

Phonological Activation in Visual Identification of Chinese Two-Character Words

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Evidence for phonological activation in the recognition of 2-character Chinese words was discovered in 2 experiments. In a meaning-judgment task, Experiment 1 exposed two words with stimulus onset asynchronies (SOAs) of 0, 71, and 157 ms. At all 3 SOAs, times to make a "no" meaning judgment were longer for words that were homophones than for unrelated controls. In a lexical-decision task, Experiment 2 manipulated the phonological consistency of 1 of the 2 characters. Responses to words with a phonologically inconsistent character were slower, regardless of the left-right position of the character. These results add to previous results for 1-character words, suggesting that phonology is an obligatory constituent of word identification in Chinese. A proposed theoretical framework for 2-character word identification accounts for the results.

In alphabetic writing systems, phonological information seems to provide an early source of constraint in printed word identification. For example, the identification constituency hypothesis, in its general form, assumes that phonological information is a constituent of visual word identification and plays an important role in access to word meaning. This hypothesis has been supported by accumulating evidence from a variety of empirical paradigms, such as semantic categorization, backward masking, speech detection, letter search, and eye-movement-contingent display change procedure (e.g., Ferrand & Grainger, 1992; Frost, 1995; Lukatela & Turvey, 1994; Perfetti, Bell, & Delaney, 1988; Pollatsek, Lesch, Morris, & Rayner, 1992; Simpson & Kang, 1994; Tan & Perfetti, 1999; Van Orden, 1987; Ziegler & Jacobs, 1995; see Frost, 1998, for a review of recent literature).

In contrast, for Chinese, the traditional view has given phonology little or no role in word recognition, assuming instead that word meaning is accessed directly from graphic forms (see Hoosain, 1991). This identification-without-phonology or meaning-first position reflects the general principle that the graphic units of written Chinese map onto morphemes rather than onto phonemic units, allowing a close and direct relation between graphic form and word meaning (Leong, 1986; Mattingly, 1992).

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Recent research with Chinese single-character words, however, has suggested a stronger role for phonology in Chinese reading. In a primed perceptual-identification paradigm, Perfetti and Zhang (1991, Experiment 3) observed a synchrony of phonologic and semantic priming effects when a single-character prime was exposed for 50 ms, followed by a character target of 35 ms. Using a backward-masking procedure, Tan, Hoosain, and Peng (1995) exposed a target character for 60 ms, followed by a mask character that was presented for 40 ms. As in Perfetti and Zhang's experiment, they found no evidence for semantic effects in the absence of phonological effects. Equally interesting, when the target character had vague meaning, they found phonological effects in the absence of semantic effects. Such results suggest a very rapid activation of phonology and are not consistent with a meaning-first hypothesis (see Tan & Perfetti, 1998, for a detailed review of recent discoveries).

The generality of these demonstrations of phonology is limited, however, because the research has used exclusively single-character words. Estimates of modern Chinese show that multiple-character words are actually more common than single-character words. According to the *Modern Chinese Frequency Dictionary* (1986), two-character words amount to 64% of a 1,310,000-word corpus, whereas one-character words make up only 34%. This estimate, based on reading materials of mainland China, is very close to the estimate (66%) based on the materials in Taiwan (Huang & Liu, 1978). In light of the preponderance of two-character words, one might equivalently characterize the previous research as showing phonological coding in character identification or in single-character word identification. It is important to learn whether the identification of two-character words fits the picture that is emerging for single characters.

Past studies have suggested that a frequently used two-character word may develop a separate, holistic entry in the mental lexicon (Liu, 1988; see also Leong & Tamaoka, 1998). Using a forced-choice task, Cheng (1981) found that an individual target character was identified better as part of

a two-character word than as part of a two-character nonword. This two-character word superiority effect indicates that such words do have some unitary characteristics. Experiments conducted by Wu, Chou, and Liu (1994) revealed a word-level frequency effect in naming and lexical decision, providing additional evidence for the psychological reality of polycharacter words. Such evidence might be taken to suggest that multicharacter words are represented and accessed as holistic lexical units. From this conclusion one might also infer that phonological activation arises from the retrieval of word-level phonological codes in the mental lexicon, with phonological information of constituent characters playing no role in whole word recognition. On such an assumption, phonological activation of two-character words is a byproduct of word identification.

Additional considerations, however, suggest a more important role for character phonology in two-character word recognition. Because two-character words comprise two morphemes and two syllables in most cases, it is plausible to assume that the identification of whole words is mediated by the activation of their constituents.¹ This assumption is supported in English word recognition by the discovery that whole word recognition effects—in particular the word superiority effect—can be explained by interactive processes that act on constituent letters as well as word units (McClelland & Rumelhart, 1981). For Chinese, the general question becomes whether the activation of constituent characters plays a similar role in identifying whole words. If so, it is plausible to expect that the activation of a constituent character includes its phonology, which serves as an early source of constraint in identification of the whole word. Some empirical support exists for the general conclusion that constituent identity mediates whole word recognition. Taft and Zhu (1995) observed that component characters' attributes, such as frequency and position, influenced lexical decision to two-character words. In a text-reading experiment, Perfetti and Tan (1996) found that readers tried to combine a character with a following character to construct a two-character word, even when sentence context required that the first character stand alone as a one-character word. In Japanese kanji, Tamaoka and Hatsuzuka (1998) found that lexical decision to two-character words was faster when characters' meanings were related to the meaning of whole words than when they were unrelated, indicating that the meaning of components is computed in processing bimorphemic kanji words. These findings suggest that a component character retains its individual identity as a perceptual unit, and two-character word identification thus undergoes a constituent character assembling process.

Although the general possibilities suggested by a character assembly process include complex relations among morphological, semantic, and phonological processes, we focus here on the activation and assembly of the phonological form (the syllable) of a constituent character. If characters' graphic forms are linked to their phonological syllables closely, as suggested by the interactive constituency model (Perfetti & Tan, 1998; Tan & Perfetti, 1997), then an encounter with a character, whether it is part of a two-character word or not, should lead to access of phonological

representations. Such activation may also serve the function of helping to maintain information in working memory during the assembly process. On this view, not only is character-level phonology activated nonoptionally, but it has functional consequences for bisyllabic word recognition.

There is little research that is relevant for the hypothesis of phonological processes in two-character word perception, however. Hoosain and Osgood (1983), using primarily polycharacter words in their comparison of English and Chinese judgments of affective word meaning, suggested that the affective value of Chinese words is obtained more directly with less phonological processing than in English. However, although their results showed faster affective meaning processing in Chinese, they did not directly address the presence or absence of phonological activation.

