*), 里 (/li3/, *inside*) does not correspond to a piece of the word's phonological form; it is the syllable that segmentally is exactly the word. Thus, Chinese writing does not allow a true segmental analysis that is fundamental to alphabetic systems (Leong 1997; Mattingly 1987).

Another salient characteristic of Chinese phonology is its extensive homophony. In modern-day usage there are about 4,574 characters in terms of the *Modern Chinese Frequency Dictionary* (1986) and 420 distinct syllables (disregarding tone). Therefore, on average 11 characters share one pronunciation. In auditory perception of Chinese words, context plays a large role in selecting an intended word from among its phonetically similar cohorts (Li & Yip 1996). In visual recognition, characters with the same sound are disambiguated by their graphic forms. Thus, a graphic form serves, in principle, to select meaning while providing an escape from rampant homophony.

In summary, written Chinese as described above has some unique characteristics as far as the script-sound relation and the script- meaning relation are concerned. It is these attributes that have led some researchers to claim that phonological processing does not occur in visual identification of Chinese characters and/or that character meaning is activated earlier than phonology (e.g., Baron & Strawson 1976; M. J. Chen et al. 1988; Hoosain 1991; Hoosain & Osgood 1983; Hung & Tzeng 1981; Peng et al. 1985; Smith 1985; Tzeng & Hung 1978; Wang 1973).

2. The identification-with-phonology hypothesis: Basic assumptions

Contrary to the hypothesis that phonological activation does not occur in Chinese word reading, recent studies have demonstrated a powerful role of phonological information, which places Chinese word identification closer to that of other languages than is often assumed (e.g., Cheng & Shih 1988; Hung et al. 1992; Lam, Perfetti & Bell 1991; Perfetti & S. Zhang 1991). The identification-with-phonology hypothesis, as construed by Perfetti, Tan and colleagues (Perfetti & S. Zhang 1995a, b; Perfetti & Tan 1998a, b; Tan et al. 1995, 1996; Tan & Perfetti 1997a), claims that phonology is central to word recognition rather than the result of an optional process or a byproduct of word identification. Phonology, as a constituent of word perception, provides early sources of constraint in word reading. This *centrality assumption* was proposed by Perfetti et al. (1992), paralleling the identification constituency principle developed by Perfetti, Bell and Delaney (1988) with English.

As an elaboration of the above assumption, Perfetti and Tan (1998a), based on their experimental findings, suggest that phonological information is activated at the same moment as the complete identification of a character's orthographic information ('complete graphic recognition'). By 'complete' Perfetti and Tan (1998a) mean the extent to which the activation of a character's orthographic representation is sufficient for the identification system to distinguish this representation from other (similar and partly activated) representations. Thus, although analysis and integration of graphic information of

a character initiates identification, phonological activation does not lag behind the activation of a fully disambiguated graphic form, but rather is part of a psychological moment of identification.

As for the timing relations of phonological and meaning activation in the recognition of single character words, there is a possibility that semantic meaning lags behind phonology (Tan et al. 1995, 1996). More specifically, the speed of meaning activation depends on the attributes of words meaning. It has been evidenced that a word's referential (semantic) meaning, associative relation, and connotative sense are not accessed synchronously (e.g., Hoosain & Osgood 1983; Tan et al. 1996). The timing asynchrony of phonological and meaning activation, accordingly, depends on the meaning valence under investigation. However, the *phonology-semantics lag assumption* holds across various situations.

Although phonology may be activated earlier than semantics, this does not mean that phonology mediates access of meaning. Tan and Perfetti (1997a) argued that phonology, once activated, spreads over the meaning nodes connecting with it. Because of the high degree of homophony, identifying a specific word from its activated phonetic segments is not likely. A segmentally defined syllable by itself can never pick out a single word meaning from the multiple meanings associated with the syllable. Phonology may influence meaning activation; but it cannot simply mediate meaning access as an additional step in identification or through a separate route. Because the number of meanings associated with a certain syllable is, in principle, a function of homophone density (i.e., the number of characters sharing one pronunciation) of this syllable, the limits of phonology are set by the degree of *phonological diffusion*, i.e., the extent to which a given phonological form (syllable) is associated with many different characters (high diffusion) or relatively few characters (low diffusion).

In summary, the identification-with-phonology hypothesis has been elaborated on several important points. This hypothesis is applicable both to the recognition of single characters and two-character words.

3. Early phonological activation in visual recognition of Chinese single-character words: Theoretical grounds and empirical evidence

The identification-with-phonology hypothesis seems to be counter to the conventional wisdom of written Chinese as previously discussed. This raises the general question of why phonology may be activated very early, even presemantically during recognition. Perfetti and associates (Perfetti & Tan 1998a; Perfetti & S. Zhang 1995a), in a more universal sense, postulate a *determinacy principle* that claims that the asymmetry of the (graphic) form-

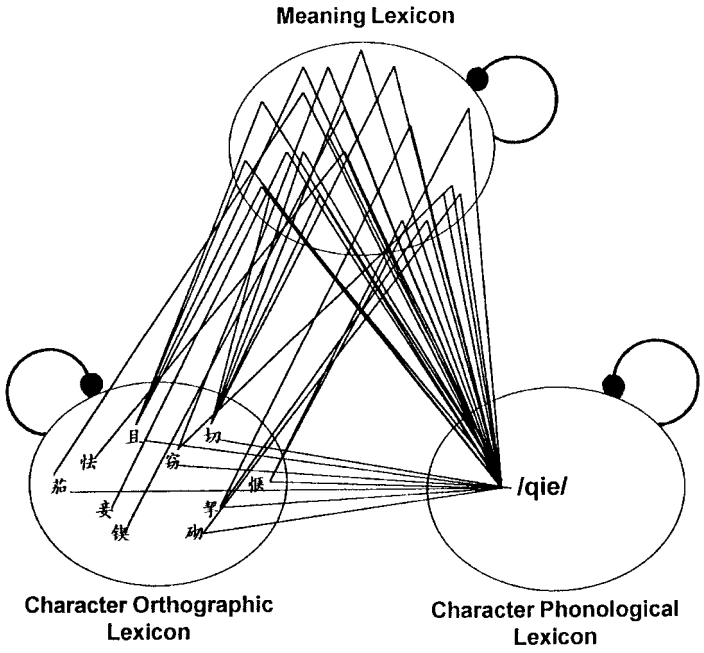

Figure 1. A framework of the mental representations of orthographic, phonological, and semantic information for Chinese characters (from Tan & Perfetti 1997a).

(phonological) form relations and the form-meaning relations determines the timing asynchrony of phonological and semantic activation. In particular, there is a nearly one-to-one form-form connection and a one-to-many form-meaning connection. For example, the word 表 is pronounced /biao3/, whether it occurs in isolation or in context. However, the graphic form (as well as the phonological form /biao3/) of 表 connects with a number of meanings, including *watch*, *table*, *express*, *surface*, *model*, *meter*, etc. As a result, the mapping from graphic form to phonological form is nearly deterministic, while the mapping from (graphic and phonological) form to meaning is under-deterministic. The latter type of connection is of a *divergence* type – one form diverges onto many meaning nodes. Figure 1, reprinted from Tan and Perfetti (1997a), characterizes the form-form and form-meaning relations. On this determinacy principle, the one-to-one single-valued relation is more readily built than the one-to-many relations in activation processes. Thus, phonological information may be activated very rapidly, even prior to meaning information.

Additional explanations for the rapidity of phonological activation have also been suggested in the literature. Tan et al. (1995, 1996), for example, have noted that although neither the grapheme-phoneme correspondence

rules nor subcharacter-subsyllable conversion rules can be used to learn and pronounce characters, written Chinese has a very limited number of characters, resulting in a close, character-level form-sound association. According to the *Modern Chinese Frequency Dictionary* (1986), 4,574 characters make up 100 percent of a 1,810,000-character Chinese corpus, with the first 2,000 characters amounting to 98 percent. Cheng (1982), by comparing Chinese and English words, reported that only 2,460 characters are needed to amount to 99% of a 1,177,984-character corpus (Liu, Chuang & Wang 1975), whereas 40,000 English words are needed to account for the same proportion of a one million-word English corpus (Kucera & Francis 1967). Thus, commonly-used characters make up of a large proportion of Chinese reading materials. In daily reading and practice, it is easy to build a close association between a graphic form and its corresponding phonological form at character level. Here we label this proposal the *overlearning hypothesis*.

Relevant to the overlearning proposal is that pervasive homophony might lower the activation threshold of a lexical phonological entry. As illustrated in Figure 1, although each of the characters 切且怯窃茄惬妾锲挈趄 has its own orthographic representation in the orthographic subsystem, all these graphic forms converge onto one single phonological unit /qie/ – a typical *convergence* type. Hypothetically, in learning to read, encounter with any of these characters will activate the common phonological representation, leading to lowering of its activation threshold. This is a frequency-driven threshold lowering phenomenon (Tan et al. 1996).

Note that the proposals of overlearning and convergent connections do not explain the question of why a character's (referential) meanings may be activated slowly relative to phonology, although they provide a basis for the rapidity of phonological activation. The determinacy principle as described above, on the other hand, provides a theoretical account for the phonology-semantics lag phenomenon. This account, according to Perfetti and Tan (1998a), captures a universal linguistic property of script-sound-meaning relations across writing systems, and is in harmony with Van Orden and Goldinger's (1994) resonance/coherence framework of English word recognition (see also Stone & Van Orden 1994).

