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The Nature of Sublexical Processing in Reading Chinese Characters

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The nature of sublexical processing in reading complex (or compound) Chinese characters was investigated in 3 primed naming experiments. In Experiments 1 and 2, facilitatory priming effects were observed for target characters, which were semantically related to the phonetic radicals embedded in complex characters but not to the complex characters themselves. In Experiment 3, the presence of semantic primes, which were related to the phonetic radicals embedded in the complex targets but not to the targets themselves, was found to increase the naming latencies to the targets. It is argued that sublexical processing in reading Chinese is both a phonological and a semantic event. There are no fundamental differences between sublexical processing of phonetic radicals and lexical processing of simple and complex characters.

Theories of visual word recognition differ considerably in their assumptions about the nature of sublexical processing. In traditional dual-route models of reading (e.g., M. Coltheart, 1978; M. Coltheart, Curtis, Atkins, & Haller, 1993), sublexical orthographic units like *—own* in real words (e.g., *down, shown*) or nonwords (e.g., *pown, thown*) are used mainly as inputs to grapheme–phoneme conversion rules whose end products are phonemes, although they are also involved in cascaded activation from letters to word representations. In most connectionist models of word reading (e.g., Plaut, McClelland, Seidenberg, & Patterson, 1996; Seidenberg & McClelland, 1989), the sublexical orthographic units are both the input to distributed orthography-to-phonology networks computing phonological outputs and the input to orthography-to-semantics networks computing semantic outputs. However, these semantic outputs are primarily for the whole letter strings, not for the sublexical orthographic units, even when these units happen to be words themselves (e.g., *—own* in *down* or *boy—* in *boycott*). There is no obvious difference between processing these units and other units that do not happen to be words (e.g., *—int* in *hint* or *pint, mur—* in *murder*). In models of visual word recognition that stress the predominant role of phonology in initial lexical access and in access to meaning (e.g., Frost, 1998; Henderson, Petersen, Dixon, Twilley, & Ferreira, 1995; Lesch & Pollatsek, 1993; Lukatela & Turvey, 1994; Van Orden & Goldinger, 1994; Van Orden, Pennington, & Stone, 1990), sublexical processing of orthographic units is strictly a phonological (and orthographic) process, which activates the phonological representation of the whole word before the meaning of the word is accessed. Therefore, despite their considerable differences concerning whether the sublexical processing in reading alphabetic words is rule based and how the computation from orthography to phonology is conducted, most localist and connectionist theories of visual word recognition share the assumption that sublexical processing in reading alphabetic scripts is a process that derives the phonology and meaning of whole words from sublexical orthographic units. It is either primarily or strictly a phonological (and orthographic) event, with no significant semantic activation associated with these sublexical units.

The main purpose of the present research was to investigate whether this phonological view of sublexical processing could be applied without modification to sublexical or subcharacter processing in reading Chinese complex (or compound) characters, which are composed of semantic and phonetic radicals (see next section). These radicals may provide information concerning, respectively, the meaning and the pronunciation of the whole characters, although phonetic radicals can be meaningful characters by themselves. It has been suggested (e.g., Flores d'Arcais, Saito, & Kawakami, 1995) that because the phonetic radical–sound correspondences are overlearned in Chinese, they could be used in the same way as the grapheme–phoneme correspondences in alphabetic languages, presumably to compute "prelexical" phonology for the whole characters. If so, then sublexical processing in reading Chinese, which we restrict

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here to the processing of phonetic radicals embedded in complex characters, should be primarily a phonological event, as in alphabetic languages, and should not produce significant semantic activation related to the properties of radicals themselves. Indeed, most of the previous research on sublexical processing of phonetic radicals (e.g., Fang, Horng, & Tzeng, 1986; Hue, 1992; Peng, Yang, & Chen, 1994; Seidenberg, 1985) concentrated on the phonological effect of phonetic radicals on reading complex characters. The question of whether sublexical processing of phonetic radicals contained in complex characters generates detectable independent semantic activation, leading to competition in the semantic system, has not been addressed.

In this article, we provide evidence from three primed naming experiments showing that the sublexical processing of phonetic radicals of complex or compound characters is not only a phonological and orthographic event but also a semantic event. The processing of phonetic radicals not only contributes to the mapping from orthography to phonology in lexical access but also generates clear independent activation in the semantic system. The semantic representations corresponding to phonetic radicals, which are morphemes in isolation, are automatically activated in reading complex characters, even though they serve only to interfere with the semantic processing of the whole character. In other words, there are no fundamental differences between sublexical processing of phonetic radicals and lexical processing of simple and complex characters in reading Chinese.

Before we move to our experiments and to the discussion of their implications for theories of lexical processing in Chinese, we give a brief introduction to the structural properties of Chinese characters and the Chinese writing system. Previous research on sublexical processing of phonetic radicals is also summarized.

Structural Properties of Chinese Characters and Sublexical Phonological Processing

The Chinese writing system is often described as logographic or morphosyllabic, where the basic orthographic units, the characters, correspond directly to morphemic meanings and syllables. With some exceptions, each character represents one morpheme and has one pronunciation in isolation, although different characters may have the same pronunciations. The characters can be broadly differentiated into two categories (D. Li, 1993): simple and complex,[1] both of which are composed of strokes and arranged in squares of similar size. Simple characters (e.g., 义, /yi[4]/, "righteousness")[2] make up about 5% of the total characters in Modern Chinese (D. Li, 1993) and are holistic visual patterns that cannot be divided meaningfully into sublexical units. No phonological information can be represented at the sublexical level for simple characters. At the lexical or character level, there is no systematic correspondence between orthography and semantics or between orthography and phonology. Orthographically similar characters (e.g., 由, /you[2]/, "because of"; 甲, /jia[3]/, "first"; and 田, /tian[2]/, "field") usually have different pronunciations and have no semantic similarities. Orthographically different characters may share semantic properties (e.g., 水, /shui[3]/, "water" and 干, /gan[1]/, "dry") or have the same pronunciations (e.g., 义, /yi[4]/, "righteousness"; 乙, /yi[4]/, "second"; and 亦, /yi[4]/, "also").

Complex characters constitute about 95% of all Modern Chinese characters, and most of them (over 80%) are composed of semantic and phonetic radicals (D. Li, 1993; B. Yin & Rohsenow, 1994).[3] Most of these complex characters are composed of a semantic radical on the left and a phonetic radical on the right (e.g., 议, /yi[4]/, "discuss"), although some arrange their radicals in other ways (e.g., in an *over–under structure,* like 花, /hua[1]/, "flower," or in an *enclosing structure,* like 图, /tu[2]/, "map"; see B. Yin & Rohsenow, 1994). Semantic radicals have the function of indicating the semantic category of morphemes corresponding to the complex characters, whereas phonetic radicals have the function of pointing to the pronunciations of whole characters (i.e., encoding phonological information at the subcharacter level). However, because of the evolution of the writing system, both functions are not complete, with exceptions and irregularities littered across the writing system.

The phonological relations between phonetic radicals and the complex characters into which they are embedded can roughly be differentiated into five major types (see Table 1). According to our analyses of the complex characters covered in a corpus of Modern Chinese (Institute of Language Teaching and Research, 1986), less than 30% of the complex characters composed of semantic and phonetic radicals have exactly the same pronunciations as their phonetic radicals (see also Fan, Gao, & Ao, 1984, and Y. Li & Kang, 1993, for similar statistical analyses with similar results), whereas about one third of complex characters are totally irregular and their pronunciations have no relation with their phonetic radicals. About another one third of complex characters have either the same segmental templates (but different lexical

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[1] Characters were differentiated into six categories (pictographic, indicative, associative, picto-phonetic, notative, and borrowed) in a classic work (Shuwen Jiezi, A.D. 121; see B. Yin & Rohsenow, 1994), which is still referred to today. Whereas the first four categories were based on the way the characters were created, the last two refer to the expansion of the use of existing characters. It seems that there is little psychological relevance of many of these categories (e.g., pictograms or ideograms). Adopting this etymological categorization can only be misleading in psychological research into the reading of Modern Chinese.