More relevant is a character decision study by Tan and Peng (1991), who presented a high-frequency two-character word prime for 150 ms, followed immediately by a legal high-frequency character target or an illegal pseudocharacter containing two components that did not co-occur. Either the first or the second character of the two-character word prime was a homograph having two different pronunciations. In effect, the other character of the two-character word prime created a context that forced a unique pronunciation of the homograph. On the critical trials, the target was homophonic either with the correct pronunciation of the homograph or with the inappropriate pronunciation of homographs. Results were significant priming, relative to an unrelated prime without visual or phonological similarity to the target, for both the appropriate (priming effect = 72 ms) and inappropriate (69 ms) pronunciation of the homographic prime, indicating that the context-free pronunciations of the ambiguous character were activated and not suppressed by the whole word pronunciation within 150 ms. This result suggests a parallel with conclusions from research on English polysyllabic words, which points to a primary role for phonological computation of constituent syllables (Henderson, Dixon, Petersen, Twilley, & Ferreira, 1995; Tousman & Inhoff, 1992).

In examining the question of phonology during two-character word reading processes, we sought to obtain evidence both for word-level phonological activation and for constituent phonological assembly in our experiments. For the first goal, we carried out Experiment 1, using a task for which phonological activation at the word level interferes with the reader's goal of meaning evaluation (Perfetti & Zhang, 1995). For the second goal, we carried out Experiment 2, using two-character words that contained

¹ Although a majority of two-character Chinese words consist of two morphemes and two syllables, a few two-character combinations represent single morphemes or monosyllables. For example, words like 玻璃 (/bol li4/, *glass*, with numbers referring to tone) and 葡萄 (/pu2 tao2/, *grape*) are bisyllabic monomorphemic words in which the constituent characters are not free morphemes. In addition, when a root morpheme joins the morpheme 儿 (/er/) to form a polymorphemic word, such as 花儿 (/hua/ + /er/ = /hual/, *flower*), this word is pronounced monosyllabically.

constituent characters whose pronunciations were either consistent or inconsistent. In both experiments, the critical observations are indicators of interference arising from phonological activation. Such interferences observed in the conditions of these experiments are taken as evidence of obligatory phonological processing.

Experiment 1

Perfetti and Zhang (1995) demonstrated phonological interference in a task in which readers judged whether pairs of single characters, presented sequentially, had the same meaning. The key results concerned “no” trials. They observed higher error rates and longer decision times for reaching “no” decisions for pairs of characters that were homophones compared with unrelated pairs. This interference effect was obtained for stimulus onset asynchronies (SOAs) ranging from 90 ms, the shortest SOA tested, to 310 ms. This phonological interference effect in a semantic task was taken to implicate a nonoptional phonological activation initiated by the presentation of each character. The question for Experiment 1 was whether we could observe comparable interference when the words were composed from two characters.

On theoretical and methodological grounds, phonological and orthographic activation patterns are very sensitive to temporal variables (e.g., Ferrand & Grainger, 1993; Lesch & Pollatsek, 1993; Luo, Johnson, & Gallo, 1998; Perfetti & Bell, 1991; Perfetti & Tan, 1998; Rayner, Sereno, Lesch, & Pollatsek, 1995; Tan, Hoosain, & Siok, 1996; Weekes, Chen, & Lin, 1998). In exploring a suitable temporal range for two-character word recognition, we carried out pilot work that indicated that semantic decisions were difficult at a 71-ms SOA. This seemed to suggest that the identification of a two-character word typically might not be completed within 71 or so milliseconds. To have a window that would be sensitive to early identification processes for the experiment, we chose 71 and 157 ms. In addition, we used a simultaneous display, which we refer to as 0-ms SOA.

Method

Participants. Ninety native Chinese Putonghua speakers participated in this experiment, 30 at each SOA. The 30 participants at the 0-ms SOA were graduate students or visiting scholars from the University of Pittsburgh or Carnegie Mellon University. Sixty participants at the 71- and 157-ms SOAs were undergraduate students from the Beijing Institute of Business. All of the participants had normal or corrected-to-normal vision.

Materials and design. Twenty-seven two-character words were selected as core words. The core words were commonly used, with a mean frequency of 27.71 ($SD = 43.32$) per million, according to the *Modern Chinese Frequency Dictionary* (1986). Each core word was paired with three two-character cohort words: (a) a word (synonym) that was semantically similar to the core word; (b) a homophonic word whose two constituent characters had an identical pronunciation and an identical tone to the two constituent characters of the core word; and (c) an unrelated two-character word. All of these words were also commonly used. No characters were shared within pairs of words.

Because the concept of “word” is not always clear for Chinese readers (Hoosain, 1991), some two-character combinations may be regarded as words by some readers but not by others. This issue is present in the selection of materials for any study of two-character words. In the first experiment, 1 core word and 4 and 5 cohort words in the homophonic and semantic conditions, respectively, were not listed as two-character words in the *Modern Chinese Frequency Dictionary* (1986). We asked 4 native Chinese speakers to assess the familiarity of these 10 words in terms of a 7-point rating scale, ranging from 1 (*not familiar*) to 7 (*very familiar*). The mean rating for each of these words was no less than 4.0. For all of the other words, the average frequencies in the three conditions were 26.75 ($SD = 29.90$), 23.23 ($SD = 46.55$), and 23.36 ($SD = 39.41$), respectively. Table 1 illustrates the examples of experimental materials. The complete set of experimental items is presented in Appendix A.

All of the participants received all of the three types of cohorts (synonyms, homophones, controls), producing a within-subjects design. SOA was a between-subjects variable. At each SOA, participants were divided into three groups of 10. Stimuli were counterbalanced across participant groups such that one group viewed one of the three cohorts paired with a core word. Thus, no word was repeated for any participant. For each group of participants, we had another nine pairs of semantically related words as fillers, to which the correct response was “yes.” The stimulus pairs were presented in random order.

Procedure. An IBM-compatible microcomputer was used to run this experiment. The Chinese words were presented in white against a black background in a 24-point, normal (Song) font. Each word was approximately 2.1 cm \times 1.2 cm (width \times height). Participants were seated approximately 50 cm from the screen.

Each trial began with the presentation of a fixation cross at the center of the screen for 1,000 ms. After the offset of the fixation, a core word was exposed. In the 0-ms SOA condition, the two words (core and cohort) were presented synchronously, one above the other. The word pairs remained on the screen until participants made a decision. At the SOAs of 71 ms or 157 ms, the core word was exposed for 71 or 157 ms, followed immediately by the cohort word in the same location. The participants were asked to judge, as quickly and accurately as possible, whether the two words were related in meaning. They indicated a positive response by pressing the key corresponding to the index finger of their dominant hand

Table 1
Examples of Materials for Experiment 1

Condition	Core word	Synonym target	Homophone foil	Control foil
Word	仪器	设备	遗弃	促进
Pronunciation	/yi(2)qi(4)/	/she(4)bei(4)/	/yi(2)qi(4)/	/cu(4)jin(4)/
Translation	instrument	equipment	abandon	promote
Correct response		“yes”	“no”	“no”

Note. The number following pinyin refers to the change of tone.

and a negative response by pressing the key corresponding to the index finger of their nondominant hand. For the 71- and 157-ms exposure durations, the response times were obtained by measuring the interval between the onset of the cohort (the second word) and the onset of the participant's response.