In the case of Chinese, it has been argued that semantic dimensions of a character are not as readily accessed as are widely assumed (Tan et al. 1996). In a system with relatively few characters, each character acquires rich meanings, indeed multiple meanings. This leads to a kind of semantic uncertainty when readers attempt to retrieve the meaning of a character out of context. For example, the high-frequency character 服 (/fu2/) has the following meanings as listed in the dictionary: (a) *clothes, dress*; (b) *take (medicine)*; (c) *serve*; (d) *be convinced, obey*; (e) *be accustomed to*; (f) *dose*; and (g) *surname*. Of

the seven meanings, the first four are frequently used and it is difficult to say which meaning is a dominant meaning. Empirical evidence has revealed that it is difficult for subjects to express this character's meaning within a brief time: they either reported different meanings or could not report any meaning. This demonstrates a semantic uncertainty effect (Tan et al. 1996).

Likewise, there is another kind of character in Chinese which has relatively few meanings, usually with a dominant one. Readers, however, cannot express their meanings. In Tan et al.'s (1996) study, when 9 subjects were required to report the meaning of 巴 (/ba1/, *hope honestly*; *cling to*), eight of them could not retrieve any meaning of this character, although they all acknowledged that 巴 was a single-character word with meanings independent of context. This demonstrates a kind of semantic inaccessibility. In the study of Tan et al. (1996), they collapsed semantic uncertainty and inaccessibility, labeling them *semantic vagueness*.

It is interesting to note that when subjects were required to express a character's meaning, they repeatedly pronounced the character, with a difficulty in reporting meaning. This simple phenomenon indicates that the activation of meaning(s) of some Chinese characters becomes a difficult event when characters appear out of context. This difficulty, on one hand, makes presemantic phonological activation a reality. On the other hand, it leads to a suggestion that semantic vagueness influences the time course of semantic information of characters (Perfetti & Tan 1998a).

Thus, there is a set of interrelated observations that help explain the important role of phonology, an importance that would otherwise be puzzling within the traditional description of the Chinese writing system. The identification-with-phonology hypothesis is not only consistent with certain facts (i.e., form-form and form-meaning mapping asymmetry, overlearning, connection convergence, and semantic vagueness), but also has some direct empirical support. In the following we review current findings that show ubiquity of early phonology activation.

1. *Phonological effects in the primed perceptual identification paradigm*. Perfetti and S. Zhang (1991) presented a character prime either for 20 ms or for 50 ms, which was followed immediately by a character target exposed for 35 ms before being pattern-masked. Primes were visually, phonologically, or semantically similar to a target, or were unrelated to it. Subjects were required to write down the target. At the 20-ms exposure duration, neither phonological nor semantic priming was obtained. When the prime was exposed for 50 ms, however, both homophonic primes and semantic primes facilitated target identification. These findings suggested that phonology is accessed within the first 50 ms of character identification and that semantic activation

does not precede phonological activation in Chinese. Moreover, this research, paralleling studies with English and other alphabetic systems (e.g., Ferrand & Grainger 1992; Frost 1994, 1995; Lukatela & Turvey 1996; Perfetti et al. 1988; Pollatsek, Lesch, Morris & Rayner 1992; Rayner, Sereno, Lesch & Pollatsek 1995; Van Orden 1987; Ziegler & Jacobs 1995; Ziegler, Montant & Jacobs 1997; for a review see Frost 1998), indicated a high sensitivity of phonological information to temporal variables.

Following Perfetti and S. Zhang (1991), W. Zhang, Feng and He (1994) employed the same perceptual identification paradigm, presenting a prime for 25, 35, or 45 ms that was replaced by a target for 40 ms. The main findings were that within 35 ms, primes both homophonic and visually similar to targets facilitated target identification, while primes homophonic but visually dissimilar to targets inhibited recognition. Phonological effects disappeared at 45 ms, at which point semantic primes began to enhance target processing. Although there were some differences in the results of these two studies, both W. Zhang et al. (1994) and Perfetti and S. Zhang (1991) found evidence for phonological priming at brief exposures when perceptual identification was required.

2. *Evidence from backward masking*. Using the backward masking paradigm modeled by Naish (1980) and Perfetti et al. (1988), Tan et al. (1995) varied exposure duration and relationship of target and mask. On each trial, a character target was exposed for a brief time, followed immediately by a character mask that was replaced by a pattern mask of 1,500 ms. Subjects were asked to write down the targets. When the target and mask were presented for 50 ms and 30 ms, respectively, graphically similar masks affected target recognition, whether targets were frequently or less frequently used. There were no effects from homophonic or semantic masks relative to unrelated control masks, a result replicating what Perfetti and S. Zhang (1991, Experiment 1) observed in backward masking. With exposure durations of the target and mask increased to 60 ms and 40 ms, respectively, Tan et al. (1995) demonstrated a significant effect of phonological masks on the identification of high-frequency targets in the absence of any corresponding effect of semantic masks. This finding suggested that phonological information is used earlier than semantic information during recognizing high-frequency characters.

In another study with the same paradigm, Tan et al. (1996) manipulated target exposure duration, target semantic vagueness, and mask type. Characters' semantic vagueness was distinguished in terms of subjects' evaluation with a 7-point rating scale. A semantically precise character has a dominant and well-specified meaning in readers' mental lexicon; whereas a semantically vague character either has high semantic uncertainty or has

meanings which cannot be precisely elucidated without context. There were four mask types: visually similar, homophonic, meaning related, and control. In Experiment 1, targets and masks in the meaning-related conditions were semantically related without strong association. When a target was exposed at threshold +14 ms, homophonic masks enhanced recognition, while semantic masks did not matter, regardless of targets' semantic precision. In Experiment 2, targets and masks in the meaning-related masking situations were strongly associatively related (with or without semantic overlap). At threshold +14 ms, homophonic masks facilitated identification, a finding consonant with the finding of Experiment 1. Moreover, associate masks facilitated target processing for characters with precise semantics but not for characters with vague semantics. These outcomes indicated that phonology is activated before semantics and that semantic and associative dimensions of word meaning are accessed asynchronously.

Sought-for codes in backward masking and masked priming: Phonological or graphic? Both target and mask/prime were exposed briefly in the backward masking and masked priming paradigms employed in the studies just introduced. One may argue that, because visual information is available only for a very short time, data-driven processing of words is severely limited in these situations, which might encourage subjects to rely on phonology to make best performance (e.g., Verstaen, Humphreys, Olson & d'Ydewalle 1995). Conceivably, a phonological strategy will lead to phonological effects in Chinese and an additional effect of homophonic masks over graphemic masks in English (due to graphemic similarity between homophonic targets and masks; see Perfetti & Bell 1991).

Nevertheless, the above strategic account is questionable when we focus on the data from Chinese. Graphic masking/priming effects always preceded phonological effects in the studies by Perfetti and S. Zhang (1991) and by Tan et al. (1995, 1996). Phonological activation in these cases did not precede or even coincide with orthographic activation. Rather, it immediately followed orthographic activation, popping out with a fully-identified orthographic unit.

Even in English, research with the backward masking procedure has shown that phonology does not help target identification in some situations. Tan and Perfetti (1998) presented an English word target for 28 ms, followed immediately by a word mask of 28 ms. Homophonic masks produced significantly *less* effects than did graphemic masks, a result in contrast with the finding with English pseudoword masks (e.g., Perfetti & Bell 1991).

Our investigations with Chinese as well as English word masks suggest that orthographic but not phonological codes are sought for in the data-limited

paradigms. Phonology, whether it helps or hinders, is accessed as part of word identification.

3. *Phonological interference effects in the meaning judgment task*. In masking and priming paradigms, evidence for the role of phonological, graphic, and meaning dimensions generally rests on whether these sources of information enhance performance relative to some baseline (but see Tan & Perfetti, 1998). A more complete picture can be obtained by considering a paradigm in which the use of some information source, e.g., phonology, actually inhibits performance. Such a paradigm further may be able to demonstrate whether the information is activated automatically. Perfetti and S. Zhang (1995b) devised this kind of task. In the synonym judgment task, subjects were presented with successive characters and asked to decide whether they had the same meaning. In some cases, the succeeding character (core) had the same pronunciation as the preceding character (cohort) while having a different meaning. In the homophone judgment task, subjects were asked to decide whether two characters presented successively had the same pronunciation. In some cases, the core character had similar meaning to the cohort character while having different pronunciation. They varied cohort-core stimulus onset asynchronies (SOAs) at 90, 140, 260, and 310 ms. In the homophone judgment task, there was no meaning interference at the shortest SOA, and meaning interference started at 140-ms SOA. But for the synonym judgment, phonological interference occurred at all four SOAs.

The Perfetti and S. Zhang (1995b) study demonstrated that although phonology interfered with meaning performance in the semantic decision task, its activation could not be suppressed, reflecting the automaticity of phonological processing. In addition, phonological interference began to occur at 90 ms SOA, whereas semantic interference began to take place at 140 ms. This may imply that phonological activation preceded semantic activation.

Because the characters were presented asynchronously in Perfetti and S. Zhang's experiments, it is conceivable that phonological interference arises through the requirement of remembering the first character. However, even if this were the case, the phonological activation must occur quickly, i.e., within 90 ms during the identification of the first character. If the subject could make the meaning judgment without this activation, then it should not occur. Nevertheless, presenting the core and cohort characters synchronously would help test the role of sequential memory demands, and S. Zhang and Perfetti (1997) recently have done so. In an experiment that presented cohort and core words at the same time (i.e., SOA = 0 ms) to minimize memory demands, they

discovered the same pattern of phonological interference effects as in other SOA conditions.