[2] Throughout this article, the pronunciations of Chinese characters are given in pinyin—the Chinese alphabetic system. Numbers in brackets (or parentheses) represent the lexical tones of syllables.

[3] A few complex characters, such as those historically categorized as associative characters (see Footnote 1), may not contain a clear phonetic component. However, many such characters (e.g., 休, /xiu[1]/, "to rest") have no obvious synchronic differences from picto-phonetic characters (or compound characters to some people), which always have a phonetic component. In this article, we do not make a clear distinction between complex and compound characters, although most of the complex characters used in this study can be categorized as compound characters in the strict sense.

Table 1
The Phonological Relations Between Phonetic Radicals and Complex Characters

Type and condition	Phonetic radical	Complex character
Regular		
Character	羊	洋
Pronunciation	/yang(2)/	/yang(2)/
Translation	sheep	ocean
Semiregular		
Character	青	情
Pronunciation	/qing(1)/	/qing(2)/
Translation	blue	affection
Rhyming		
Character	亡	忙
Pronunciation	/wang(2)/	/mang(2)/
Translation	die	busy
Alliteration		
Character	某	煤
Pronunciation	/mou(3)/	/mei(2)/
Translation	certain	coal
Irregular		
Character	白	怕
Pronunciation	/bai(2)/	/pa(4)/
Translation	white	fear

tones, which are used to differentiate lexical items in Chinese) or the same segmental rhyming parts or the same initial consonants as their phonetic radicals. Because of this, the method of reading complex characters according to their phonetic radicals, which often leads to wrong pronunciations and regularization errors, has become a standard source of jokes in Chinese. This unreliability of phonetic radicals in indicating the pronunciations of complex characters is illustrated in the following examples. All the following complex characters are pronounced in the same way as their phonetic radical 平(/ping[2]/): 评(“comment”), 坪(“level ground”), 苹(“apple”), and 萍(“duckweed”). There exists, however, an exceptional or irregular character, 秤(/cheng[4]/, “scale”), which has the same phonetic radical. In some extreme cases, characters having the same component (e.g., 也, /ye[3]/, “also,” as in 他, /ta[1]/, “he”; 地, /di[4]/, “earth”; and 池, /chi[2]/, “pool”) may have little similarity in pronunciation. On the other hand, orthographically different complex characters (e.g., 鸽, /ge[1]/, “pigeon”; 歌, /ge[1]/, “song”; and 割, /ge[1]/, “cut”) may have the same pronunciations.

There are two important facts about phonetic radicals that should be specially noted. First, the same phonetic radicals could be involved in all or part of the five categories listed in Table 1. They provide clues to the pronunciation of the whole complex characters rather than to a part of it. Therefore, sublexical phonological processing of phonetic radicals in reading Chinese may not be the same as sublexical phonemic processing of letter clusters in reading alphabetic English. Second, phonetic radicals themselves are usually independent characters in isolation that have their own meanings. The meanings of phonetic radicals, however, usually have nothing to do with the meanings of the whole characters.

There have been a number of studies on sublexical or subcharacter processing in reading Chinese complex characters. The orthographic units studied include stroke (e.g., M. J. Chen & Yung, 1989), component (e.g., Taft & Zhu, 1997), semantic radical (e.g., Feldman & Siok, 1999; Flores d'Arcais et al., 1995; Zhou & Marslen-Wilson, 1999), and phonetic radical (e.g., Fang et al., 1986; Flores d'Arcais et al., 1995; Hue, 1992; Peng et al., 1994; Seidenberg, 1985; Zhou, 1994; Zhou & Marslen-Wilson, 1999). Almost without exception, studies of phonetic radicals concentrate on the orthographic and phonological aspects of sublexical processing. The question of whether the semantic properties of phonetic radicals are automatically activated in reading complex characters has not been addressed (but see Zhou, 1994). This is presumably due to the influence of research in nonlogographic languages on the sublexical processing of orthographic units in monomorphemic words (e.g., *—own* in *town*), which do not produce detectable effects of their own in the semantic system (e.g., Sandra, 1990; Zwitserlood, 1994; see also General Discussion).

The evidence about the phonological processing of phonetic radicals comes mainly from studies on regularity and consistency effects in reading complex characters. Seidenberg (1985) found that regular complex characters, or characters having the same pronunciations as their phonetic radicals, are named faster than frequency-matched simple characters. However, this effect was observed mostly for low-frequency characters, not for high-frequency ones. Fang et al. (1986) investigated regularity and consistency effects in naming characters, where *consistency* was defined according to whether all complex characters with a particular phonetic radical are pronounced in the same way as the radical. The authors observed a consistency effect but not a regularity effect. Regular–consistent characters (e.g., 材, /cai[2]/, “materials”) were named faster than regular–inconsistent characters (e.g., 油, /you[2]/, “oil”), although the latter were not named faster than irregular–inconsistent characters (e.g., 抽, /chou[1]/, “lash”). Subsequent studies using similar designs, however, found both regularity and consistency effects for low-frequency characters (Hue, 1992; Peng et al., 1994).

The effect of sublexical phonological processing, and its interaction with the frequency of complex characters, was replicated in a study using a primed naming task. Zhou and Marslen-Wilson (1999) used as primes high- and low-frequency irregular complex characters (e.g., 粹, /cui[4]/, “pure”), whereas targets were characters (e.g., 族, /zu[2]/, “clan”) homophonic to phonetic radicals embedded in the primes (e.g., 卒, /zu[2]/, “soldier”) but not to the primes themselves. They found that targets preceded by low-frequency complex characters were named faster than when they were preceded by unrelated characters. Targets preceded by high-frequency complex characters, however, were not facilitated in naming. This pattern of priming effects, together with the regularity and consistency effects in single-character naming, suggests that in processing complex characters, phonetic radicals are decomposed and used to access their own phonological representations. However, the ability to decompose phonetic radicals and gain access to their phonology is modulated by the frequency of the complex character. Either the reading of high-frequency complex characters involves little decomposition or the phonological activation of the embedded phonetic radicals is transient and suppressed by the phonological activation of the high-frequency complex character itself by the time the target is presented.

W. G. Yin and Butterworth (1992) studied brain-damaged patients with reading disorders and concluded that reading aloud Chinese complex characters, like reading alphabetic scripts, can be accomplished using two "distinct" routines: one associating a whole written word with its complete pronunciation and one using parts of the written word. They observed that the "deep" dyslexic individuals (i.e., patients who made a lot of semantic errors in reading) did not regularize the pronunciations of (irregular) characters and could not pronounce pseudocharacters made of real semantic and phonetic radicals. On the other hand, the "surface" dyslexic individuals (i.e., patients who made fewer semantic errors) made a lot of regularization errors and could "read" about 50% of the pseudocharacters—presumably according to the pronunciations of phonetic radicals.

The typical account of these sublexical phonological effects in reading complex characters has been in terms of Glushko's (1979) activation–synthesis model or Seidenberg's (1985) time course model of orthographic and phonological activation. According to these models, lexical access begins with the extraction of salient orthographic units from the visual input, which are then used to activate in parallel their corresponding orthographic and phonological representations in the lexicon. The phonological activation is synthesized according to interactive principles (McClelland & Rumelhart, 1981) to manifest regularity or consistency effects in naming. The interaction between these effects and frequency is explained by the relative time course of phonological activation from whole characters and from sublexical units. The phonological output for high-frequency words is based mainly on their own phonological representations, which are activated before information from sublexical processing becomes available. In contrast, the phonological output for low-frequency words is influenced by phonological representations of other words activated in parallel from orthography because access to the whole-character phonology is slow (but see Jared, 1997).