Results

To reduce the impact of data at the extremes, decision times beyond three standard deviations of the grand mean were excluded (less than 3%). At the 71-ms SOA, there were 3 participants whose error rates were more than 60%. Their data were not included in our statistical analysis either. The higher error rates at 71 ms indicated that the meaning-judgment task was very difficult for participants to perform when exposure duration was brief.

The important results in this experiment were the correct "no" response latencies and the errors made in the homophone and control conditions.² These results are presented in Table 2 for the three SOA conditions.

As shown in Table 2, there were phonological interference effects across all of the SOAs. Moreover, at the SOAs of 0 ms and 71 ms, participants made more false-positive errors to homophonic foils. These results suggested that two-syllable phonological word forms were activated even though only meaning was required by the task. The analyses of variance (ANOVAs), as reported below, confirmed the reliability of these results. In the ANOVAs, foil type (homophones and controls) and SOA (0, 71, and 157 ms) were the experimental variables. *F* values are reported by participants (F_1) and by items (F_2).

For the decision latencies, foil type affected meaning decision, $F_1(1, 84) = 18.30, p < .001, MSE = 629,924.22$, and $F_2(1, 78) = 16.73, p < .001, MSE = 4,968.93$. SOA also yielded a significant effect, $F_1(2, 84) = 89.84, p < .001, MSE = 7,835,910.50$, and $F_2(2, 78) = 170.62, p < .001, MSE = 8,310,967.30$. The phonological interference effect was smaller at 157 ms than at the 0- or 71-ms SOA, but the Foil Type \times SOA interaction was not significant (both F_1 and $F_2 < 1$).

The main interest was multiple comparisons between homophone foils and control foils at each exposure duration. At the 0-ms SOA (simultaneous presentation), homophone foils yielded a 145-ms interference effect relative to control foils, $F_1(1, 29) = 5.96, p < .03, MSE = 252,980.27$, and $F_2(1, 26) = 4.73, p < .04, MSE = 176,359.19$. At 71 ms, the

difference between homophones and controls was 152 ms, $F_1(1, 26) = 5.11, p < .04, MSE = 300,048.08$, and $F_2(1, 26) = 4.15, p = .05, MSE = 180,151.13$. In the 157-ms condition, the interference effect (87 ms) from homophones relative to controls was significant, too, $F_1(1, 29) = 19.80, p < .001, MSE = 113,100.42$, and $F_2(1, 26) = 17.14, p < .001, MSE = 141,783.13$.

For the error rates, both foil type, $F_1(1, 84) = 7.02, p < .02, MSE = 9.96$, and $F_2(1, 78) = 10.20, p < .003, MSE = 8.45$, and SOA were significant, $F_1(2, 84) = 11.58, p < .001, MSE = 18.36$, and $F_2(2, 78) = 12.04, p < .001, MSE = 17.51$. The Foil Type \times SOA interaction was nonsignificant ($F_s < 1$). The error difference at the 71-ms SOA was reliable by a planned analysis test, $F_1(1, 26) = 8.35, p < .01, MSE = 6.69$, and $F_2(1, 26) = 17.22, p < .005, MSE = 8.17$. At 0-ms and 157-ms SOAs, the differences in error rates were not reliable, but they were in the same direction as the decision times.

Discussion

In making a decision about meaning similarity between pairs of two-character words, readers took longer to reject a pair of homophones than a pair of unrelated two-character words. This phonological interference effect was obtained across the three SOAs of 0, 71, and 157 ms. The interference effect suggests that the phonological information of two-character words is activated at the whole word level and is not easily suppressed, even though suppressing it would enhance performance of the meaning-judgment task.

This result extends the results of Perfetti and Zhang (1995) and suggests that phonology is accessed in Chinese word reading whether the words comprise single or multiple characters. This interference effect is also in agreement with results for English words in a meaning-decision task (Lesch & Pollatsek, 1998; Luo, 1996). Lesch and Pollatsek, for example, found that it was more difficult for participants to respond "no" to homophones of semantic associates (e.g., *BEECH*, which is homophonic to *BEACH*) of the first words (e.g., *SAND*) than to their visual controls (e.g., *BENCH*).

In summary, our finding suggests that word-level phonological processing is obligatory and highly general across words of variable grain sizes. Less clear is whether a word's phonological representation is assembled on the basis of its constituent characters. In Experiment 2, we addressed this question by using heterophonic homographs in a lexical-decision task.

Experiment 2

Written Chinese contains a large number of characters that are homographs, associated with more than one meaning. Although most of these homographs have only one pronunciation, a few of them are heterophonic homographs;

Table 2
Decision Times (RT; in Milliseconds) and Percentages of Errors (ER) in Each Cohort Condition as a Function of Exposure Duration of Core Words

SOA	Correct "yes" decision, synonym target		Correct "no" decision			
	RT	ER	Homophone foil		Control foil	
	RT	ER	RT	ER	RT	ER
0 ms	1,570	5.9	1,788	8.4	1,643	6.7
71 ms	1,320	8.5	1,525	10.7	1,373	7.7
157 ms	935	4.1	1,014	4.9	927	4.6

Note. SOA = stimulus onset asynchrony.

² "Yes" responses have no bearing on the interference effect being tested, so they are not statistically analyzed in detail here. Error rates ("no" responses to similar meaning pairs) were low (4–8%), and decision times were systematically faster as SOA increased.

that is, they are pronounced differently when connected with a different meaning or meanings. We refer to such phonologically ambiguous characters as *inconsistent* characters, and we refer to characters that have only a single pronunciation as *consistent*. Thus, an inconsistent character is one which, alone, can have more than one morphophonological value, and its participation in multimorphemic words calls on these variable values. English shows a roughly parallel case of inconsistency in words such as *windup* and *windmill*, which combine two root morphemes, one of which is morphophonologically ambiguous.