4. *Evidence from phonological priming in lexical decision*. With a primed lexical decision task, Cheng and Shih (1988, Experiment 1) presented a character as target, preceded by another character (prime) that could be visually similar and/or homophonic to the target. More precisely, four prime types were constructed: visually similar, homophonic but visually dissimilar, homophonic and visually similar, and control. They varied SOAs at two levels of 50 and 500 ms. The results indicated that lexical decision to a target character was faster when it was preceded by a homophonic prime than when preceded by a phonologically-dissimilar character prime. Moreover, the homophonic priming effect was independent of SOAs and visual similarity between prime and target. In Experiments 2 and 3, they varied SOAs at 50, 150, 500, and 750 ms, and required subjects to make a 'yes' response if both a prime and a target were legal Chinese characters and a 'no' response if either of them was a noncharacter. Response accuracy was recorded. Experiments 2 and 3 produced a compatible pattern of results as Experiment 1. Cheng and Shih suggested that phonological processing takes place automatically in identifying Chinese characters.

5. *Phonetic transfer in pronunciation judgment*. Lam et al. (1991) investigated phonetic transfer in bidialectal reading for Chinese characters. They presented character pairs and asked Cantonese-Mandarin speakers to decide whether the two characters had the same pronunciation in Mandarin. Since Chinese characters can be read with more than one dialectal pronunciation, two characters of the same pronunciation in Mandarin might have the same (S-S condition) or different (D-S condition) pronunciations in Cantonese. For a native Cantonese speaker who later learnt Mandarin as his or her second dialect, when asked to make a judgment in the D-S condition based on pronunciation in Mandarin, he or she could not suppress the decision based on Cantonese pronunciation.

6. *Phonological facilitation in picture naming*. Hung et al. (1992) employed a picture-word interference Stroop paradigm, imposing a character (or pseudocharacter) on a picture and asking subjects to name the picture. On the key trials, characters could be exactly congruent with the name of the picture (e.g., the character 羊 /yang2/ on the picture of 羊), completely incongruent with the pictured object (e.g., the character 狐, /hu2/), or homophonic (but not visually similar) to the picture's name (e.g. 仰 /yang2/). Both 羊 and 仰 facilitated picture naming relative to 狐, although 羊 produced more facilita-

tion than did 仰. Thus, in this study a character's phonology has been aroused in picture naming.

7. *Priming effects in naming*. Perfetti and S. Zhang (1991, Experiment 4) observed phonological priming when a target was named following a homophonic prime at a 180-ms SOA. With a shorter timing scale, Perfetti and Tan (1998a) presented a prime for 43, 57, 85, or 115 ms, followed immediately by a target which remained on the screen until subjects made a naming response. The prime was graphically, phonologically, semantically similar, or unrelated to the target. At 43-ms duration, graphic but not phonological nor semantic primes facilitated target identification. In the 57-ms exposure condition, however, phonological information accelerated target processing, while graphic information inhibited target naming. Semantic primes did not contribute to identification until 85 ms.

The Perfetti and Tan (1998a) study demonstrated two most interesting findings: First, semantic activation lags behind phonological activation, a result replicating previous outcome. Second, graphic facilitation at 43 ms turns to inhibition by 57 ms at the same time that phonological facilitation effects emerge. Perfetti and Tan (1998a) offered an account for the second finding on which the early facilitation phase arises from the visual components of incomplete word identification, as partial products of identification processes activate words consistent with the graphic information. The inhibition phase, which coincides with the onset of phonological priming, arises when the prime character reaches its threshold of identification. There is, on this account, a single cognitive moment of word identification. The same identification event that allows facilitation from identical phonology produces inhibition from the combination of similar graphic form and different phonology.

In summary, phonological processing in Chinese word recognition appears to be a robust phenomenon of broad generality, observable across a variety of tasks: backward masking, forward priming, meaning judgment, lexical decision, picture naming, word naming, and pronunciation judgment. Furthermore, there is cross-language convergence from recent investigations with Japanese kanji (e.g., Kayamoto, Yamada & Takashima 1996; Leong & Tamaoka 1995; Wydell, Butterworth & Patterson 1995), a script that is graphically similar to Chinese, although more phonologically ambiguous because its use has evolved around two distinct readings (the On-reading and the Kun-reading). These studies suggest immediate phonological activation in Kanji recognition.

4. Phonological activation in Chinese two-character word recognition

Is phonological information activated during two-character word identification? Empirical evidence on this issue is sparse relative to research into single-character words. In Chinese, most two-character words are compound words, a combination of two separate characters. Although a single character's meaning may be highly vague in isolation, as reviewed in the foregoing section, a two-character word's meaning usually is quite precise. As for the pronunciation of a two-character word, in most cases it represents a simple combination of two characters' sounds, although in a few cases the pronunciation of a constituent character with phonological ambiguity is dependent on the two-character context. For example, the word **漢語** is pronounced /han4yu3/, meaning *the Chinese language*, with two constituent characters pronounced /han4/ and /yu3/, respectively. For **行走**, the first character is phonologically (and morphologically) ambiguous, pronounced /xing2/ or /hang2/, while the second character reads as /zou3/. Despite phonological ambiguity at the character level, the two-character word has its own pronunciation /xing2zou3/ (*walk*). This consideration suggests that at the two-character word level the asymmetry of form-form relations and form-meaning relations has been greatly decreased and there is no semantic vagueness as in single-character word identification.

Nevertheless, the two-character words amount to a majority of modern-day used Chinese words, i.e., about 64 percent of a 1,130,000-word corpus, according to the *Modern Chinese Frequency Dictionary* (1986). Thus, they are more frequently used as linguistic units with grammatical functions than are single-character words. The high frequent usage of two-character words has produced a psychological consequence: Readers try to assemble two characters A and B as one word, even in a context where A stands alone as a single-character word. For example, Perfetti and Tan (1996) found that it took longer when fluent Chinese subjects read the lexical garden path sentence "**經理同意照顧客的想法來設計產品**" than when they read the sentence without lexical ambiguity (control) "經理同意按顧客的想法來設計產品". This is because subjects first combined **照** with **顧** to form a two-character word, getting into garden path. Perfetti and Tan (1996) proposed that fluent Chinese readers have developed a *two-character assembly strategy*.

Research on the lexical garden-path sentences is promising both for understanding Chinese sentence comprehension mechanisms and for explaining word segmentation fluidity (see Hoosain 1991). Although more research is needed before firm conclusions can be reached about multiple-character words, it is plausible to suggest that some two-character words, because of their high frequency, have acquired status as lexical entries in the mental representation systems. Even so, the phonological forms and meanings of

the constituent characters may be combined, or assembled, rather than simply stored. (Studies also suggest some whole word decomposition processes, e.g., the influence of constituent characters' frequency on lexical decision time to compound words; see Taft, Huang & Zhu 1994; B. Zhang & Peng 1991.) For now, we take the overlearning hypothesis to apply to both single characters and two-character words. Presumably, for two-character words, the associations between (whole word) orthographic unit and phonological unit have been built quite strongly. As a result, phonological activation should be immediate just as it is in single character words.

Indeed, experimental findings reported by Tan and Perfetti (1997b) have suggested that phonology is activated at whole word level. Tan and Perfetti (1997b) applied the meaning judgment paradigm to two-character Chinese words, observing a strong phonological interference effect. In this investigation, two constituent characters of cohort words for homophonic foils had identical pronunciations to the two syllables of core words (e.g., 遺棄/儀器, both pronounced /yi2qi4/). The cohort word and core word were either exposed synchronously (SOA = 0 ms) or with SOAs of 71 or 157 ms. Subjects took longer in their 'no' response to homophonic foils than to controls (e.g., 遺棄/促進) at all SOAs, indicating that phonology has been activated and produced a detrimental effect on semantic decision.

Other studies, by employing two-character words in which one constituent was a heterophonic homograph (e.g., 重 has two pronunciations, /zhong4/ and /chong2/), asked whether constituent characters' phonology influences whole word identification. In particular, if a character's phonology is non-optionally activated during word recognition, two pronunciations of a heterophonic homograph should be accessed even when it is a constituent of a two-character word where only one of its pronunciations is appropriate in an intraword context. This argument has been supported. In a primed character decision task Tan and Peng (1991) presented a two-character word as a prime, followed by a legal single character target or an illegal pseudo-character at a 150-ms SOA. The key manipulation was that either the first or the second character of two-character word primes was a homograph having two different pronunciations. In this condition, the other character of the two-character word amounted to a context, forcing the correct pronunciation of the homograph. On the critical trials, the target was (a) homophonic with the correct pronunciation of the homograph; (b) homophonic with the inappropriate pronunciation of homographs; and (c) visually dissimilar and nonhomophonic to the homographs. The result was that homographs aided character decision to target's homophonic with either the appropriate (priming effect = 72 ms) or inappropriate pronunciation (69 ms) of the homographic prime. This revealed that both pronunciations of a phonologically ambiguous charac-

ter have been activated and that word context does not suppress the activation of the irrelevant phonology within 150 ms.

In another study, Tan and Perfetti (1997b, Experiment 2) asked subjects to judge whether a two character combination is a real word or not. Response to two-character words with a phonologically ambiguous character (i.e., a character whose pronunciation in isolation may be inconsistent with its pronunciation in the two-character word; e.g., 重量) was slower than response to two-character words without an ambiguous character. This was true regardless of whether the critical constituent character was located on the left or on the right side. Thus, we have a lexical-level consistency effect, in which the phonological consistency of a constituent character affects two-character word processing. This further suggests the generality of phonological processes: They occur for whole words and for characters. It is not clear yet whether this lexical character phonology occurs before or at the same time as the activation of a whole word's phonology. In either case, however, the demonstration of the influence of characters' sound may suggest that phonology is a constituent of the visual recognition of two-character words.

Summary of Sections 3 and 4. In the foregoing two sections we have reviewed current studies that suggest the rapidity of phonological activation in Chinese word recognition. Phonological processing appears to occur across a range of stimuli (e.g., single-character words, two-character words, and pictures) and across a variety of tasks. To summarize, we illustrate the main features of these studies in Table 1.