Many connectionist models of reading used essentially the same principles in accounting for regularity and consistency effects in reading Chinese and their interaction with frequency (see Y. Chen & Peng, 1994; Seidenberg & McClelland, 1989). In these models, orthographic, phonological, and semantic information is represented in terms of distributed activation patterns over simple processing units, which are connected with each other in different weights. Lexical processing involves transforming activation patterns between different domains, and such transformations are achieved through the cooperative and competitive interactions among processing units. Because the weights of connections between processing units are derived through the network's exposure to training words, the regularity and consistency of phonology between sublexical units and whole characters naturally affect the activation of phonological patterns for the whole characters, resulting in the regularity and consistency effects in naming.

In this research, we used a primed naming technique to investigate whether the semantic properties associated with phonetic radicals are automatically activated when these radicals are embedded in complex characters. Characters (e.g., 紫, /zi[3]/, "purple") that were semantically related to the phonetic radicals (e.g., 青, /qing[1]/, "blue") of complex characters (e.g., 猜, /cai[1]/, "guess"), but not to the complex characters themselves, were used as primes or targets. Any priming effects between complex characters and semantic associates of their phonetic radicals can be taken as evidence that, in reading complex characters, readers decompose the phonetic radicals and use them to access their own semantic representations.

We used only complex characters with left–right structure because they constitute the major type of complex characters in Chinese. They are also easier to decompose in perceptual analyses than characters with other structures (e.g., Yu, Feng, Cao, & Li, 1990), and hence the effects of their sublexical semantic processing are easier to detect. Because the independent measure of performance is the participants' responses to the same targets in primed and control conditions, all the critical comparisons were within item, avoiding the difficulties of matching stimuli on different parameters (e.g., the richness of semantic properties or cumulative syllable frequency) that could influence naming performance.

In three experiments, we also differentiated types of complex characters according to the phonological relations between phonetic radicals and whole characters (see Table 1). If phonology plays a strong role in constraining access to semantics in reading Chinese, the regularity between phonetic radicals and whole characters could influence the phonological—and hence semantic—activation of phonetic radicals embedded in complex characters. For example, if phonetic radicals are homophonic to the complex characters, the semantic activation of phonetic radicals in reading these characters could be due to phonological activation of the whole characters and its spreading to semantic representations of any homophonic characters (including the radicals on their own) rather than the decomposition of these radicals from the complex characters. By using different types of complex characters, we hoped to collect converging evidence concerning how semantic activation of phonetic radicals is achieved. In Experiment 1, we investigated the sublexical semantic processing of phonetic radicals in reading regular and rhyming complex characters, whereas in Experiments 2 and 3, we concentrated on the sublexical processing of irregular complex characters.

Experiment 1

This experiment had two aims. The primary aim was to investigate whether sublexical processing in reading regular and rhyming complex characters automatically activates the semantic properties of the phonetic radicals, even though this semantic activation does not contribute to the processing

Table 2
Experiment 1: Design and Sample Stimuli

Stimulus type and condition	Prime type			
	Semantic	Complex	Control	Target
Regular				
Character	风	枫	柿	雨
Pronunciation	/feng(1)/	/Feng(1)/	/shi(4)/	/yu(3)/
Translation	wind	maple	persimmon	rain
Rhyming				
Character	少	抄	扶	多
Pronunciation	/shao(3)/	/Chao(1)/	/fu(2)/	/duo(1)/
Translation	few	transcribe	prop up	many

Note. The label *type* refers to the properties of the complex primes. Semantic primes are the characters contained in the complex primes as phonetic radicals. Semantic primes and complex primes are homophones in the regular group and rhyme with each other in the rhyming group.

of complex characters themselves. The secondary aim was to examine the possible time course of these processes of sublexical semantic activation.

To index the activation of semantic properties of phonetic radicals embedded in the two types of complex characters, we used the complex characters as primes and characters that were semantically related to their phonetic radicals as targets. For example (see Table 2), if the complex character 枫 (/feng[1]/, "maple") is the prime, containing the radical 风 (/feng[1]/, "wind"), then the target 雨 (/yu[3]/, "rain") is semantically related to the radical but not to the complex character containing the radical. Any facilitation of naming is compared both with an unrelated control condition and with a "semantic" condition, in which the radical is presented on its own. If phonetic radicals are automatically decomposed and used to access their own semantic representations, then activation of these semantic representations should facilitate the processing of targets. To chart the possible time course of sublexical semantic activation, we used different stimulus onset asynchronies (SOAs) between primes and targets. If semantic properties of phonetic radicals are initially activated and compete with the semantic activation of the whole complex characters, this sublexical activation would have to be suppressed at a certain point in time to allow access of meaning of the whole characters.

Method

Design and materials. The experimental design and sample stimuli are presented in Table 2. There were two types of complex primes: regular and rhyming. Phonetic radicals in the regular primes were homophonic to the complex characters, whereas phonetic radicals in the rhyming primes had the same rhyming parts as the complex characters. Targets were chosen to be semantically related to the phonetic radicals but not to the whole complex primes. To make sure that the targets were semantically related to the phonetic radicals and capable of detecting the semantic activation of phonetic radicals, we also had a direct semantic priming condition in which the same targets were preceded by the phonetic radicals in isolation. In a semantic relatedness judgment pretest, 20 participants rated the semantic relatedness between phonetic radicals (i.e., semantic primes) and targets on a 9-point scale ranging from 1 (*not related at all*) to 9 (*extremely related*). The average points for both regular and rhyming conditions were 8.1 (range = 7.0 to 8.9).

Forty-two regular characters and 30 rhyming characters were used as complex primes (see Appendix Table A1). All these characters were of low frequency (below 51 per million), with means of 13 per million for regular characters and 22 per million for rhyming characters. Although it would be ideal to have both high- and low-frequency complex primes to examine the possible interaction between frequency and sublexical semantic activation, as has been done for sublexical phonological processing (e.g., Seidenberg, 1985; Zhou & Marslen-Wilson, 1999), we could not find enough high-frequency complex characters that met our requirements.

Because characters can be used both as individual words on their own and as constituent morphemes in compound words, the frequency counts here, which came from the Institute of Language Teaching and Research (1986), were effectively cumulative morpheme frequencies. The average frequencies of phonetic radicals, which stood alone as semantic primes in the regular and rhyming conditions, were 604 and 616 per million, respectively. Because our main interest was in semantic priming of phonetic radicals contained in complex primes, unrelated control primes were chosen to match with the complex primes, rather than with the semantic primes, on frequency, visual complexity (in terms of number of strokes), and structure. The average frequencies of control primes in the regular and rhyming conditions were 13 and 22 per million, respectively. The average numbers of strokes were, respectively, 11 and 10.5 per character for complex and control primes in the regular condition and were both 11 in the rhyming condition. Because stroke pattern and character structure could also influence the processing of priming characters (e.g., Y. P. Chen, Allport, & Marshall, 1996), and hence the assessment of priming effects, control primes here were matched with complex primes on structural properties. Complex primes and control primes had an equal number of stroke patterns and were all of left–right structure, with semantic radicals on the left and phonetic radicals on the right (with the exception of one complex prime having the semantic radical on the right). Target characters were of different frequency, with different orthographic structures. The average frequencies for targets in the regular and rhyming groups were 630 and 505 per million, respectively. There were no orthographic, phonological, or semantic relations between control primes and targets at either the lexical or sublexical level.

Besides the critical stimuli, the experiment also included 100 pairs of filler words selected to discourage participants from using potential response strategies. Primes and targets in filler pairs were not semantically, orthographically, or phonologically related. Both simple and complex characters were used here. Complex characters were of different frequencies, with different types of structure. No filler characters had the same pronunciations as the critical stimuli. There were also 20 pairs of practice items, of which 8 pairs of primes and targets had relations similar to the critical stimuli.