In Experiment 2, we asked participants to make lexical decisions on two-character words, using heterophonic homographs to discover a character-level consistency effect. On key trials, two-character words contained an inconsistent character, one that could be pronounced variably in isolation, but two-character words provided a context that required just one of these pronunciations. Thus, at the whole word level, phonological ambiguity is not relevant, but at the component character level, it is. This is our window on the assembly of phonology within a word.³

Whether the inconsistent character is on the right or left may matter for the assembly question. First, if whole words are the only relevant unit, then position should not matter. But if assembly of character phonology occurs, then it may matter, as follows: On assumptions of serial processing (Taft, Huang, & Zhu, 1994; Taft & Zhu, 1995), an inconsistent first character could activate what turns out to be the wrong phonology (given the second character). This leads to some interference between the character phonology and the whole word phonology that may be detectable in lexical-decision times. A word with an inconsistent second character, however, may escape interference if processing is serial and if the first character somehow restricts access to just one pronunciation of the second character. On the other hand, if access to the second character is independent of the encoding of the first character, or if the two characters are accessed in parallel, then interference could occur for both first-character inconsistencies and second-character inconsistencies. More generally, a set of interconnections between single characters and multiple character words could accommodate various assumptions about assembly. In that context, the question of whether the location of the inconsistency matters can be taken to establish an empirical constraint on the details of such models.

To illustrate the procedure, the two-character word 行走 (/xing2 zou3/, *walk*, with numbers referring to tone) contains an inconsistent character in the first position. This character is pronounced both /xing2/ (P₁) and /hang2/ (P₂), although it can only be pronounced /xing2/ (P₁) in this two-character word. Both P₁ and P₂ are frequently encountered. In this word, the second character, pronounced /zou3/ (P₃), is a consistent character. If constituent characters mediate whole word identification, and if their phonology is computed in recognition, then the orthographic form of 行 will diverge onto P₁ and P₂. Once P₂ is activated, it will compete with P₁ and interfere with the combination of P₁ and P₃. This kind of competition or interference cannot occur for a two-character word that has no phonologically

ambiguous constituent characters. Thus, the prediction is that the activation of characters' phonology will result in a character-level phonological ambiguity or consistency effect. Previous studies with heterophonic homographs in English (e.g., Kroll & Schweickert, 1978), Serbo-Croatian (Frost, Feldman, & Katz, 1990), and Hebrew (Frost & Kampf, 1993) have demonstrated the effects of phonological ambiguity in recognition.

One may argue that a character-level consistency effect, if any, might reflect the confound of phonological and semantic ambiguities, because each pronunciation of a phonologically inconsistent character is connected with different semantic values. For example, when the character 行 is pronounced /xing2/, it means "go," "travel," "temporary," "prevail," "perform," "doing," "behavior," and "capable." When it is pronounced /hang2/, however, the character means "line" or "row," "seniority among brothers and sisters," "trade" or "profession," "business firm," and so forth. Research with English has revealed that readers perform lexical decisions faster for words with many meanings than for words with few meanings (Balota, Ferraro, & Connor, 1991; Kellas, Ferraro, & Simpson, 1988; see Azuma & Van Orden, 1997), and experiments looking at eye fixations to semantically ambiguous and unambiguous words in different sentence contexts have found longer fixation durations for ambiguous words than unambiguous words in neutral contexts (e.g., Rayner & Duffy, 1986).

Nevertheless, one important feature of Chinese is that many characters have a number of distinct meanings, resulting in semantic indeterminacy (vagueness) for characters in isolation (Perfetti & Tan, 1998; Tan et al., 1996). Thus, in effect, many single characters are homographs. In Experiment 2, to control for the possible influence of semantic uncertainty, we matched the average number of meanings across the two sets of characters, consistent and inconsistent. Thus, whether a character's multiple meanings are activated selectively or exhaustively (Hoosain, 1991; Li & Yip, 1996), the difference between consistent and inconsistent characters will reflect the impact of phonological ambiguity rather than semantic ambiguity.

Experiment 2 was similar to Tan and Peng's (1991) experiment in its use of character inconsistency. Tan and Peng, however, asked whether both pronunciations of phonologically ambiguous character primes facilitated target identification, whereas our Experiment 2 used a lexical-decision

³ Note that character-level consistency differs from sub-character-level consistency, which refers to whether a phonetic component's pronunciation is consistent in all characters that contain this component. Sub-character level consistency effects have been observed for commonly used characters in previous research (e.g., Fang, Horng, & Tzeng, 1986), in contrast to results in English, which tend to find consistency effects only for low-frequency words (e.g., Andrews, 1982; Glushko, 1979). However, investigations exploring the role of components in character recognition have generally failed to control for the combinability of phonetic portions (e.g., the number of characters containing a specific phonetic component), a factor which has been observed to influence character recognition (Chen & Weekes, 1997; Feldman & Siok, 1997; see also Taft & Zhu, 1997).

task, without prime, to examine whether constituent characters' phonological inconsistency *retarded* lexical decision on two-character words. Thus, both the lexical-decision task of Experiment 2 and the meaning-judgment task of Experiment 1 were designed to expose conditions in which phonological information, if it was activated, hindered participants' performance.

Method

Participants. Eighteen native Chinese Putonghua speakers participated in Experiment 2. All participants were graduate students or visiting scholars from the University of Pittsburgh or Carnegie Mellon University. They had normal or corrected-to-normal vision.

Materials and design. Forty-four two-character words were selected as word targets. Twenty-two words contained an inconsistent character, 11 located on the left side, and 11 located on the right side. The other 22 words were their controls. Two key sets of words with inconsistent constituent characters were matched against their corresponding controls across stroke number, whole word frequency, constituent character frequency, and meaning number of each character. Word and character frequency was assessed in terms of the *Modern Chinese Frequency Dictionary* (1986), whereas the count of meanings was based on the *Modern Chinese-English Dictionary* (1992). For the words having an inconsistent character, if the wrong pronunciation was assigned to the inconsistent character, the resulting phonological form was always a nonword. The examples and key characteristics of experimental items were illustrated in Table 3. The complete set of experimental items is presented in Appendix B.

In addition to 44 legal two-character words, 44 nonwords were created by combining two legal characters. The specific combination of characters in the nonwords, although they individually combine in forming other words, are never used as words in either spoken or written Chinese. The complexity of nonwords was similar to the legal words' complexity, according to the number of character strokes.

All of the participants received all of the 88 items so that character consistency and position were within-subjects variables. All items were presented in random order.

Procedure. An IBM-type computer was used to present Chinese words in white against a black background in a 24-point,

normal (Song) font. Each word was approximately 2.1 cm × 1.2 cm (width × height). Participants were seated approximately 50 cm from the screen.

Each trial began with the presentation of a fixation cross at the center of the screen for 1,000 ms. After the offset of the fixation, a target item was exposed. Participants were required to decide whether the item was a real two-character word. They indicated a positive response by pressing the key corresponding to their dominant hand and a negative response by pressing the key corresponding to their nondominant hand. The response latency was obtained by measuring the interval between the onset of a target and the onset of the participant's response. The target remained on the screen until participants made a response. Before the formal experiment, each participant received 10 practice trials.