5. The activation of word meaning: Phonological diffusion but not phonological mediation

Another important question meriting careful consideration is that of whether phonology mediates access to Chinese word meaning. As discussed in the preceding sections, 'early phonological processes' and 'phonological mediation' are two different questions in the identification-with-phonology hypothesis. Indeed, activating phonological codes before arriving at meaning by no means implies that phonological processing necessarily mediates meaning processing (see for comprehensive discussion, e.g., Lesch & Pollatsek 1993; Perfetti & Tan 1998b; Tan & Perfetti 1997a).

Studies addressing the 'mediation' issue with single-character words have produced mixed results, while studies with two-character words have failed to obtain a 'mediation' effect. We first focus on the discoveries with single characters. In a semantic decision task, Yeung (1989) presented a character prime for 500 ms, followed immediately by a character target that was

Table 1. Summary of empirical evidence for rapidity of phonological activation

Author(s)	Task	Materials	Exposure duration	Main findings
Cheng and Shih (1988, Expt. 1)	Primed character decision	Single-character words	SOA = 50 ms or 500 ms	Homophonic primes facilitated decision at two SOAs, regardless of their visual similarity to targets.
Cheng and Shih (1988, Expt. 2)	Character decision (Ss were asked to make a 'yes' response if both a prime and a target were legal characters and a 'no' response if either of them was a noncharacter)	Single-character words	SOA = 50, 150, 500 and 750 ms	Homophonic primes accelerated response at all SOAs. Phonological priming effects were independent of visual similarity.
Perfetti and S. Zhang (1991, Expt. 3)	Primed perceptual identification (subjects were asked to write down targets)	Single-character words	Primes were exposed for 20 or 50 ms; targets for 35 ms	Both homophonic primes and semantic primes enhanced target identification at 50 ms but not at 20 ms.
Perfetti and S. Zhang (1991, Expt. 1)	Backward masking (subjects were asked to write down targets)	Single-character words	Targets were presented at threshold. Mask were exposed for 30 ms	Neither homophonic nor semantic masking was found.
Perfetti and S. Zhang (1991, Expt. 4)	Primed naming	Single-character words	180-ms SOA	Homophonic primes as well as semantic primes facilitated target naming.

Table 1 (continued)

Author(s)	Task	Materials	Exposure duration	Main findings
Lam, Perfetti and Bell (1991)	Pronunciation decision (Cantonese-Mandarin speakers judged whether a pair of characters had the same pronunciation in Mandarin)	Single-character words	Two characters remained on the screen until subjects made a decision (Unlimited)	When the decision is based on Mandarin pronunciation, Cantonese pronunciation interfered with decision for 'no' type responses.
Tan and Peng (1991)	Primed character decision	Two-character words as primes. On key trials, one constituent character was homographs with two pronunciations.	150-ms SOA	Heterophonic homographs helped response to single-character targets homophonic either with appropriate or inappropriate pronunciation of the homographic primes.
Hung, Tzeng and Tzeng (1992)	Picture-word interference Stroop paradigm	Single-character words were imposed on pictures	Unlimited	Characters homophonic to the name of a picture facilitated picture naming.
W. Zhang, Feng and He (1994)	Primed perceptual identification (subjects were asked to write down targets)	Single-character words	Primes were exposed for 25, 35, or 45 ms; targets for 40 ms	At 25 and 35 ms, homophonic primes that were visually similar to targets enhanced recognition of high-frequency targets, while homophones without visual similarity to targets yielded inhibition. Semantic priming did not occur until 45 ms.

Table 1 (continued)

Author(s)	Task	Materials	Exposure duration	Main findings
Perfetti and S. Zhang (1995a)	Meaning judgment task	Single-character words	SOA = 90, 140, 260, or 310 ms	For 'no' type responses, interference occurred at all SOAs when two characters had the same pronunciation but different meanings.
Tan, Hoosain and Peng (1995)	Backward masking	Single-character words	Targets/masks were exposed for 50/30 ms or 60/40 ms	At 50/30 ms, only graphic masking was obtained. At 60/40 ms, homophones enhanced recognition of high-frequency but not low-frequency targets. Semantic masks enhanced recognition for semantic-precise but not for semantic-vague (high-frequency) targets.
Tan, Hoosain and Siok (1996)	Backward masking	Single-character words	Targets were presented at threshold or at threshold +14 ms; masks for 42 ms	At threshold +14 ms, homophones facilitated recognition. The effects of meaning-related masks depended on the meaning dimensions under investigation.
S. Zhang and Perfetti (1997)	Meaning judgment task	Single-character words	Unlimited (0-ms SOA)	For two characters with the same sound but different meanings, interference occurred.
Tan and Perfetti (1997b, Expt. 1)	Meaning judgment task	Two-character words	SOA = 0, 71 or 157 ms	When a pair of two-character words had the same pronunciation but different meanings, interference occurred at all SOAs.

Table 1 (continued)

Author(s)	Task	Materials	Exposure duration	Main findings
Tan and Perfetti (1997b, Expt. 2)	Lexical decision	Two-character words	Unlimited	Response to two-character words with a phonologically ambiguous character was slower than response to the words without an ambiguous character.
Perfetti and Tan (1998a)	Primed naming	Single-character words	SOA = 43, 57, 85, or 115 ms	At 43 ms, only graphic primes yielded a (facilitation) effect. By 57 ms, homophonic primes accelerated naming, while graphic primes inhibited naming. No semantic priming effect until 85 ms.

exposed at a threshold +10 ms duration. The target could: (a) be opposite in meaning to the prime, (b) simply sound the same as what the opposite would be, or (c) be unrelated to the prime. Participants were required to indicate whether the target was opposite in meaning to the prime or not. When the target sounded the same as meaning opposite, the rate of misidentifying them was significantly higher as compared with control characters. This appears to indicate that the meaning of characters was accessed by a phonological code.

Subsequent empirical evidence provides partial support for the phonological mediation perspective. By adopting the semantic categorization procedure developed by Van Orden (1987), Leck, Weekes and M. J. Chen (1995) presented to subjects a category name for 1,500 ms. After a 500-ms interval, a target character was presented until the participant made a response. Targets were either simple characters or compound characters that contained two-or-more identifiable components. For simple targets, only visually similar foils took longer to reject. For compound targets (e.g., 煤), visually similar but phonologically dissimilar foils (e.g., 爛), as well as visually + phonologically similar foils (e.g., 媒), took longer to reject, while phonologically similar but visually dissimilar foils (e.g., 霉) did not take significantly longer to reject. Leck et al. suggested that although the direct visual route plays an important role in access to meaning, especially for simple characters, phonological information also influences compound character categorization.

The above two studies suggest that a phonology-based route of accessing character meaning seems to play a role, at least for some characters. However, there are other investigations reaching a different conclusion (H. C. Chen, Flores D'Arcais & Cheung 1995). H. C. Chen et al. (1995), for instance, employed the Van Orden categorization paradigm, presenting a category name for 1,500 ms, which was replaced by a target character of 500 or 1,000 ms followed by a pattern mask. Subjects made more errors and took longer on visually similar (but phonologically dissimilar) foils, but not on phonologically similar foils of no visual similarity. H. C. Chen et al. interpreted this finding as indicating that phonology plays no role in access of character meaning, while further concluding that results cast serious doubts on the hypothesis that phonology is activated non-optionally in Chinese.

The distinction between early phonology and phonological mediation requires a more careful conclusion, even if the no-difference results were quite general and not merely a failure to obtain an effect. A lack of phonological mediation is not evidence against early, non-optional phonological activation. Indeed, on the identification-with-phonology account, phonology is not used to bring out something, and 'mediation' misses the heart of what occurs, at least in its usual understanding. The mediation question requires consideration of the interconnections among forms and meanings in the

identification systems. The pervasive homophony in Chinese immediately suggests that diffusion of phonological activation – a given syllable maps to many meanings and back to many graphic forms – is important. This in turn means that phonological contribution to meaning activation, if any, must depend on characters' homophone density, i.e., the number of characters sharing one pronunciation. According to the connection divergence assumption illustrated in Figure 1, each meaning of a character has one node in the semantic subsystem, and a character's orthographic unit connects with all the meaning nodes it denotes. On the other hand, the connections from the phonological subsystem to the meaning lexicon are more diffused, because the pronunciation /qie/ connects with the meaning nodes of all characters pronounced /qie/. So the degree of divergence is determined by the number of homophones a character has. When a character has few homophones, its phonology will play a greater role in access of meaning than when a character has many homophones. This is because one phonological code diverges onto more meaning nodes for the character of high homophone density (high diffusion) than for the character of low homophone density (low diffusion). Based on this perspective, Tan and Perfetti (1997a) explored the phonological 'mediation' question using a phonologically mediated priming paradigm (Fleming 1993; Lesch & Pollatsek 1993). In this paradigm, Lesch and Pollatsek (1993) have reported that an English word target (e.g., *sand*) is facilitated more by a homophone of its synonym (e.g., *beech*, which is homophonic to *beach*, an associate of *sand*) than by a control (*bench*). Further, they observed that there was no difference in priming magnitude between *beech – sand* and *beach – sand* when primes were exposed for 50 ms, followed by a 200-ms pattern mask before presentation of targets. This suggests that word meaning is accessed via the phonological code /biytc/. In Tan and Perfetti's (1997a) study, prime character homophone density (low, medium, and high), prime type (synonym, homophone of synonym, and control), and SOA (129, 243, and 500 ms) were varied. The priming effects from synonyms and their homophones relative to controls are shown in Figure 2. The main findings are summarized as follows: (1) Naming time for a Chinese target word was facilitated by a prime homophonic to a synonym of the target, as well as by the synonym itself. (2) This phonological effect was restricted to primes with relatively few homophones. For words with many homophones, there was no mediated priming. (3) The effect of synonym priming itself was influenced by the number of homophones. Synonym primes with many homophones were less effective than were primes with few homophones. (4) Synonym primes were more effective than were their homophones in producing priming. (5) Each of the preceding results held at both 129 ms and 243 ms SOA. (6) At 500 ms, only synonym primes enhanced target processing.