A Latin square design was used to assign the critical primes and their targets to three test versions. The same targets appeared only once in one version, and one third of the targets were preceded by one of the three types of primes. The same filler prime–target pairs were used in the three test versions. A pseudorandom ordering was used to arrange the stimuli in each version, so that across the test versions the primes and targets from the same quintets of critical stimuli appeared in the same position in the testing sequence. Three SOAs between primes and targets were used to track the potential time course of semantic activation: 57 ms, 100 ms, and 200 ms. They were treated as a between-subject factor.

Procedure. The preparation of stimuli was as follows. All primes (in *kaiti* font) and targets (in *songti* font) were generated by a computer word-processing program and stored as individual image files on a hard disk. A target word was about 3.5 × 2.3 cm in size, and the prime was slightly smaller. Both *kaiti* and *songti* are standard fonts in Chinese, and although the same words were visually different in different fonts, they kept the same structures.

The presentation of stimuli to participants and recording of reaction times were controlled by the dual-screen version of DMASTR, made available to us by Ken and Jonathan Forster. In each trial, an eye fixation signal ("+") was first presented at the center of a computer screen for 300 ms, followed by a 300-ms blank interval. A prime was then presented for 57 ms, 100 ms, or 200 ms, depending on the SOA condition, and overwritten immediately by the corresponding target, which was presented for 400 ms. There was a 3-s interval between the disappearance of the last target and the appearance of the next eye fixation point. When the primes were presented for 57 ms, participants were aware of the presence of primes and most participants were able to identify the primes clearly (see the study by Zhou & Marslen-Wilson, 1998b, in which participants were asked to make judgments concerning the semantic or phonological relations between the primes and targets).

Participants were tested individually in a quiet room. They were seated about 60 cm from the screen and were asked to read into a microphone as quickly and as accurately as possible the second character of each trial. The microphone was interfaced with a computer to record voice onset latencies. Participants' performance was monitored by an experimenter, and naming errors were recorded immediately by hand on preprinted scoring sheets.

Each participant saw first a list of 20 prime–target practice items. There was a break after practice and a break in the middle of the main test session. The first 3 pairs after each break were always fillers. The complete test session for each participant was about 20 min.

Participants. A total of 102 participants were tested for the experiment: 36 for the 57-ms SOA condition, 36 for the 200-ms SOA condition, and 30 for the 100-ms SOA condition. All participants were native speakers of Mandarin Chinese and were undergraduate students at Beijing Normal University. They were paid for their participation.

Table 3
Experiment 1: Mean Naming Latencies (in Milliseconds)

	Prime type		
Type and SOA	Semantic	Complex	Control
Regular			
57 ms	550	569	582
100 ms	562	573	580
200 ms	520	527	536
Rhyming			
57 ms	565	574	581
100 ms	568	577	590
200 ms	524	537	533

Note. SOA = stimulus onset asynchrony.

Results

Two participants, 1 at the SOA of 57 ms and 1 at the SOA of 200 ms, were excluded from analyses because the voice key failed to register over 10% of their responses. There were 1.9%, 2.3%, and 1.8% missing data points, respectively, at the SOA of 57 ms, 100 ms, and 200 ms because of the failure of the voice key to register naming latencies, the false triggering of the voice key by extraneous noise, or the naming of errors by participants. We did not analyze naming errors further because there were so few of them and because, if we did, there would be too many empty data points in statistical tests (but see Footnote 4). Mean naming latencies were, on the basis of correct responses, computed for each participant and each item; the overall mean latencies for each condition are presented in Table 3. The priming effects are plotted in Figure 1, collapsed over stimulus group.

In the initial analyses of naming latencies, analyses of variance were conducted for participants (F_1 and t_1) and items (F_2 and t_2), with prime type (semantic vs. complex vs. control) and stimulus group (regular vs. rhyming) as within-subject factors and SOA as a between-subjects factor. There was a significant main effect of prime type, $F_1(2, 194) = 52.36, p < .001, MSE = 349$, and $F_2(2, 140) = 10.85, p < .001, MSE = 1{,}811$. Responses to targets were faster when they were preceded by semantic primes (547 ms) or by complex primes (558 ms) than when they were preceded by unrelated control primes (566 ms). Of greatest interest were the planned comparisons between complex primes and

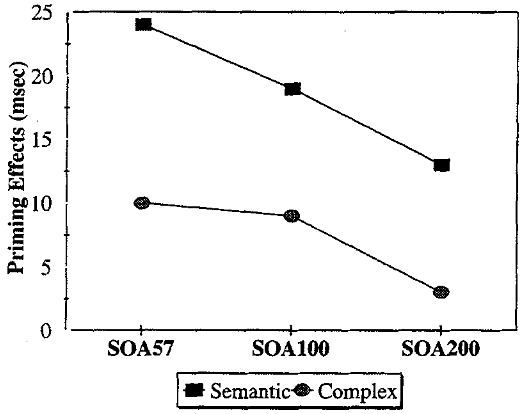

Figure 1. Experiment 1: Priming effects (in milliseconds) for semantic and complex primes (collapsed over stimulus group). SOA = stimulus onset asynchrony.

control primes. Because there was no interaction between prime type and stimulus group in the initial analyses, $F_1(2, 194) = 1.02, p > .10, MSE = 556$, and $F_2 < 1$, stimuli from regular and rhyming groups were collapsed in the planned comparisons. Compared with control primes, complex primes produced an average of an 8-ms facilitatory effect over the three SOA conditions, which was significant by participant, $F_1(1, 97) = 14.62, p < .001, MSE = 192$, and marginally significant by item, $F_2(1, 71) = 3.49, 0.5 < p < .10, MSE = 1{,}884$. As Figure 1 suggests, these effects were strongest at short SOAs. At the SOA of 57 ms, the 11-ms facilitatory effect was significant, both by participant, $t_1(34) = 2.94, p < .01$, and by item, $t_2(71) = 2.65, p < .01$. At the SOA of 100 ms, the 10-ms facilitatory effect was significant by participant, $t_1(29) = 2.54, p < .05$, but not by item, $t_2(71) = 1.32, p > .10$. The 4-ms facilitatory effect at the SOA of 200 ms was not significant, $t_1 < 1$ and $t_2 < 1$. There was, however, no significant interaction between prime type and SOA, $F_1(2, 97) = 1.81, p > .10, MSE = 192$, and $F_2 < 1$. Thus, responses to targets were facilitated by the presence of complex primes whose phonetic radicals were semantically related to the targets. This effect was most evident when the complex primes were presented for a very brief time.

We analyzed priming effects for semantic primes in the same way. The main effect of prime type was highly significant, $F_1(1, 97) = 98.08, p < .001, MSE = 184$, and $F_2(1, 71) = 18.76, p < .001, MSE = 2{,}073$, indicating that targets were named faster when they were preceded by semantic primes than when they were preceded by control primes. The interaction between prime type and SOA was significant by participant, $F_1(2, 97) = 3.67, p < .05, MSE = 184$, and marginally significant by item, $F_2(2, 142) = 2.61, .05 < p < .10, MSE = 431$. Effects were reduced at the longer SOA (see Figure 1), although they were still significant in planned tests ($p < .01$). The overall difference between semantic primes and complex primes was also significant, $F_1(1, 97) = 45.01, p < .001$ $MSE = 294$, and $F_2(1, 70) = 9.34, p < .01, MSE = 1{,}444$, suggesting that semantic primes had stronger facilitatory effects than complex primes on the processing of targets.

Discussion

The strong effects of semantic primes at different SOAs replicated our previous findings and suggested that semantic activation in reading logographic Chinese occurs very early, with immediate consequences for linked phonological representations and for the naming latencies (e.g., Zhou & Marslen-Wilson, 1997, 1998b, in press; Zhou, Shu, Bi, & Shi, 1999). More importantly, the present experiment demonstrated that phonetic radicals contained in both regular and rhyming complex primes can effectively facilitate the processing of targets, which are semantically related to the radicals but not to the whole characters. Note that because primes and targets in this study normally did not share initial phonemes, the effects of both semantic and complex primes cannot be reduced to the "onset effect" (e.g., Forster & Davis, 1991; Shen & Forster, 1999) that may have marred some other primed naming studies.