Results

Decision times beyond three standard deviations of the grand mean were excluded (less than 2%). The mean decision latencies and error rates for real words are summarized in Table 4, as a function of phonological consistency and position. The main result is an interference effect in decision times. Words with inconsistent characters produced longer decisions than words with consistent characters. For response accuracies, the differences among conditions were not significant but were in the same direction as the decision times. The overall error rates for words and nonwords were 1.8% and 4.3%, respectively.

ANOVAs confirmed a significant consistency effect. When phonologically inconsistent characters were located on the left side, the lexical-decision response to whole words was 22 ms slower than to controls in which no inconsistent characters were contained, $F_1(1, 17) = 4.59, p < .05, MSE = 3,117.36$, and $F_2(1, 20) = 5.90, p < .05, MSE = 2,832.20$. Likewise, when phonologically inconsistent characters appeared on the right side, the response to whole words was 28 ms retarded relative to controls, $F_1(1, 17) = 7.91, p < .02, MSE = 8,993.36$, and $F_2(1, 20) = 6.95, p < .05, MSE = 3,458.45$. There was no significant difference between left- and right-side inconsistent characters.

Table 3
Examples of Materials for Experiment 2

Condition and measure	Words with phonological consistency and their controls							
	Inconsistent character, left		Consistent character, left (control)		Inconsistent character, right		Consistent character, right (control)	
Two-character word	行程		见识		体重		明净	
Whole word pronunciation	/xing(2)cheng(2)/		/jian(4)shi(4)/		/ti(3)zhong(4)/		/ming(2)jing(4)/	
Two pronunciations of the ambiguous character	/xing(2)/ /hang(2)/				/zhong(4)/ /chong(2)/			
Translation of the whole word	route of travel		knowledge		weight		bright	
	<i>M</i>	<i>SD</i>	<i>M</i>	<i>SD</i>	<i>M</i>	<i>SD</i>	<i>M</i>	<i>SD</i>
Word frequency	25.1	38.3	23.5	37.9	28.1	21.3	33.2	42.7
Frequency of left-side characters	684.0	973.0	680.7	971.3	646.5	613.2	631.6	579.6
Frequency of right-side characters	759.8	963.2	770.9	955.9	798.2	982.7	754.9	998.6
No. of meanings of left-side characters	5.9	4.01	5.09	3.48	5.18	2.18	5.27	3.00
No. of meanings of right-side characters	6.27	4.00	5.09	4.23	6.18	2.40	5.18	2.40

Table 4
Lexical-Decision Latencies (RT; in Milliseconds)
and Percentages of Errors (ER) as a Function
of Constituent Character Consistency

Position	Phonological consistency			
	Consistent		Inconsistent	
	RT	ER	RT	ER
Left	711	1.67	733	2.68
Right	714	1.25	742	1.53

Discussion

The longer decision time to words with phonologically inconsistent characters reflects readers' high sensitivity to character-level phonological information. Access to this character level information appears to be context independent, such that the phonological values of the component characters are activated regardless of whether they are the first or second character. One might have expected a slightly different result based on a context-sensitive, left-to-right processing assumption: A right-position inconsistency would go unnoticed because only one reading of the inconsistent character is possible in the context of the first processed character. That the inconsistency effect was observed for both left and right characters provides no evidence for this assumption.

Notice, however, that the results do not argue against a serial-processing assumption. Rather, the failure to find position effects may suggest that context cannot preselect the (morpho)phonological form of the second character. Thus, identifying two-character words may be characterized by a two-stage process, the first context free and the second context sensitive. In the first stage, there is general activation of the phonological values of a character; in the second stage, context selects the specific phonological value that is required. Such a process is suggestive of the activation-selection account of lexical-ambiguity resolution (Kintsch & Mross, 1985; Swinney, 1979).

General Discussion

The results of the two experiments suggest a prominent role of phonological processing in two-character word reading. Just as in single-character word reading, the phonological form of a two-character bisyllabic word is activated at the whole word level. This activation was rapid enough to allow phonological interference to occur within only 71 ms exposure to a word (Experiment 1). The fact that phonological interference was also obtained in a simultaneous display of two words further demonstrates the generality of the effect. This result for simultaneous displays has also been obtained by Zhang (1996) in experiments with one-character words. Thus, the phonological interference effect is general across one- and two-character words, and it is general across asynchronous and synchronous word displays. It is clear that Chinese readers find it difficult to suppress phonological

activation of words even when the demands of the task encourage them to do so.

The study also addressed the question of how this phonological activation of bisyllabic words occurs. Experiment 2 provides evidence that phonological activation occurs for individual characters, which then are assembled into a bisyllabic (and bimorphemic) representation. The presence of a constituent character with more than one pronunciation retarded word decisions, even though the word context provided by the other character forced a unique pronunciation of the inconsistent character. Furthermore, the fact that this inconsistency effect was independent of position within the word suggests that the activation of phonology is context independent. Otherwise, one would have expected inconsistencies in the second character to have been negated by the context of the first character (assuming the first character was the first encoded). Thus, the phonology of a constituent character not only mediates whole word identification, it appears to do so through a context-free activation process that occurs before whole word context selects the required encoding of the character.

The inconsistency effect found in Experiment 2, at first glance, may appear at odds with experiments of Wydell, Butterworth, and Patterson (1995), who found no evidence for consistency effects with two-character Japanese kanji words based on On reading (the Chinese reading) and Kun reading (the Japanese reading). A number of differences may be involved in the failure to find consistency effects in Japanese compared with our result in Chinese (cf. Kinoshita, 1998). In Japanese, but not in Chinese, most characters have at least two pronunciations. The phonological ambiguity of script may lead readers to develop different learning and reading strategies. Equally important is the fact that almost all single Chinese characters can occur independently as a word, whereas many kanji characters cannot be used as a word independently. Thus, Wydell et al.'s results might reveal the absence of sub-word-level consistency effects in Japanese, whereas Experiment 2 revealed consistency effects at character-word levels in Chinese. Indeed, even in Japanese, when single characters that can occur as words are used, consistency effects have been found in naming (Kayamato, Yamada, & Takashima, 1996).