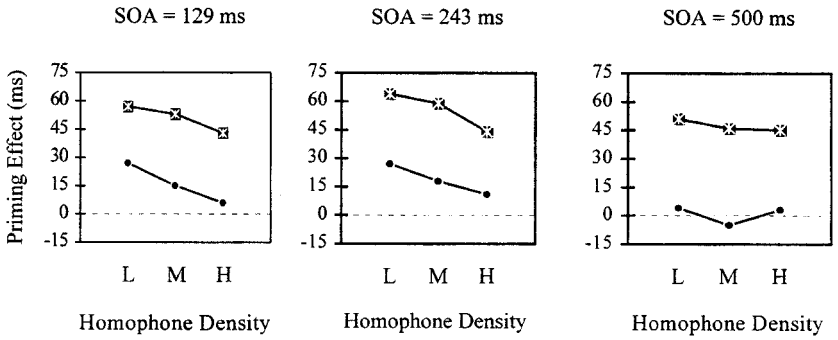

Figure 2. Phonological contribution to meaning activation as a function of homophone density. L = Low homophone density; M = Medium homophone density; H = High homophone density. (Data are based on Tan & Perfetti 1997a) —×— Synonyms; —●— Homophones of synonyms.

The above results suggest that phonological information contributes to recognition. Within 243 ms, phonological activation must generally occur for all characters, as demonstrated by the finding that semantic priming effects were modulated by homophone density. It is inappropriate, however, to conclude that phonology 'mediates' meaning access, because semantic priming was uniformly greater than phonologically-related priming. It is difficult to envision a process that first examines a character for its homophones and then selectively activates the phonology of just those meeting some criterion. Instead, the selective 'mediation' results must be seen as reflecting the results of a highly general phonological process. This helps cast mediation in a new light: It is not a process at all, but a result. The universal process is activation; the effects of this activation are subject to other processes that are partly controlled by the interconnections among the components of the identification system.

Does phonological information 'mediate' access to the meaning of two-character words? By now a series of experiments by X. Zhou and Marslen-Wilson (1996) has reported a null effect. X. Zhou and Marslen-Wilson, using a phonologically mediated priming paradigm which is similar to the paradigm employed by Tan and Perfetti (1997a) with single characters, observed that neither the homophones of targets' associates (e.g., 捷徑, which was a homophone of 潔淨; the latter was associatively related to the target 衛生) nor the pseudohomophones (e.g., 安權—危險) influenced lexical decision to targets at a 100-ms SOA. X. Zhou and Marslen-Wilson concluded that phonology does not mediate access to two-character words' semantics.

Indeed, the distinction between phonological activation as process, and mediation as results, combined with the findings that constituent characters'

phonology influences two-character word identification (Tan & Peng 1991; Tan & Perfetti 1997a), leads to the following conclusion: The phonology of constituent characters and that of whole words are activated during two-character word identification; however, whether these activations result in access to word meaning is far from clear. When we explore whether phonology mediates access to the meaning of a two-character word, we need to decompose the question: Is there a whole-word phonology that 'mediates' access to the meaning of the whole word? Are the meanings of a constituent character activated during recognition? If so, does a constituent character's phonology influence access to its meanings? And further, if a character's phonology may influence this character's or even the whole word's (say, when a constituent character is semantically transparent to the meaning of the whole word) meaning activation, can this kind of effect be referred to as 'mediation'? Does homophone density of constituent characters influence the activation of whole words' meaning? etc. To provide a more convincing interpretation of the mediation issue in two-character word recognition, all these questions need to be addressed.

6. Phonological processing in the visual identification of Chinese and English words: A comparison

The preceding sections have focused on the evidence supporting the centrality of phonological processing in word identification. Nevertheless, there must also be orthographic and phonological processes that are distinctive for specific writing systems. The differences between writing systems and between orthographies must at some level influence word identification. Frost, Katz and Bentin (1987) proposed the orthographic depth hypothesis in response to their finding of phonological computation in Hebrew, Serbo-Croatian and English: The effect of phonology varied across shallow and deep orthographies. In the case of Chinese, Hoosain (1991), in harmony with Tzeng and Hung (1981), claims that there are correlations between language characteristics and cognitive processing. Written Chinese, due to its special script-sound-meaning convergence, may lead to processes somewhat different from those that handle alphabetic systems. In what follows we compare the attributes of phonological processing between Chinese and English, focusing on the issue of how 'early' phonology is activated in two writing systems. As the recognition processes of two-character words are not clear, the following comparisons are based on discoveries from single-character words.

A Chinese character, as a monosyllabic morpheme, consists of different strokes packed into a square shape. Despite the fact that characters may

be analyzed into components of different function (e.g., semantic radicals or phonetic components), many of them are not linearly constructed. For example, while 甜 has a clear left-to-right structure, the structures of 哉國 are not linear at all. Moreover, pronunciation is not 'spelled out' in a character, leading to a dissociation between visual form and phonological form at the grapheme-phoneme level (Hoosain 1991).

These features, which sharply contrast with the linear structures and phonemic transparency of English words, imply that the construction of characters discourages a strict serial processing of visual information (Feldman & Siok 1997; Tan et al. 1996; but see Taft & Zhu 1997). Although analyses of stokes and subcharacter parts occur in recognition (e.g., Huang 1986; Leong, Cheng & Mulcahy 1987; Liu 1988), feature and component processing may be carried out in a nonserial fashion. Furthermore, a less incremental visual processing may allow phonological information and visual information to be activated in distinct cycles, or out of phase (Perfetti & Tan 1998a). That is, the compositional nature of the characters – their nonlinearity and their syllabic (rather than phonemic) mapping – allows a very strong activation of a visual graphic form *before* an associated phonology is activated. Phonology, which may arise *with* the activation of graphic form in alphabetic systems, may arise *from* the activation of a fully disambiguated visual form in Chinese. Thus, as Perfetti and Tan (1998a) suggested, phonological activation occurs at the same moment as the activation of complete orthographic information. Figure 3, collapsing Perfetti and Tan's (1998a) naming data across semantically vague and precise characters, illustrates that phonological and graphic information is activated as two independent events.

In English, however, research has demonstrated an in-phase growth of graphemic and phonological activation. In a masked priming paradigm, for example, Perfetti and Bell (1991) presented a pseudoword prime for 25, 35, 45, 55, or 65 ms, followed immediately by a target presented for 30 ms and then a pattern mask, which was used to interrupt ongoing processing of the target word. Primes were graphemically or phonemically similar to the target, or unrelated to it. As shown in Figure 4, at 25 ms, the rate of target word identification was unaffected by a phonemically similar (pseudohomophone) prime (e.g., *creap* followed by the target *creep*) and by a graphemic prime (e.g., *crelp – creep*). By 35 ms, there was a large graphemic effect, but only a small and unreliable phonemic effect. By 45 ms, the phonemic effect was highly significant (relative to graphemic primes) and did not increase further through 65 ms. These findings suggest that graphemic and phonological activation goes together over time, with graphemic information only slightly stronger than phonemic information (see also Ferrand & Grainger 1994;

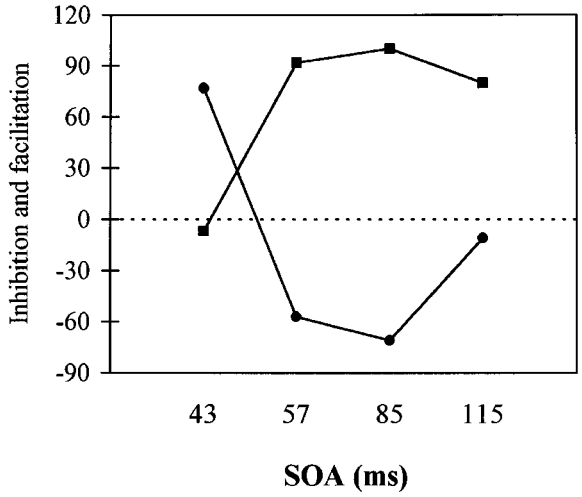

Figure 3. Net priming effects (in millisecond) from Chinese visually similar primes and homophonic primes relative to controls in a naming task. These results suggest that phonological activation in Chinese is independent of graphic activation. (Data are based on Perfetti & Tan 1998) —●— Visually similar; —■— Homophonic.

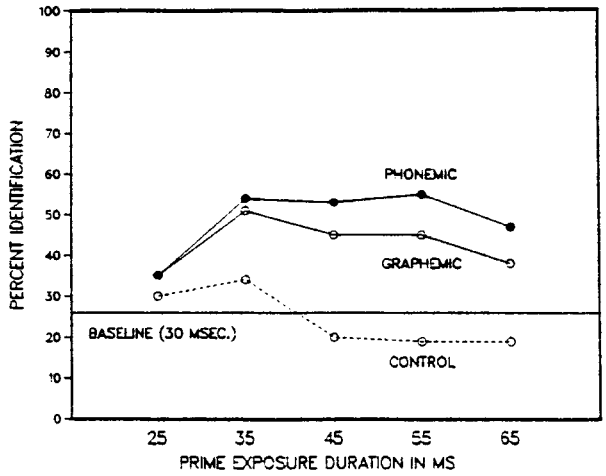

Figure 4. English priming effects in a perceptual identification paradigm (from Perfetti & Bell 1991, Experiment 2).