These facilitatory effects indicate that, in reading complex characters, readers decompose the embedded phonetic radicals and use them to access their own semantic representations, whose activation spreads to other related words, including the semantic targets used in the experiment. Nonetheless, the sublexical semantic priming effects across different SOAs were substantially weaker than the direct semantic priming effects produced by phonetic radicals presented on their own (8 ms vs. 19 ms, on average). This may indicate that the semantic activation of phonetic radicals in complex characters has to compete with the semantic activation of whole characters. The trends over SOAs (see Figure 1) suggest that this competition becomes stronger, whereas sublexical semantic activation becomes weaker over time. The absence of significant interaction between SOA and the priming effects may be due to the relative insensitivity of SOA as a between-subjects factor.

Before we accept the argument of decomposition and sublexical semantic activation in reading complex characters, we have to consider an alternative account for the priming effect between complex characters and target characters. This account is based on the assumption that access to semantics in reading Chinese, like reading alphabetic languages, is predominantly constrained by phonology (e.g., Lesch & Pollatsek, 1993; Lukatela & Turvey, 1994; Van Orden, 1987; Van Orden & Goldinger, 1994; van Orden et al., 1990; but see M. Coltheart & Coltheart, 1997; V. Coltheart, Patterson, & Leahy, 1994; Jared & Seidenberg, 1991; Taft & van Graan, 1998). Tan and Perfetti (1997), for example, claimed that target characters (e.g., 宽, /kuan[1]/, "wide") were facilitated not only by their semantic primes (e.g., 阔, /kuo[4]/, "broad") but also by characters (e.g., 括, /kuo[4]/, "include") that had no direct relation with the targets but were homophonic to (and orthographically different from) the semantic primes (but see Zhou & Marslen-Wilson, in press, who did not replicate this study). The phonological activation, because of the presence of the mediated homophone primes, is argued to spread to linked semantic representations, resulting in facilitatory priming effects for targets that shared semantic properties with one of these activated semantic representations.

This raises the possibility that the priming effects between regular complex primes and targets in the present experiment were due to this phonological mediation rather than the decomposition of phonetic radicals from complex primes and direct activation of phonological and semantic representations of these radicals. Thus, the presence of a regular complex prime activates its phonological representation, which is shared with all other homophonic characters, including its phonetic radical on its own. This phonological activation spreads to all the corresponding semantic representations of homophonic morphemes. The semantic activation of the phonetic radical spreads further to its semantic associates, facilitating the processing of the target used in the experiment. A similar argument would need to be applied to rhyming complex primes, although it is less clear here that phonological mediation could be sufficient to activate the semantic representations of characters rhyming with the primes.

Table 4
Experiment 2: Design and Sample Stimuli

	Prime type			
Condition	Semantic	Complex	Control	Target
Character	青	猜	波	紫
Pronunciation	/qing(1)/	/cai(1)/	/bo(1)/	/zi(3)/
Translation	blue	guess	wave	purple

Note. Semantic primes are the characters contained in the irregular complex prime as phonetic radicals.

To rule out this alternative account and to provide more clear-cut evidence for decomposition and sublexical semantic activation, we used in Experiment 2 irregular complex characters as primes and characters that are semantically related to the phonetic radicals embedded in the complex characters as targets. Because the phonetic radical of an irregular character does not share phonological properties with the complex character (see Table 1), the phonological activation of the whole character could not mediate the semantic activation of its phonetic radical. Therefore, if there is no orthographic decomposition and no sublexical semantic activation in reading complex characters, we should not observe any priming effects between irregular complex primes and target characters. If there is decomposition in reading complex primes, but only the phonology of the decomposed phonetic radicals is accessed, we should not observe priming effects between irregular complex characters and targets, either. If there is decomposition in reading complex primes, and the semantic as well as phonological properties of the phonetic radicals are activated, we should observe significant priming effects between irregular primes and targets, just as in Experiment 1.

Experiment 2

Method

Design and stimuli. The experimental design and sample stimuli are presented in Table 4. Forty-eight irregular complex characters (e.g., 猜, /cai[1]/, "guess"), whose phonetic radicals (e.g., 青, /qing[1]/, "blue") had clear semantic associates (e.g., 紫, /zi[3]/, "purple"), were selected as complex primes (see Appendix Table A2). The associates were used as targets, which were also primed by the phonetic radicals presented alone (i.e., as semantic primes). Because of restrictions on the selection of stimuli, only low- and medium-frequency irregular characters were used and no attempt was made to investigate the potential frequency effect of complex characters on the semantic activation of phonetic radicals. Unrelated control primes (e.g., 波, /bo[1]/, "wave") were chosen to match with complex primes on frequency, visual complexity (in terms of the number of strokes), and structure. The average frequencies for semantic (radical), complex, and control primes were 939, 155, and 154 per million, respectively. The average numbers of strokes per character for the three types of primes were 5.6, 8.6, and 9.3, respectively. Complex primes and control primes all had left–right composition of semantic and phonetic radicals and had an equal number of stroke patterns. The average frequency of the targets was 666 per million, and the average number of strokes was 7.6 per character.

Table 5
Experiment 2: Mean Naming Latencies (in Milliseconds)

	Prime type		
SOA	Semantic	Complex	Control
57 ms	541	554	564
100 ms	544	558	567
200 ms	540	560	560

Note. SOA = stimulus onset asynchrony.

A Latin square design was used to assign critical targets and their primes into three test versions, with each version having 16 primes of each type. Sixty unrelated prime–target pairs were used as fillers in each version. The filler characters, as in Experiment 1, were of various frequencies and with various types of orthographic structure. No syllables used in critical stimuli were used in fillers. The same procedure used in Experiment 1 was used here to create the three testing sequences. Twenty pairs of practice items were also constructed.

Procedure. The preparation of stimuli and the testing of participants were conducted in the same way as in Experiment 1. The primes were presented for 57 ms, 100 ms, or 200 ms, according to the SOA condition.

Participants. Ninety undergraduate students at Beijing Normal University were tested, with 30 for each SOA condition. They were native speakers of Mandarin Chinese and were not tested for Experiment 1.

Results

Three items had high rates of missing responses (at around 50% in one or more conditions), primarily because of naming errors. They were excluded from analyses in all three SOA conditions. For the remaining responses to the 45 targets, there were 30 (2.1%), 24 (1.7%), and 20 (1.4%) missing cells, respectively, at the SOAs of 57 ms, 100 ms, and 200 ms. Most of the missing cells were due to extraneous noise or failure of the voice key to register responses, although there were a few naming errors. Mean naming latencies were then computed and are reported in Table 5. Priming effects are plotted in Figure 2.

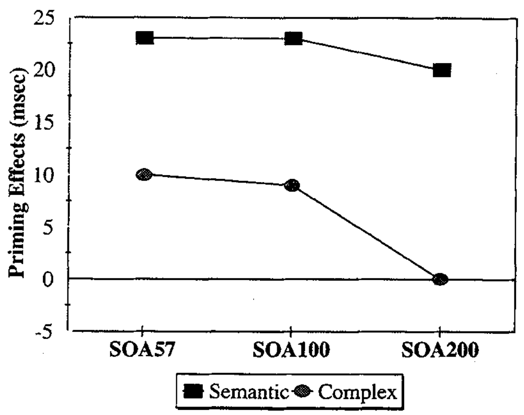

Figure 2. Experiment 2: Priming effects (in milliseconds) for semantic and complex primes. SOA = stimulus onset asynchrony.