The demonstration of phonological activation of two-character words and their constituent characters has important implications for the recognition process that identifies bimorphemic words. Two-character word identification may entail two processing systems (as illustrated in Figure 1): the form system that processes and represents form (i.e., graphic and phonologic) information and the meaning system where the meanings of characters and words are represented by a set of nodes. Character entries and polycharacter word entries are organized at the same level both in the orthographic processor and in the phonological processor. In the form system, character units in the orthographic processor connect with character units in the phonological processor; similarly, there are connections for polycharacter word units between the two processors. Within each processor, character entries connect with relevant polycharacter word entries, and there are also inhibitory connections for words that are

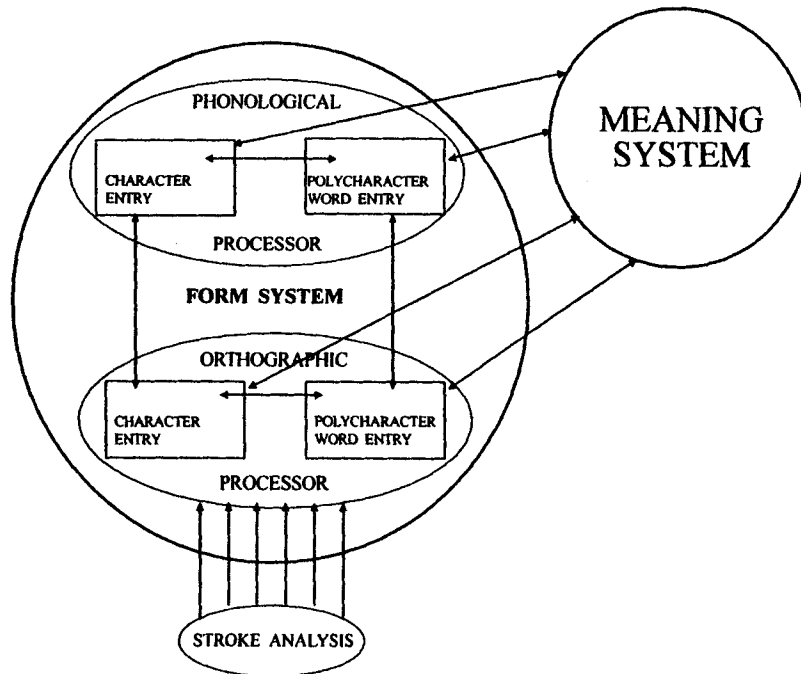


Figure 1. A framework of the visual recognition of Chinese two-character words. In this framework, key assumptions are that character units and polycharacter word units are organized at the same level, both in the orthographic processor and in the phonological processor, and that two characters and whole words are processed with some degree of independence.

highly similar in pronunciation or appearance. Both the units in the orthographic processor and units in the phonological processor connect with corresponding meaning nodes.

In this framework, the word-identification system first detects and analyzes visual features of a two-character word, that is, strokes and their positional relations, as Perfetti and Tan (1998) assumed. The detected features then send activation synchronously to the two constituent characters' orthographic units and to the two-character word's orthographic unit. (Other characters' and words' orthographic units are also partially activated provided that they share the component with constituent characters.) The orthographic entries of two separate characters may reach activation threshold before the orthographic entry of the whole word. As the orthographic units of constituent characters and the whole word are activated, they send excitation to the corresponding phonological units in the phonological processor. At the same time, constituent characters are combined through an assembly process. The assembly process is influenced by the frequency of co-occurrences of two separate characters. When two characters frequently co-occur, they are assembled more easily than when two characters co-occur less frequently. Once the assembly is successful, it produces a dynamic resonance with the two-character word entry. Thus, the whole word entry gets more activation. The unitization of two characters and the activation of the whole word proceed independently and synchronously. Similar assembly processes take place in the phonological processor and the meaning system. Whether

the assembly process is completed before, after, or at the same time as the complete recognition of the whole word depends on other factors. For example, in the form system, in addition to the frequency of co-occurrences of two characters, the number of compound words a character enters into and the ambiguity of phonological information may influence the unitization process. In the meaning system, on the other hand, whether constituent characters' meanings are activated and assembled before or after access to the whole word's meaning presumably depends on semantic richness of isolated characters and semantic transparency of constituent characters to the whole word.

According to the framework, the phonological interference effect in the meaning-decision task is explained by assuming that the outcome of perceptual processing for homophones leads to competition at the decision stage, which requires participants to respond "yes" to sameness. Thus, a decision stage that is to be informed by the meaning system instead is occasionally informed by the form system.

In the lexical-decision task (Experiment 2), when one constituent character is phonologically inconsistent, its two phonological representations are activated and connected with one orthographic entry. Reaction time increases in proportion to the amount of such "cross-talk" present (Seidenberg & McClelland, 1989). Moreover, the inappropriate phonological representation leads the assembly process down a garden path, increasing the decision time.

The above framework, borrowing some assumptions of the interactive constituency model (Perfetti & Tan, 1998)

and Van Orden and Goldinger's (1994) construct of resonance, emphasizes that two characters and whole words are processed with some degree of independence. Whether the characters are actually processed serially or in parallel is beyond the present results. Note that this model has a two-way link between orthographic units and meaning nodes, as well as between phonological units and meaning nodes. This does not mean that there is both a phonological and orthographic route to meaning. Rather, it represents the convergence of phonological, graphic, and semantic information sources onto a word identity (Tan & Perfetti, 1997).

Conclusion

The present experiments with Chinese two-character words suggest that both word-level and character-level phonological information provides early sources of constraints in two-character word identification. In circumstances of two different experiments, phonological activation interfered with the word judgments required of participants. Although suppression of phonological activity should have served the participant in performing the tasks required, it did not occur. This evidence of mandatory phonology as part of word identification is consistent with previous discoveries with Chinese single characters that phonological information is accessed very early, perhaps earlier than semantic activation.

The results further suggest that two-character word identification entails a constituent assembly process that includes phonology. The discovery of a character consistency effect that was independent of character position suggests that the initial activation of character phonology is context free.