Lukatela & Turvey 1996). They also reveal that phonological information is accessed before complete identification of an English word's graphic form.

Despite the ample evidence for the very early, perhaps presemantic, phonological processes, phonology does not 'mediate' access to word meaning in Chinese. 'Phonological mediation', a concept that has been widely used in the literature on English word recognition since the 1970s (e.g.,

Coltheart 1978; Van Orden 1987), usually means that phonology is used to bring about meaning activation. By now there has been a considerable body of experimentation suggesting that access of English word meanings is mediated by phonology (e.g., Lesch & Pollatsek 1993; Lukatela & Turvey 1993; Luo 1996; Peter & Turvey 1994; Van Orden 1987), although more recently Van Orden and Goldinger (1994; see also Van Orden, Pennington & Stone 1990) depart from this traditional phonological mediation account. Lesch and Pollatsek (1993), as introduced earlier, discovered that homophone primes of targets' associates were as effective as associates at 50-ms duration in the naming task. This finding provides strong evidence for a phonologically mediated pathway of arriving at English word meaning.

In Chinese, due to rampant homophony, 'mediation' is a misleading concept. As reported in Tan and Perfetti (1997a), homophones of synonyms were less effective than were synonyms in priming, and more importantly, the effects from homophones were modulated by homophone density. These results suggest the generality of phonological activation that cannot be interpreted within the classic framework of phonological mediation. Indeed, what is most important in visual Chinese word recognition is 'phonological diffusion' over meaning nodes, which is a function of a character's homophone density.

With the 'how early' issue in mind, one question is whether phonetic portions of phonetic compounds influence whole character identification. If so, can the role of phonetic components be regarded as 'pre-lexical'? The pre- and post-lexical distinction, which has provoked enduring interest in English word recognition, is more complex than it sometimes appears because the definitions of 'lexical access' have varied across studies (e.g., Monsell, Patterson, Graham, Huges & Milroy 1992; Posner & Carr 1992). It matters whether access implies meaning or merely some minimal (dictionary-like) word information (see Carr & Pollatsek 1985; Tan et al. 1995). Here we use 'prelexical' in the latter, widely- accepted (and narrow) sense, referring to it as 'before access to meaning-unrelated lexical information'. Given this constraint, the consensus is that prelexical phonology occurs when the first three phonemes /plei/ of the word 'plague' are activated prior to the activation of the full phonology /pleig/. Thus, consonant with the argument that phonological information in English can be activated before recognition of complete orthographic information, there is a pre-lexical phonology for English words.

The studies reviewed in the preceding sections did not vary the regularity or validity of phonetic components (i.e., whether phonetic components are pronounced identically to compound characters), so phonology was activated at the character level, i.e., through a character-as-a-whole to sound-as-a-whole association (e.g., Hoosain 1991; Tan et al. 1996). In Chinese

psycholinguistics there have been experiments that were intended to explore the role of phonetic portions in whole character recognition (Fang, Horng & Tzeng 1986). A replicable finding has been that phonetic components do not affect the recognition of commonly-used characters (e.g., Liu, Wu & Chou 1996; Seidenberg 1985; see Kao & Hoosain 1986). Seidenberg (1985), for example, found that naming time to high-frequency compound characters was not different for compounds with a valid phonetic component than for compounds with an invalid component, although there was a significant phonetic effect for low-frequency characters. With a semantic judgment task Zhang and Perfetti (1997) found that the validity of phonetic components did not influence semantic decision to a pair of characters.

Perhaps the role of sub-characters' phonology will be eventually demonstrated in recognition of frequently-used characters. But even so, can one conclude that phonetic components influence compound character perception 'prelexically'? Intuitively, one may respond to this question with 'yes'. However, we argue that 'prelexical' is not an apt term in Chinese reading. A phonetic component is not merely prelexical (or sublexical) in the way that the *pla* in *plague* is prelexical (sublexical) in English. The phonetic itself is nearly always a character that can stand alone as a word. Specific models of Chinese character reading accommodate this important fact in different ways. According to the hierarchical models of character recognition (e.g., Taft & Zhu 1997; Zhu & Taft 1994), there are three levels of representation from strokes through components (radicals) and whole characters. Components of compound characters, whether they are themselves real (simple) characters, are organized in the component level. Thus, for the compound 理 (/li3/, *reason*, *truth*, etc.), if its phonetic component 里 (/li3/, *inside*) is activated phonologically before the recognition of 理, that may imply that 'prelexical' phonology influences compound character identification.

By contrast, Perfetti and Tan (1998b) developed an *Interactive Constituency Model* of Chinese character identification, in which both compound characters and their components that are real characters are represented in the same character orthographic subsystem, connecting to the same phonological subsystem. Thus, if a component's phonology influences whole character identification, this influence occurs in the single-character word orthographic lexicon. This implies a phonology that is activated lexically rather than prelexically. One may argue, of course, that a sub-character phonology is still 'prelexical' relative to the whole character, if it is accessed prior to phonetic compound perception. On this account, the same phenomenon has two totally different interpretations in terms of the 'pre- and post-lexical distinction'. The point is not that one of these frameworks is the right one, but rather to highlight the difficulty of answering the prelexical question in Chinese. 'Prelexical

Table 2. Summary of the differences of phonological processing in Chinese and English word identification

Phonology in Chinese word identification	Phonology in English word identification
1. Phonology is activated with the complete identification of orthographic information; Presumably, the activation of phonological information takes place at the same moment as the activation of a fully disambiguated graphic form.	1. Phonology may be activated before complete identification of orthographic information.
2. Phonological activation is independent of graphic activation, due to lack of grapheme-phoneme mappings.	2. Phonological activation goes together with orthographic activation, due to graphemes and phonemes hopelessly linking together.
3. For single-character words, word-level phonology plays a dominant role in identification. There is no evidence for the role of sub-character level phonology in identifying frequently-used characters.	3. A large body of experimentation has revealed the role of sub-lexical phonology.
4. The concept of 'pre-lexical phonology' is odd in Chinese character recognition, according to Perfetti and Tan's (1998b) Constituency model.	4. The concept of 'pre-lexical phonology' is meaningful.
5. Phonology influences but does not 'mediate' access to meaning. 'Mediation' is misleading in Chinese. What is important is 'phonological diffusion'.	5. Phonology influences and mediates access to meaning. 'Mediation' is a useful concept, although more recently Van Orden and Goldinger (1994) tend to use 'phonological-semantic coherence'.

phonology', as an useful term in English word recognition, adds conceptual confusions rather than helps elucidate cognitive processes in Chinese. Based on this consideration and the emphasis on phonology as part of character identification, we suggest that phonological processing in Chinese character identification takes place lexically. This suggestion is in line with Perfetti et al.'s (1992) concept of 'at-lexical phonology'.

Taken together, the results discussed in this section suggest that phonological activation in Chinese has some unique characteristics compared with its computation in English. These different features are summarized in Table 2.

Summary and conclusion

To recapitulate, phonological processing appears to be a robust event that has been demonstrated both in single character recognition and in two-character word processing. Phonology is activated rapidly in Chinese, presumably, at the same time as the activation of a fully disambiguated graphic form. For single-character words, the concepts of the determinacy principle, overlearning, connection convergence, and semantic vagueness provide an account for the rapid, perhaps presemantic, phonological processes. As two-character words make up of a majority of present-day Chinese words, overlearning at the two-character level constitutes a basis for phonological codes as early sources of constraint in printed two-character word identification.

Theoretically, 'early phonological processes' and 'phonological mediation' are two different questions in the identification-with-phonology hypothesis. Phonological activation may be highly general and nonoptional; whether it leads to the selection of a single meaning depends on other circumstances, including a character's homophone density.

Although phonology, as a constituent of visual word identification, is accessed universally across writing systems, phonological activation in Chinese has some unique features relative to phonological computation in English and other alphabetic writing systems. Phonology in Chinese is activated at the same time as, rather than before, the activation of a completely disambiguated graphic form. 'Mediation' and 'prelexical phonology', two important concepts in English psycholinguistics, may not be apt descriptors for Chinese.

Acknowledgments

The preparation of this article was assisted by NSF grant SBR-9616519. We are grateful to Che Kan Leong for his thoughtful discussion and comments.

Notes

1. There are some characters that do not occur independently as a word. However, in the studies with Chinese single characters that are reviewed in this paper, all characters employed could be a word.
2. Estimates on the validity of phonetic components range from 27% (Fan, Gao & Ao 1984) to 48% (Y. Zhou 1978), depending on specific calculation assumptions. An often cited one is that only 38% of phonetic components are helpful for the whole characters (Y. Zhou 1978).
3. The numeral following pinyin refers to the change of tone.

References

Baron, J. & Strawson, C. (1976). Use of orthographic and word-specific knowledge in reading words aloud, *Journal of Experimental Psychology: Human Perception and Performance* 2: 386–393.

Carr, T. H. & Pollatsek, A. (1985). Recognizing printed words: A look at current models. In: D. Besner, T. G. Waller & E. MacKinnon (eds.), *Reading research: Advances in theory and practice*, Vol. 5 (pp. 1–82). New York: Academic Press.

Chen, H.-C., Flores d'Arcais, G. B. & Cheung, S.-L. (1995). Orthographic and phonological activation in recognizing Chinese characters, *Psychological Research* 58: 144–153.

Chen, M. J., Yung, Y. F. & Ng, T. W. (1988). The effect of context on the perception of Chinese characters. In: I. M. Liu, H.-C. Chen & M. J. Chen (eds.), *Cognitive aspects of the Chinese language* (pp. 27–39). Hong Kong: Asian Research Service.