Statistical analyses with prime type as a within-subject factor and SOA as a between-subjects factor revealed a highly significant main effect of prime type, $F_1(2, 174) = 53.79$, $p < .001$, $MSE = 206$, and $F_2(2, 88) = 21.30$, $p < .001$, $MSE = 816$. We focus here on the planned comparisons for the priming effects of complex primes across different SOAs, as assessed against control primes. The main effect of prime type was significant by participant, $F_1(1, 44) = 37.69$, $p < .001$, $MSE = 872$, and marginally significant by item, $F_2(1, 44) = 3.08$, $p < .10$, $MSE = 907$. Targets were named faster when they were preceded by complex primes than when they were preceded by unrelated control primes. As in Experiment 1, these effects were stronger at shorter SOAs. At the SOA of 57 ms, the 10-ms facilitatory effect was significant by participant, $t_1(29) = 3.58$, $p < .01$, and by item, $t_2(44) = 2.48$, $p < .05$. The 9-ms effect at the 100-ms SOA was significant by participant, $t_1(29) = 2.13$, $p < .05$, and marginally significant by item, $t_2(44) = 1.74$, $.05 < p < .10$. No effects were found at the 200-ms SOA (both t_1 and $t_2 < 1$). Again, however, this trend did not result in a significant interaction between SOA and prime type, $F_1(2, 87) = 2.10$, $p > .10$, $MSE = 174$, and $F_2(2, 88) = 2.25$, $p > .10$, $MSE = 315$. In summary, complex primes were capable of facilitating the processing of target characters that were semantically related to the phonetic radicals of these complex primes, but these effects were restricted mainly to the short SOA.

In the analyses of semantic priming effects, as assessed against control primes, the main effect of prime type was highly significant, $F_1(1, 87) = 93.68$, $p < .001$, $MSE = 223$, and $F_2(1, 44) = 37.69$, $p < .001$, $MSE = 872$. Targets were named faster when they were preceded by semantically related characters than when they were preceded by unrelated characters. The interaction between prime type and SOA was not significant, $F_1 < 1$ and $F_2 < 1$, indicating that the semantic priming effects were essentially the same across different SOAs. The main effect of SOA was not significant, $F_1 < 1$ and $F_2 < 2$. The overall difference between semantic primes and complex primes was highly significant, $F_1(1, 87) = 47.96$, $p < .001$, $MSE = 222$, and $F_2(1, 44) = 24.62$, $p < .001$, $MSE = 343$, suggesting that effects of semantic priming were much larger than the effects of complex primes.

Discussion

The strong effects of semantic priming replicated our previous findings and suggested that semantic activation can efficiently flow to phonology, resulting in the facilitatory effects in naming target characters. More importantly, the significant priming effects between complex characters and the semantic associates of their phonetic radicals demonstrated that the phonetic radicals of complex characters are decomposed and used to access not only their corresponding form representations in the lexicon but also their semantic properties, which are not related to the complex characters. This sublexical semantic activation cannot be attributed to mediation through the phonological activation of the complex characters because the phonetic radicals and the irregular complex characters containing them do not share phonological properties.

The smaller priming effect between complex primes and targets, compared with direct semantic priming, again suggests competition in the semantic system between representations corresponding to the whole complex characters and representations corresponding to their embedded phonetic radicals. The trend over SOA suggests that this competition has a time course, with the semantic activation of phonetic radicals being effectively suppressed within 200 ms. Indeed, this trend becomes clearer when the priming effects for complex primes in Experiments 1 and 2 are combined: The interaction between SOA and prime type was marginally significant, $F_1(2, 281) = 2.86$, $p < .06$, $MSE = 363$, and $F_2(2, 228) = 2.70$, $p < .07$, $MSE = 416$, suggesting that the priming effect at the SOA of 200 ms was much smaller than the effects at shorter SOAs. The main effect of prime type was also stronger in the combined analyses, $F_1(1, 281) = 19.91$, $p < .001$, $MSE = 363$, and $F_2(1, 114) = 6.12$, $p < .05$, $MSE = 484$.

Experiment 3

Experiment 2 demonstrates that the priming effect between complex characters and semantic associates of their phonetic radicals cannot be attributed to the spread of activation from the phonological processing of the whole complex characters because the phonetic radicals did not have the same phonological forms as the whole characters. The purpose of the third experiment was to obtain converging evidence for the argument that the sublexical processing of phonetic radicals in complex characters is not only a phonological event but also a semantic event.

To do this, Experiment 3 essentially inverted the order of the materials used in Experiment 2, so that irregular complex characters became targets rather than primes. The phonetic radicals contained in these complex targets were primed either by the phonetic radical presented on its own or by a "radical semantic" prime, which is semantically related to the embedded phonetic radical but not to the meaning of the complex character as a whole (see Table 6). Thus, for example, the complex target 猜 (/cai[1]/, "guess") is preceded either by the radical itself (青, /qing[1]/, "blue") or by a radical semantic prime (紫, /zi[3]/, "purple") that is semantically related to the radical but not to the complex character. By definition, of course, these irregular complex targets share neither phonological nor semantic properties with their phonetic radicals.

In Experiments 1 and 2, we looked for facilitatory effects. Here, we predicted interference effects. If reading complex characters involves decomposing phonetic radicals automatically and using them to access their own semantic representations, then preactivation of these radicals, either by radical primes or by radical semantic primes, should strengthen this decomposition process and increase the competition between the underlying representations corresponding to the embedded phonetic radicals and to the targets. This competition should, in turn, slow down the activation of the targets, including their phonological representations,

Table 6
Experiment 3: Design and Sample Stimuli

Condition	Prime type Radical	 Radical semantic	 Control	Target
Character	青	紫	裂	猜
Pronunciation	/qing(1)/	/zi(3)/	/lie(4)/	/cai(1)/
Translation	blue	purple	split	guess

Note. Radical primes are the characters contained in the irregular complex targets as phonetic radicals. Radical semantic primes are related to the characters embedded in targets as their phonetic radicals, not to the targets themselves.

leading to longer naming latencies relative to control priming conditions.

Method

Design and materials. The design and sample stimuli are presented in Table 6. Forty-five complex characters (e.g., 猜, /cai[1]/, "guess") that were used as primes in Experiment 2 were taken as targets in the present experiment, preceded by radical semantic primes (e.g., 紫, /zi[3]/, "purple") that were related to the phonetic radicals of these complex characters but not to the complex characters themselves. The same complex characters were also preceded by their phonetic radicals (e.g., 青, /qing[1]/, "blue"), which were presented alone in another condition. New control primes were selected to match with semantic primes on frequency, visual complexity, and structure. Both semantic and control primes were of left–right structure for semantic and phonetic radicals. The average frequencies of radical primes, radical semantic primes, and control primes were 1,036, 639, and 643 per million, respectively. The average number of strokes per character were 5.1, 7.5, and 6.9, respectively, for the three types of primes. For the targets, the average frequency was 160 per million and the average number of strokes was 8.2 per character (see Appendix Table A3).

As in the previous experiments, we used a Latin square design to assign critical primes and the corresponding targets into three test versions. Each participant saw all the 45 targets, 15 of them preceded by one of the three types of primes. In each version, there were 60 pairs of unrelated characters that acted as fillers to reduce the proportion of related items. Filler characters were of various orthographic structure and frequency. No syllables used in the critical stimuli were used again in fillers. A pseudorandom ordering was used to arrange the stimuli, so that across the three test versions the same targets appeared in the same positions. Twenty pairs of practice items were also used. Again, three SOAs between primes and targets were used: 57 ms, 100 ms, and 200 ms.

Procedure. The preparation of stimuli and the testing of participants were conducted in the same way as in the previous experiments.

Participants. One hundred two native speakers of Mandarin Chinese were tested for this experiment: 30 for the 57-ms SOA condition, 36 for the 100-ms SOA condition, and 36 for the 200-ms SOA condition. They were undergraduate students at Beijing Normal University and were not tested for Experiments 1 and 2.