References

- Andrews, S. (1982). Phonological recoding: Is the regularity effect consistent? *Memory & Cognition*, *10*, 565-575.
- Azuma, T., & Van Orden, G. (1997). Why SAFE is better than FAST: The relatedness of a word's meanings affects lexical decision times. *Journal of Memory and Language*, *36*, 484-504.
- Balota, D. A., Ferraro, F. R., & Connor, L. T. (1991). On the early influence of meanings in word recognition: A review of the literature. In P. Schwanenflugel (Ed.), *The psychology of word meanings* (pp. 187-222). Hillsdale, NJ: Erlbaum.
- Chen, M. J., & Weekes, B. (1997, August). *Semantic consistency and character recognition*. Paper presented at the International Symposium on Cognitive Processes of the Chinese Language, Hong Kong, China.
- Cheng, C. M. (1981). Perception of Chinese characters. *Acta Psychologica Taiwanica*, *23*, 137-153.
- 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, China: Centre of Asian Studies.
- Feldman, L., & Siok, W. 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: Human Experimental Psychology*, *33(A)*, 325-350.
- Ferrand, L., & Grainger, J. (1993). The time-course of orthographic and phonological code activation in the early phases of visual word recognition. *Bulletin of the Psychonomic Society*, *31*, 119-122.
- 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., Feldman, L., & Katz, L. (1990). Phonological ambiguity and lexical ambiguity: Effects on visual and auditory word recognition. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *16*, 569-580.
- Frost, R., & Kampf, M. (1993). Phonetic recoding of phonologically ambiguous printed words. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *19*, 23-33.
- Glushko, R. (1979). The organization and activation of orthographic knowledge in reading aloud. *Journal of Experimental Psychology: Human Perception and Performance*, *2*, 361-379.
- Henderson, J. M., Dixon, P., Petersen, A., Twilley, L., & Ferreira, F. (1995). Evidence for the use of phonological representations during transsaccadic word recognition. *Journal of Experimental Psychology: Human Perception and Performance*, *21*, 82-97.
- 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 & Psychophysics*, *34*, 573-577.
- Huang, J. T., & Liu, I. M. (1978). Effects of two-character word frequency, meaningfulness, and imagery on paired-word learning. *Chinese Journal of Psychology*, *20*, 1-4.
- Kayamoto, Y., Yamada, J., & Takashima, H. (1996). *The consistency of multiple-pronunciation effects in reading: The case of Japanese logographs*. Unpublished manuscript, Hiroshima University, Hiroshima, Japan.
- Kellas, G., Ferraro, F. R., & Simpson, G. (1988). Lexical ambiguity and the timecourse of attention allocation in word recognition. *Journal of Experimental Psychology: Human Perception and Performance*, *14*, 601-609.
- Kinoshita, S. (1998). The role of phonology in reading Japanese: Or why I don't hear myself when reading Japanese. *Reading and Writing: An Interdisciplinary Journal*, *10*, 439-455.
- Kintsch, W., & Mross, F. (1985). Context effects in word identification. *Journal of Memory and Language*, *24*, 336-339.
- Kroll, J. F., & Schweickert, J. M. (1978, November). *Syntactic disambiguation of homographs*. Paper presented at the annual meeting of the Psychonomic Society, San Antonio, TX.
- Leong, C. K. (1986). What does accessing a morphemic script tell us about reading and reading disorders in an alphabetic script? *Annals of Dyslexia*, *36*, 82-102.
- Leong, C. K., & Tamaoka, K. (Eds.). (1998). *Reading and writing: Cognitive processing of the Chinese and Japanese languages*. Dordrecht, the Netherlands: Kluwer Academic.
- 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.
- Lesch, M., & Pollatsek, A. (1998). Evidence for the use of assembly phonology in accessing the meaning of printed words. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *24*, 573-592.
- Li, P., & Yip, C. W. (1996). Lexical ambiguity and context effects in spoken word recognition: Evidence from Chinese. In G. Cottrell (Ed.), *Proceedings of the 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, China: Asian Research Service.
- Lukatela, G., & Turvey, M. T. (1994). Visual lexical access is initially phonological: 1. Evidence from associative priming by words, homophones, and pseudohomophones. *Journal of Experimental Psychology: General*, *123*, 107–128.
- 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.
- Luo, C. R., Johnson, R. A., & Gallo, D. A. (1998). Automatic activation of phonological information in reading: Evidence from the semantic relatedness decision task. *Memory & Cognition*, *26*, 833–843.
- 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 Science.
- McClelland, J. L., & Rumelhart, D. E. (1981). An interactive activation model of context effects in letter perception: Part 1. An account for basic findings. *Psychological Review*, *88*, 375–407.
- Modern Chinese frequency dictionary*. (1986). Beijing, China: Beijing Language Institute Press.
- Modern Chinese-English Dictionary*. (1992). Beijing, China: Foreign Language Teaching and Research Press.
- 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, November). *Are there structural principles in sentence understanding across languages?* Paper presented at the meeting of the Psychonomic Society, Chicago.
- Perfetti, C. A., & Tan, L. H. (1998). 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., & 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. (1995). Very early phonological activation in Chinese reading. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *21*, 24–33.
- 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.
- Rayner, K., & Duffy, S. (1986). Lexical complexity and fixation times in reading: Effects of word frequency, verb complexity, and lexical ambiguity. *Memory & Cognition*, *14*, 191–201.
- 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., & McClelland, J. L. (1989). A distributed, developmental model of word recognition and naming. *Psychological Review*, *96*, 523–568.
- Simpson, G., & Kang, H. (1994). The flexible use of phonological information in word recognition in Korean. *Journal of Memory and Language*, *33*, 319–331.
- Swinney, D. A. (1979). Lexical access during sentence comprehension: (Re)consideration of context effects. *Journal of Verbal Learning and Verbal Behavior*, *18*, 645–660.
- Taft, M., Huang, J., & Zhu, X. (1994). The influence of character frequency on word recognition responses in Chinese. In H.-W. Chang, J.-T. Huang, C.-W. Hue, & O. J. L. Tzeng (Eds.), *Advances in the study of Chinese language processing* (pp. 59–73). Taipei: National Taiwan University.
- Taft, M., & Zhu, X. (1995). The representation of bound morphemes in the lexicon: A Chinese study. In L. B. Feldman (Ed.), *Morphological aspects of language processing* (pp. 293–316). Hillsdale, NJ: Erlbaum.
- Taft, M., & Zhu, X. (1997). Submorphemic processing in reading Chinese. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *23*, 761–775.
- Tamaoka, K., & Hatsuzuka, M. (1998). The effect of morphological semantics on the processing of Japanese two-kanji compound words. *Reading and Writing: An Interdisciplinary Journal*, *10*, 293–322.
- Tan, L. H., Hoosain, R., & Peng, D.-L. (1995). Role of 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 processes of Chinese characters. *Acta Psychologica Sinica*, *3*, 272–278.
- Tan, L. H., & Perfetti, C. A. (1997). 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. (1998). Phonological codes as early sources of constraint in Chinese word identification: A review of current discoveries and theoretical accounts. *Reading and Writing: An Interdisciplinary Journal*, *10*, 165–200.
- Tan, L. H., & Perfetti, C. A. (1999). Phonological and associative inhibition in the early stages of English word identification: Evidence from backward masking. *Journal of Experimental Psychology: Human Perception and Performance*, *25*, 59–69.
- Tousman, S., & Inhoff, A. (1992). Phonology in multisyllabic word recognition. *Journal of Psycholinguistic Research*, *21*, 525–544.
- Van Orden, G. C. (1987). A ROWS is a ROSE: Spelling, sound and reading. *Memory & 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.
- Weekes, B., Chen, M. J., & Lin, Y. B. (1998). Differential effects of phonological priming on Chinese character recognition. *Reading and Writing: An Interdisciplinary Journal*, *10*, 201–222.
- Wu, J.-T., Chou, T.-L., & Liu, I.-M. (1994). The locus of the character/word frequency effect. In H.-W. Chang, J.-T. Huang, C.-W. Hue, & O. J. L. Tzeng (Eds.), *Advances in the study of Chinese language processing* (pp. 31–58). Taipei: National Taiwan University.
- 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.
- Zhang, S. (1996). *The universal characteristics of phonological processes in writing system comparisons*. Unpublished doctoral dissertation, University of Pittsburgh.
- Ziegler, J., & Jacobs, A. (1995). Phonological information provides early sources of constraint in the processing of letter strings. *Journal of Memory and Language*, *34*, 567–593.