Cheng, C. M. (1982). Analysis of present-day Mandarin, *Journal of Chinese Linguistics* 10: 281–358.

Cheng, C. M. & Shih, S. I. (1988). The nature of lexical access in Chinese: Evidence from experiments on visual and phonological priming in lexical judgment. In: I. M. Liu, H.-C. Chen & M. J. Chen (eds.), *Cognitive aspects of the Chinese language* (pp. 1–14). Hong Kong: Asian Research Service.

Coltheart, M. (1978). Lexical access in simple reading tasks. In: G. Underwood (ed.), *Strategies of information processing* (pp. 151–216). New York: Academic Press.

DeFrancis, J. (1989). *Visual speech: The diverse oneness of writing systems*. Honolulu: University of Hawaii.

Fan, K. Y. (1986). *Graphic symbols of Chinese characters*. Paper presented at the symposium on Chinese character modernization, Beijing, China (in Chinese).

Fan, K. Y., Gao, J. Y. & Ao, X. P. (1984). Pronunciation principles of Chinese characters and alphabetic writing scripts, *Hanzi gaige* [*Chinese Character Reform*] 3: 23–27 (in Chinese).

Fang, S. P., Horng, R. Y. & Tzeng, O. J. L. (1986). Consistency effects in the Chinese character and pseudo-character naming tasks. In: H. S. R. Kao & R. Hoosain (eds.), *Linguistics, psychology, and the Chinese language* (pp. 11–21). Hong Kong: Center of Asian Studies.

Feldman, L. & Siok, W. T. T. (1997). The role of component function in visual recognition of Chinese characters, *Journal of Experimental Psychology: Learning, Memory, and Cognition* 23: 776–781.

Ferrand, L. & Grainger, J. (1992). Phonology and orthography in visual word recognition: Evidence from masked nonword priming, *Quarterly Journal of Experimental Psychology* 33A: 325–350.

Ferrand, L. & Grainger, J. (1994). Effects of orthography are independent of phonology in masked form priming, *Quarterly Journal of Experimental Psychology* 47A: 325–350.

Fleming, K. (1993). Phonologically mediated priming in spoken and printed word recognition, *Journal of Experimental Psychology: Learning, Memory, and Cognition* 19: 272–284.

Frost, R. (1994). Prelexical and postlexical strategies in reading: Evidence from a deep and a shallow orthography, *Journal of Experimental Psychology: Learning, Memory, and Cognition* 20: 116–129.

Frost, R. (1995). Phonological computation and missing vowels: Mapping lexical involvement in reading, *Journal of Experimental Psychology: Learning, Memory, and Cognition* 21: 398–408.

Frost, R. (1998). Toward a strong phonological theory of visual word recognition: True issues and false trails, *Psychological Bulletin* 123: 71–99.

Frost, R., Katz, L. & Bentin, S. (1987). Strategies for visual word recognition and orthographic depth: A multilingual comparison, *Journal of Experimental Psychology: Human Perception and Performance* 13: 104–115.

Hoosain, H. (1981). Processing of English and Chinese words. In: H. S. R. Kao & C. M. Cheng (eds.), *The psychological research into the Chinese language*. Taiwan: Wen Hoe Press.

Hoosain, R. (1991). *Psycholinguistic implications for linguistic relativity: A case study of Chinese*. Hillsdale, NJ: Erlbaum.

Hoosain, R. & Osgood, C. E. (1983). Information processing times for English and Chinese words, *Perception and Psychophysics* 34: 573–577.

Huang, J. T. (1986). Visual integration process in recognizing fragmented Chinese characters. In: H. S. R. Kao & R. R. Hoosain (eds.), *Linguistic, psychology, and the Chinese language* (pp. 45–54). Hong Kong: Hong Kong University Press.

Hung, D. L. & Tzeng, O. J. L. (1981). Orthographic variations and visual information processing, *Psychological Bulletin* 90: 377–414.

Hung, D. L., Tzeng, O. J. L. & Tzeng, A. K. Y. (1992). Automatic activation of linguistic information in Chinese character recognition. In: R. Frost & L. Katz (eds.), *Orthography, phonology, morphology, and meaning* (pp. 119–130). Amsterdam: North-Holland.

Jin, J. H. (1985). On the Chinese character, *Hanzi gaige* [*Chinese Character Reform*] 4: 44–50 (in Chinese).

Kao, H. S. R. & Cheng, C. M. (1981). *The psychological research into the Chinese language*. Taiwan: Wen Hoe Press (in Chinese).

Kao, H. S. R. & Hoosain, R. (1986). *Linguistics, psychology, and the Chinese language.* Hong Kong: Center of Asian Studies.

Kayamoto, Y., Yamada, J. & Takashima, H. (1996). The consistency of multiple-pronunciation effects in reading: The case of Japanese logographs. Manuscript, Hiroshima University.

Kucera, H. & Francis, W. N. (1967). *Computational analysis of present-day American English*. Providence, RI: Brown University Press.

Lam, A., Perfetti, C. A. & Bell, L. (1991). Automatic phonetic transfer in bidialectal reading, *Applied Psycholinguistics* 12: 299–311.

Leck, K. J., Weekes, B. S. & Chen, M. J. (1995). Visual and phonological pathways to the lexicon: Evidence from Chinese readers, *Memory and Cognition* 23: 468–476.

Leong, C. K. (1973). Reading in Chinese with reference to reading practices in Hong Kong. In: J. Downing (ed.), *Comparative reading: Cross-national studies of behavior and processes in reading and writing* (pp. 383–402). New York: Macmillan.

Leong, C. K. (1997). Paradigmatic analysis of Chinese word reading: Research findings and classroom practices. In: C. K. Leong & R. M. Joshi (eds.), *Cross-language studies of learning to reading and spell: Phonological and orthographic processing* (pp. 379–417). Dordrecht: Kluwer Academic Publishers.

Leong, C. K., Cheng, P. W. & Mulcahy, R. (1987). Automatic processing of morphemic orthography by mature readers, *Language and Speech* 30: 181–196.

Leong, C. K. & Tamaoka, K. (1995). Use of phonological information in processing kanji and katakana by skilled and less-skilled Japanese readers, *Reading and Writing: An Interdisciplinary Journal* 7: 377–393.

Lesch, M. F. & Pollatsek, A. (1993). Automatic access of semantic information by phonological codes in visual word recognition, *Journal of Experimental Psychology: Learning, Memory, and Cognition* 19: 285–294.

Li, P. & Yip, C. W. (1996). Lexical ambiguity and context effects in spoken word recognition: Evidence from Chinese. In: G. Cottrell (ed.), *Proceedings of 18th Annual Conference of the Cognitive Science Society*. Hillsdale, NJ: Erlbaum.

Liu, I.-M. (1988). Context effects on word/character naming: Alphabetic versus logographic languages. In: I.-M. Liu, H.-C. Chen & M. J. Chen (eds.), *Cognitive aspects of the Chinese language* (pp. 81–92). Hong Kong: Asian Research Service.

Liu, I.-M. (1995). Script factors that affect literacy: Alphabetic vs. logographic languages. In: I. Taylor & D. R. Olson (eds.), *Scripts and literacy* (pp. 145–162). Dordrecht: Kluwer Academic Publishers.

Liu, I.-M. Wu, J.-T. & Chou, T.-L. (1996). Encoding operation and transcoding as the major loci of the frequency effect, *Cognition* 59: 142–168.

Liu, I. M., Chuang, C. J. & Wang, S. C. (1975). *Frequency count of 40,000 Chinese words*. Taipei: Lucky Books (in Chinese).

Lukatela, G. & Turvey, M. T. (1993). Similar attentional, frequency, and associative effects for pseudohomophones and words, *Journal of Experimental Psychology: Human Perception and Performance* 19: 166–178.

Lukatela, G. & Turvey, M. T. (1996). Inhibition of naming by rhyming primes, *Perception and Psychophysics* 58: 823–835.

Luo, C. R. (1996). How is word meaning accessed in reading? Evidence from the phonologically mediated interference effect, *Journal of Experimental Psychology: Learning, Memory, and Cognition* 22: 883–895.

Mattingly, I. C. (1987). Morphological structure and segmental awareness, *Cahiers de Psychologie Cognitive* 7: 488–493.

Mattingly, I. G. (1992). Linguistic awareness and orthographic form. In: R. Frost & L. Katz (eds.), *Orthography, phonology, morphology, and meaning* (pp. 11–26). Amsterdam: Elsevier.

Modern Chinese frequency dictionary (1986). Beijing, China: Beijing Language Institute Press.

Monsell, S., Patterson, K., Graham, A., Hughes, C. H. & Milroy, R. (1992). Lexical and sublexical translation of spelling to sound: Strategic anticipation of lexical status, *Journal of Experimental Psychology: Learning, Memory, and Cognition* 18: 452–467.

Naish, P. (1980). The effects of graphemic and phonemic similarity between targets and masks in a backward visual masking paradigm, *Quarterly Journal of Experimental Psychology* 32: 57–68.

Peng, D. L., Guo, D. J. & Zhang, S. L. (1985). The retrieval of information of Chinese characters in making similarity judgment under recognition condition, *Acta Psychologica Sinica* 17: 227–234 (in Chinese).

Perfetti, C. A. & Bell, L. (1991). Phonemic activation during the first 40 ms of word identification: Evidence from backward masking and masked priming, *Journal of Memory and Language* 30: 473–485.

Perfetti, C. A., Bell, L. & Delaney, S. (1988). Automatic phonetic activation in silent word reading: Evidence from backward masking, *Journal of Memory and Language* 27: 59–70.