Results

Mean naming latencies and percentages of response error are reported in Table 7. Priming effects are plotted in Figure 3. We excluded three targets at 100-ms and 200-ms SOAs from analysis because of high naming errors and voice-key failures. To standardize the stimuli across different SOAs, we also excluded these targets from analyses at the 57-ms SOA. Across SOAs and prime types, error rates were generally higher than in the previous experiments. This was partly because the targets in the present experiment were visually complex and mainly of low frequency.

The initial analyses of naming latencies, with prime type as a within-subject factor and SOA as a between-subjects factor, showed a highly significant main effect of prime type, $F_1(2, 198) = 22.99$, $p < .001$, $MSE = 1{,}420$, and $F_2(2, 82) = 12.83$, $p < .001$, $MSE = 2{,}281$. Our main interest, however, was in the priming effects for radical semantic primes at different SOAs, as assessed against the unrelated control primes. These are the conditions in which the prime is a character that is semantically related to the phonetic radical contained in the target but not to the target itself. Here, the main effect of prime type was significant by participant, $F_1(1, 99) = 8.60$, $p < .01$, $MSE = 1{,}457$, and marginally significant by item, $F_2(1, 41) = 4.07$, $.05 < p < .10$, $MSE = 2{,}551$. Responses to complex targets were slower when they were preceded by radical semantic primes than when they were preceded by unrelated controls, with stronger effects at longer, rather than at shorter, SOAs. The 6-ms inhibitory effect at the 57-ms SOA was not significant (t_1 and $t_2 < 1$); the 17-ms inhibitory effect at the 100-ms SOA was marginally significant, $t_1(35) = 2.00$, $.05 < p <$

Table 7
Experiment 3: Mean Naming Latencies (in Milliseconds) and Percentages of Error

SOA	Prime type Radical	 Radical semantic	 Control
57 ms			
M	667	668	662
% error	4.1	5.8	4.8
100 ms			
M	689	659	642
% error	7.6	6.0	6.4
200 ms			
M	694	668	650
% error	5.8	5.2	6.0

Note. SOA = stimulus onset asynchrony.

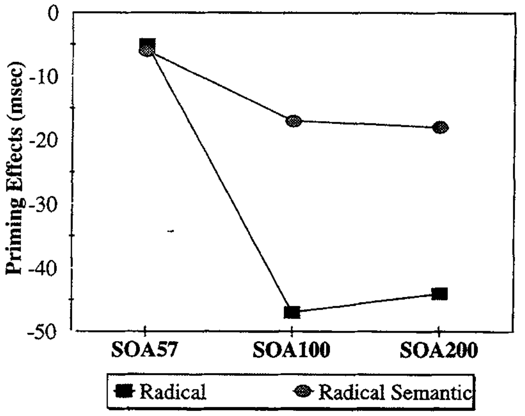

Figure 3. Experiment 3: Priming effects (in milliseconds) for radical and radical semantic primes. SOA = stimulus onset asynchrony.

.10, and $t_2(41) = 1.85$, $.05 < p < .10$; and the 18-ms inhibitory effect at the 200-ms SOA was significant by participants, $t_1(35) = 2.17$, $p < .05$, and by items, $t_2(41) = 2.07$, $p < .05$.

Analyzing the naming latencies for radical primes and control primes, we found a significant main effect of prime type across SOAs, $F_1(1, 99) = 48.98$, $p < .001$, $MSE = 1{,}326$, and $F_2(1, 41) = 30.43$, $p < .001$, $MSE = 1{,}237$. Targets were named more slowly when they were preceded by radical primes than when they were preceded by control primes. These are the conditions in which the prime character is the phonetic radical of the target word. The significant interaction between prime type and SOA, $F_1(2, 99) = 6.60$, $p < .01$, $MSE = 1{,}326$, and $F_2(2, 82) = 9.29$, $p < .001$, $MSE = 1{,}237$, indicates that these inhibitory effects differed across SOAs. The effects at 57 ms did not reach significance (t_1 and $t_2 < 1$), unlike those at the 100-ms and 200-ms SOAs ($p < .01$).

Analyzing the response error rates, we did not find any significant effects in either global analyses or planned tests (all $F_1 < 1$ and $F_2 < 1$). A rough categorization of naming errors revealed that the most common errors were orthographically based.[4] These errors were made when targets were preceded by either related or unrelated primes. They suggested that phonetic radicals were decomposed from complex targets and used to access their own representations and representations of other characters containing these radicals. There were also a few morphologically based errors, where, for example, a character was pronounced as another character where the two characters form a compound word (e.g., 贿 , /hui[4]/, "bribe," pronounced as 赂 , /lu[4]/, see Taft & Zhu, 1995, for a study related to this phenomenon). Semantic errors, although relatively common in naming Chinese characters (see Zhou & Marslen-Wilson, in press), were infrequent here.

Discussion

The significant inhibitory effect of phonetic radical primes (e.g., 青 , /qing[1]/, "blue") on the naming of irregular complex characters (e.g., 猜, /cai[1]/, "guess") replicated the finding of Zhou (1994), who systematically manipulated the relative frequencies of phonetic radicals and complex characters and the phonological relations between them. However, it is difficult to pinpoint the locus of this inhibitory effect because radical primes were related to complex targets in several dimensions. It is possible that the presence of radical primes preactivated the phonological and semantic representations corresponding to radicals and that this activation facilitated the processes of decomposing these phonetic radicals in reading complex targets. The phonological and semantic activation of complex characters had to compete with the phonological and semantic activation of phonetic radicals, leading to slower naming latencies in naming the targets. Alternatively, the inhibitory effects for radical primes may be simply due to the orthographic similarity between radical primes and complex targets. It has been found that orthographically similar but phonologically different characters (e.g., 田, /tian[2]/, "field" and 申, /shen[1]/, "apply") inhibit each other in the visual–visual primed naming task (H.-C. Chen & Shu, 1997; Zhou, 1994; but see Perfetti & Tan, 1998, for a slightly different pattern; see also Shen & Forster, 1999, for facilitatory effects between orthographically similar characters in masked priming). When orthographic targets are presented, the shared orthographic properties between primes and targets are used to activate the phonological representations of targets as well as to reactivate partially the phonological representations of primes. The competition between phonological representations of primes and targets leads to slower responses to targets.

The more important result here, though, was the finding that the presence of radical semantic primes, related to the phonetic radicals of complex targets but not to the targets themselves, could delay the phonological activation of these targets, where this effect could not be explained on orthographic or phonological grounds. This finding is consistent with the data of Experiments 1 and 2 and with the view that there is an automatic decomposition process in reading complex characters and that both phonological and semantic properties of phonetic radicals are activated. The presence of radical semantic primes preactivated the representations of radical characters. This preactivation made it easier for the phonetic radicals to decompose from the complex targets and to achieve higher levels of semantic and phonological activation, leading to stronger competition with the semantic and phonological representations of complex characters.

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[4] These errors included pronouncing targets as visually similar characters (usually having common phonetic radicals, e.g., 隐 , /yain[3]/, "concealed," pronounced as 稳 , /wen[3]/, "steady"; 魄 , /po[4]/, "soul," as 魁 , /kui[2]/, "chief" or 愧 , /kui[4]/, "ashamed"; 贿 , /hui[4]/, "bribe" as 赌 , /du[3]/, "gamble" or 堕 , /duo[4]/, "fall"; and 拙 , /zhuo[1]/, "clumsy" as 掘 , /jue[2]/, "dig") or pronouncing the whole characters as their radicals (mostly phonetic radicals, e.g., 坛 , /tan[2]/, "jar" as 云 , /yun[2]/, "cloud"; 烁 , /shuo[4]/, "shining" as 乐 , /le[4]/, "happy"; and 弧 , /hu[2]/, "arc" as 弓 , /gong[1]/, "bow").

This delayed the naming of complex targets relative to control conditions, with the stronger effects at longer SOAs.