Appendix A

Stimuli Used in Experiment 1 and Their Pronunciations (in Pinyin)

Core	Semantic	Homophonic	Control
仪器 (yī2 qì4)	设备 (shè4 bèi4)	遗弃 (yì2 qì4)	促进 (cù4 jìn4)
树木 (shù4 mù4)	花草 (huā1 cǎo3)	数目 (shù4 mù4)	平坦 (píng2 tǎn3)
抱负 (bào4 fù4)	志向 (zhì4 xiàng4)	报复 (bào4 fù4)	唯独 (wéi2 dú2)
形成 (xíng2 chéng2)	造就 (zào4 jiù4)	行程 (xíng2 chéng2)	应当 (yīng1 dāng1)
附和 (fù4 hè2)	追随 (zhuī1 suí2)	负荷 (fù4 hè2)	劳模 (láo2 mó2)
精力 (jīng1 lì4)	能量 (néng2 liáng4)	经历 (jīng1 lì4)	保皇 (bǎo3 huáng2)
宝石 (bǎo3 shí2)	珍珠 (zhēn1 zhū1)	饱食 (bǎo3 shí2)	崇高 (chóng2 gāo1)
赋予 (fù4 yǔ3)	交给 (jiāo1 gěng3)	富裕 (fù4 yù4)	并存 (bìng4 cún2)
锋利 (fēng1 lì4)	尖锐 (jiān1 ruì3)	风力 (fēng1 lì4)	搬运 (bān1 yùn4)
店员 (diàn4 yuán2)	职工 (zhì2 gōng1)	电源 (diàn4 yuán2)	嘲笑 (chāo2 xiào4)
充饥 (chōng1 jī1)	解饿 (jiě3 è4)	冲击 (chōng1 jī1)	唱片 (chàng4 piàn1)
惩治 (chéng2 zhì4)	处罚 (chū4 fá2)	诚挚 (chéng2 zhì4)	过时 (guò4 shí2)
例证 (lì4 zhèng4)	论据 (lùn4 jù4)	立正 (lì4 zhèng4)	糊口 (hú2 kǒu3)
廉洁 (lián2 jié2)	无私 (wú2 sī1)	联结 (lián2 jié2)	会同 (huì4 tóng2)
启示 (qǐ3 shì4)	领悟 (lǐng3 wù4)	起誓 (qǐ3 shì4)	郊区 (jiāo1 qū1)
失声 (shī1 shēng1)	喊叫 (hǎn3 jiào4)	师生 (shī1 shēng1)	莲花 (lián2 huā1)
身世 (shēn1 shì4)	境遇 (jìng4 yù4)	绅士 (shēn1 shì4)	龙头 (lóng2 tóu2)
手掌 (shǒu3 zhǎng3)	拳头 (quán2 tóu2)	首长 (shǒu3 zhǎng3)	若是 (ruò4 shì4)
书店 (shū1 diàn4)	阅览 (yuè4 lǎn3)	输电 (shū1 diàn4)	稍微 (shāo1 wēi1)
童话 (tóng2 huà4)	寓言 (yù4 yán2)	同化 (tóng2 huà4)	神志 (shén2 zhì4)
图形 (tú2 xíng2)	描绘 (miào2 huì4)	徒刑 (tú2 xíng2)	爽快 (shuāng3 kuài4)
闻名 (wén2 míng2)	盛誉 (shèng4 yù4)	文明 (wén2 míng2)	巧妙 (qiǎo3 miào4)
销售 (xiāo1 shòu4)	卖出 (mài4 chū1)	消瘦 (xiāo1 shòu4)	夺得 (duó2 de2)
性质 (xìng4 zhì4)	特征 (tè4 zhēng1)	兴致 (xìng4 zhì4)	昏暗 (hūn1 àn4)
蜜蜂 (mì4 fēng1)	昆虫 (kūn1 chóng2)	密封 (mì4 fēng1)	据说 (jù4 shuō1)
地质 (dì4 zhì4)	土壤 (tǔ2 rǎng3)	帝制 (dì4 zhì4)	龙船 (lóng2 chuán2)
助益 (zhù4 yì4)	好处 (hǎo3 chù4)	注意 (zhù4 yì4)	密集 (mì4 jí2)

Appendix B

Stimuli Used in Experiment 2

InconL	Control	InconR	Control
校对 (jiao4 dui4, xiao4)	顶用 (ding3 yong4)	体重 (ti3 zhong4, chong2)	军情 (jun1 qing2)
率领 (shuai4 ling3, lu4)	沿海 (yan2 hai3)	复辟 (fu4 bi4, pi1)	城镇 (cheng2 zhen4)
阿婆 (a1 po2, e1)	纷乱 (fen1 luan4)	方便 (fang1 bian4, pian2)	水管 (shui3 guan3)
曾经 (ceng2 jing1, zeng1)	骨头 (gu2 tou2)	矿藏 (kuang4 zang4, cang2)	宝贵 (bao3 gui4)
剥夺 (bo1 duo2, bao1)	壮丽 (zhuang4 li4)	首长 (shou3 zhang3, chang2)	推走 (tui1 zou3)
行走 (xing2 zou3, hang2)	见识 (jian4 shi2)	首都 (shou3 du1, dou1)	引起 (yin3 qi3)
觉悟 (jue2 wu4, jiao4)	群岛 (qun2 dao3)	厌恶 (yan4 wu4, e4)	砍伐 (kan3 fa2)
没落 (mo4 luo4, mei2)	年底 (nian2 di3)	反省 (fan2 xing3, sheng3)	明净 (ming2 jing4)
朝阳 (zhao1 yang2, chao2)	透射 (tou4 she4)	音乐 (yin1 yue4, le4)	落户 (luo4 hu4)
弹簧 (tan2 huang2, dan4)	痛斥 (tong4 chi4)	恐吓 (kong3 he4, xia4)	苍茫 (cang1 mang2)
传记 (zhuan4 ji4, chuan2)	患处 (hai4 chu4)	体系 (ti3 xi4, ji4)	少将 (shao4 jiang4)

Note. InconL = Inconsistent characters were located on the left side (the second pronunciation of inconsistent characters is shown following whole word's pronunciation in parentheses); InconR = Inconsistent characters were located on the right side.

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