Perfetti, C. A. & Tan, L. H. (1996). *Are there structural principles in sentence understanding across languages?* Paper presented at the Psychonomic meeting, Chicago, November 1996.

Perfetti, C. A. & Tan, L. H. (1998a). The time course of graphic, phonological, and semantic activation in visual Chinese character identification, *Journal of Experimental Psychology: Learning, Memory, and Cognition* 24: 101–118.

Perfetti, C. A. & Tan, L. H. (1998b). The constituency model of Chinese character identification. In: J. Wang, A. Inhoff & H.-C. Chen (eds.), *Reading Chinese script: A cognitive analysis*. Hillsdale, NJ: Erlbaum (in press).

Perfetti, C. A. & Zhang, S. (1991). Phonemic processes in reading Chinese words, *Journal of Experimental Psychology: Learning, Memory, and Cognition* 17: 633–643.

Perfetti, C. A. & Zhang, S. (1995a). The universal word identification reflex. In: D. Medin (ed.), *The psychology of learning and motivation*, Vol. 33 (pp. 159–189). New York: Academic Press.

Perfetti, C. A. & Zhang, S. (1995b). Very early phonological activation in Chinese reading, *Journal of Experimental Psychology: Learning, Memory, and Cognition* 21: 24–33.

Perfetti, C. A., Zhang, S. & Berent, I. (1992). Reading in English and Chinese: Evidence for a 'universal' phonological principle. In: R. Frost & L. Katz (eds.), *Orthography, phonology, morphology, and meaning* (pp. 227–248). Amsterdam: North-Holland.

Peter, M. & Turvey, M. (1994). Phonological codes are early sources of constraint in visual semantic categorization, *Perception and Psychophysics* 55: 497–504.

Pollatsek, A., Lesch, M., Morris, R. K. & Rayner, K. (1992). Phonological codes are used in integrating information across saccades in word identification and reading, *Journal of Experimental Psychology: Human Perception and Performance* 18: 148–162.

Posner, M. & Carr, T. (1992). Lexical access and the brain: Anatomical constraints on cognitive models of word recognition, *American Journal of Psychology* 105: 1–26.

Rayner, K., Sereno, S. C., Lesch, M. F. & Pollatsek, A. (1995). Phonological codes are automatically activated during reading: Evidence from an eye movement priming paradigm, *Psychological Science* 6: 26–32.

Seidenberg, M. S. (1985). The time course of phonological code activation in two writing systems, *Cognition* 19: 1–30.

Smith, F. (1985). *Reading without nonsense*, 2nd edn. New York: Teachers College Press.

Stone, G. O. & Van Orden, G. C. (1994). Building a resonance framework for word recognition using design and systems principles, *Journal of Experimental Psychology: Human Perception and Performance* 20: 1248–1268.

Taft, M., Huang, J. & Zhu, X. (1994). The influence of character frequency on word recognition responses in Chinese. In: H. W. Chang, J. T. Hung, C. W. Hue & O. Tzeng (eds.), *Advances in the study of Chinese language processing* (pp. 59–73). Taipei: National Taiwan University.

Taft, M. & Zhu, X. (1997). Sub-morphemic processing in reading Chinese, *Journal of Experimental Psychology: Learning, Memory, and Cognition* 23: 761–775.

Tan, L. H., Hoosain, R. & Peng, D.-L. (1995). Role of early presemantic phonological code in Chinese character identification, *Journal of Experimental Psychology: Learning, Memory, and Cognition* 21: 43–54.

Tan, L. H., Hoosain, R. & Siok, W. W. T. (1996). The activation of phonological codes before access to character meaning in written Chinese, *Journal of Experimental Psychology: Learning, Memory, and Cognition* 22: 865–883.

Tan, L. H. & Peng, D.-L. (1991). Visual recognition process of Chinese characters, *Acta Psychologica Sinica* 23: 272–278 (in Chinese).

Tan, L. H. & Perfetti, C. A. (1997a). Visual Chinese character recognition: Does phonological information mediate access to meaning?, *Journal of Memory and Language* 37: 41–57.

Tan, L. H. & Perfetti, C. A. (1997b). Phonology as a constituent of word identification: Evidence from reading Chinese two-character words. Manuscript submitted for publication.

Tan, L. H. & Perfetti, C. A. (1998). Phonological and associative inhibition in the early stages of English word identification: Evidence from backward masking, *Journal of Experimental Psychology: Human Perception and Performance* (in press).

Treiman, R. A., Baron, J. & Luk, K. (1981). Speech recoding in silent reading: A comparison of Chinese and English, *Journal of Chinese Linguistics* 9: 116–125.

Tzeng, O. J. L. & Hung, D. L. (1978). Reading the Chinese character: Some basic research, *Acta Psychologica Taiwanica* 20: 45–49.

Tzeng, O. J. L. & Hung, D. L. (1981). Linguistic determinism: A written language perspective. In: O. J. L. Tzeng & H. Singer (eds.), *Perception of print: Reading research in experimental psychology* (pp. 237–255). Hillsdale, NJ: Erlbaum.

Tzeng, O. J. L., Hung, D. L. & Wang, W. S.-Y. (1977). Speech recoding in reading Chinese characters, *Journal of Experimental Psychology: Human Memory and Language* 3: 621–630.

Van Orden, G. C. (1987). A ROWS is a ROSE: Spelling, sound and reading, *Memory and Cognition* 15: 181–198.

Van Orden, G. C. & Goldinger, S. D. (1994). Interdependence of form and function in cognitive systems explains perception of printed words, *Journal of Experimental Psychology: Human Perception and Performance* 20: 1269–1291.

Van Orden, G. C., Pennington, B. F. & Stone, G. O. (1990). Word identification in reading and the promise of subsymbolic psycholinguistics, *Psychological Review* 97: 488–522.

Verstaen, A., Humphreys, G. W., Olson, A. & d'Ydewalle, G. (1995). Are phonemic effects in backward masking evidence for automatic prelexical phonemic activation in visual word recognition?, *Journal of Memory and Language* 34: 335–356.

Wang, W. S.-Y. (1973). The Chinese language, *Scientific American* 228: 50–60.

Wydell, T. N., Butterworth, B. & Patterson, K. E. (1995). The inconsistency of consistency effects in reading: The case of Japanese Kanji, *Journal of Experimental Psychology: Learning, Memory, and Cognition* 21: 1155–1168.

Xu, Y. (1991). Depth of phonological recoding in short-term memory, *Memory and Cognition* 19: 263–273.

Yeung, N. C. (1989). *Pre-lexical phonological activation in silent reading of Chinese*. Unpublished master's thesis, the University of Hong Kong.

Yik, W. F. (1978). The effect of visual and acoustic similarity on short-term memory for Chinese words, *Quarterly Journal of Experimental Psychology* 30: 487–494.

Zhang, B. Y. & Peng, D. L. (1991). *Decomposed representations of Chinese compound words*. Paper presented at the annual meeting of the Educational Psychology Society, Changsha, China, May 1991 (in Chinese).

Zhang, H. & Shu, H. (1989). Effects of phonetic components on naming compound characters, *Acta Psychologica Sinica* 21: 284–289 (in Chinese).

Zhang, S. & Perfetti, C. A. (1993). The tongue-twister effects in reading Chinese, *Journal of Experimental Psychology: Learning, Memory, and Cognition* 19: 1082–1093.

Zhang, S. & Perfetti, C. A. (1997). *Whole-word phonology in reading Chinese*. Unpublished manuscript.

Zhang, W. T. & Feng, L. (1992). Processes of reading Chinese words and pinyin: A comparison. In: P. Kuang & J. Zhang (eds.), *Proceedings of the 5th international symposium on cognitive aspects of the Chinese language* (pp. 72–76). Beijing, China: Science Press (in Chinese).

Zhang, W. T., Feng, L. & He, H. D. (1994). The activation of phonological and semantic information in Chinese character recognition. In: H.-W. Chang, J.-T. Huang, C.-W. Hue & O. J. L. Tzeng (eds.), *Advances in the study of Chinese language processing* (pp. 185–198). Taiwan: National Taiwan University (in Chinese).

Zhou, Y. (1978). To what degree are the 'phonetics' of present-day Chinese characters still phonetic?, *Zhongguo Yuwen* 146: 172–177 (in Chinese).

Zhou, X. & Marslen-Wilson, W. (1996). Direct visual access is the only way to access the Chinese mental lexicon. In: G. Cottrell (ed.), *Proceedings of 18th Annual Conference of the Cognitive Science Society* (pp. 714–719). Hillsdale, NJ: Erlbaum.

Zhu, X. (1988). Analysis of cueing function of phonetic components in modern Chinese. In: X. Yuan (ed.), *Proceedings of the symposium on the Chinese language and characters* (pp. 260–288). Beijing, China: Guang Ming Daily Press (in Chinese).

Zhu, X. & Taft, M. (1994). The influence of perceptual experience on Chinese character processing. In: H. W. Chang, J. T. Huang, C. W. Hue & O. Tzeng (eds.), *Advances in the study of Chinese language processing* (pp. 85–100). Taipei, Taiwan: National Taiwan University.

Ziegler, J. C. & Jacobs, A. M. (1995). Phonological information provides early sources of constraint in the processing of letter strings, *Journal of Memory and Language* 34: 567–593.

Ziegler, J. C., Montant, M. & Jacobs, A. M. (1997). The feedback consistency effect in lexical decision and naming, *Journal of Memory and Language* 37: 533–554.

Addresses for correspondence: Dr Li-Hai Tan, Learning Research and Development Center, University of Pittsburgh, 3939 O'Hara Street, Pittsburgh, PA 15260, USA
Phone: (412) 624-7020; Fax: (412) 624-9149; E-mail: tanl@vms.cis.pitt.edu