General Discussion

In this study, we observed that the presence of complex primes facilitated the processing of targets that were semantically related to the phonetic radicals contained in regular or irregular complex primes (Experiments 1 and 2). Moreover, the presence of semantic primes, which were related to the phonetic radicals of irregular characters but not to the complex characters themselves, could delay the recognition and phonological activation of the complex characters (Experiment 3). The semantic activation of phonetic radicals in complex characters appeared to last a relatively long time. The patterns of the priming effects in the three experiments strongly suggest that in reading complex characters, readers automatically decompose the embedded phonetic radicals from the whole complex characters and map them onto their own phonological and semantic representations, in parallel to the mapping based on the whole characters. Thus, the sublexical processing of phonetic radicals is, like lexical-level processing, not only a phonological event but also a semantic event. There are no fundamental differences between lexical processing of whole characters and sublexical processing of phonetic radicals in reading Chinese.

Sublexical Semantic Activation

The finding of automatic activation of semantic representations of phonetic radicals in (low-frequency) complex characters is parallel to the finding of sublexical phonological activation (e.g., Fang et al., 1986; Hue, 1992; Peng et al., 1994; Seidenberg, 1985; Zhou & Marslen-Wilson, 1999) and to the finding of sublexical semantic activation of semantic radicals (Feldman & Siok, 1999; Zhou & Marslen-Wilson, 1999). Both Feldman and Siok and Zhou and Marslen-Wilson found that semantic radicals could aid the processing of whole characters if these radicals have relatively transparent relations with the meanings of whole characters. However, the present finding of sublexical semantic activation for phonetic radicals is perhaps surprising, given that the semantic activation of phonetic radicals contained in complex characters almost always works against the processing of the whole character.

The evident sublexical semantic activation in reading Chinese also contrasts with the absence of such activation in reading monomorphemic words in alphabetic languages. We ran a primed naming experiment (with an SOA of 57 ms) to examine the potential sublexical semantic activation in English. This experiment used a design similar to Experiment 1. Monomorphemic words (e.g., *boycott*) into which other words (i.e., *boy*) were embedded as their initial components were used as primes, and words that were semantically related to the embedded words were used as targets (e.g., *girl*). No priming effects were found in naming latencies to such targets, even when there were clear syllabic and orthographic (in terms of bigram frequency) boundaries between the embedded words and the remaining parts of primes. The absence of sublexical semantic activation in reading English (see also Sandra, 1990, and Zwitserlood, 1994, for Dutch) is consistent with the assumptions of the reading models, which, in general, do not allow the semantic system to have two separate patterns activated simultaneously (e.g., M. Coltheart et al., 1993; Frost, 1998; Seidenberg & McClelland, 1989; Van Orden et al., 1990).

This leads us to the question of why there should be a discrepancy in sublexical processing between Chinese and alphabetic languages. Although the underlying mechanisms for sublexical processing in logographic and alphabetic languages are essentially the same, we believe that the application or the performance of these mechanisms varies according to the structural properties of different writing systems. There are at least three contrasts that make the phonetic radicals more salient orthographic units than letter clusters, leading sublexical processing in Chinese to be both phonological and semantic and sublexical processing in English to be primarily phonological.

First, complex characters in Chinese can be thought of as analogous to compound words, with both semantic and phonetic radicals representing meanings. In contrast, sublexical orthographic units or letter clusters in English (monomorphemic) words do not usually represent meanings. Even when they do (e.g., *own* in *town*), after stripping these units, one finds that the remaining parts may not correspond to any words (except for a few pseudocompound words like *shamrock* or *capsize*). However, the semicompoundhood of complex characters or alphabetic words themselves may not be sufficient to produce significant sublexical semantic activation. Using a visual–visual priming lexical decision task, Zwitserlood (1994; see also Sandra, 1990) did not find significant priming effects between Dutch semantically opaque compounds (e.g., *blackmail*) or pseudocompounds and semantic associates of their components (e.g., *while*).

Second, phonetic radicals are integrated orthographic units, whose constituents (e.g., strokes) have no systematic correspondences in phonology or semantics. Phonetic radicals provide clues to the pronunciation of the whole complex characters rather than to a part of it. In contrast, sublexical orthographic units in English can be differentiated further into components (e.g., letters), which do have quasi-regular correspondences to phonology, although not to semantics. Letter clusters are mapped onto phonological units, which constitute part of the whole-word phonology. Moreover, there are usually clear visual separations between phonetic and semantic radicals, at least for complex characters with left–right structure. But in alphabetic languages, there are no clear visual cues for the separation between intralexical orthographic units, even when taking "soft" constraints, such as phonotactic rules or bigram frequency, into consideration. A letter string can be decomposed into different orthographic units of various sizes. Therefore, compared with letter strings in alphabetic words, phonetic radicals as orthographic units in Chinese characters are more salient and integrated. In reading Chinese, one decomposes semantic radicals from whole characters and uses them to access semantics (Feldman & Siok, 1999; Zhou & Marslen-Wilson, 1999) and their phonology, if these radicals happen to be words by themselves (Zhou, Lu, & Shu, in press). Phonetic radicals, like other integrated units, are likely to be mapped onto semantics as well.

Third, phonetic radicals are repeatedly used in different characters, and their frequencies as independent characters are usually higher than those of the whole characters in which they are embedded. Moreover, the relations between phonetic and semantic radicals and the complex characters are either explicitly or implicitly taught to children when they learn characters.[5] Adult readers continue to decompose characters when they check characters in written dictionaries.[6] In English, however, the sublexical orthographic units that happen to correspond to real words are less likely to be used in different words, and it is rare, if not strange, for parents or teachers to point out to children that there is a word embedded in the new monomorphemic word.

These contrasts make phonetic radicals much more salient and integrated orthographic units in complex characters than letter clusters in alphabetic words, even when these clusters happen to correspond to words. The efficient decomposition and processing of phonetic radicals, especially for those in low-frequency complex characters, lead to both sublexical phonological activation and sublexical semantic activation. This sublexical semantic activation is an automatic process in reading Chinese because it almost always interferes with the semantic activation of the whole characters. Note also that the priming effects we obtained in this study cannot be attributed to participants' strategic adaptation to the relations between semantic associates and phonetic radicals of complex characters. If participants can strategically control orthographic decomposition and sublexical semantic activation, they would have been able to avoid using this procedure in Experiment 3, given that it was harmful to the completion of the task at hand.

An issue not addressed in the present study concerns how semantic information of phonetic radicals embedded in complex characters is activated—through direct visual access from orthography to semantics or through indirect phonological mediation, or both? This issue is related to the vexing question of whether semantic activation of Chinese characters in general is predominantly constrained by phonological activation. A number of studies on Chinese or Japanese kanji, using experimental techniques such as semantic categorization (e.g., V. Coltheart et al., 1994; Jared & Seidenberg, 1991; Van Orden, 1987) or phonologically mediated semantic priming (e.g., Fleming, 1993; Lesch & Pollatsek, 1993; Lukatela & Turvey, 1994), produced inconclusive evidence. Although most studies (e.g., H.-C. Chen, Cheung, & Flores d'Arcais, 1995; Leck, Weekes, & Chen, 1995; Sakuma, Sasanuma, Tatsumi, & Masaki, 1998; Wydell, Patterson, & Humphreys, 1993; Zhou & Marslen-Wilson, in press; Zhou et al., 1999) found no effect or a weak effect of "pure" phonology on semantic activation, others (e.g., Perfetti & Tan, 1998) reported strong phonological effects (see Zhou & Marslen-Wilson, in press, for a review and a discussion). It is our view that access to lexical semantics in reading Chinese is not simply due to direct computation from orthography or to mediation though phonological activation. It is normally the interaction between phonology and orthography that determines semantic activation. To the extent that phonological and orthographic effects on semantic activation can be separated in experiments, it is orthography, rather than phonology, that plays a relatively more important role in constraining semantic activation (see Shen & Forster, 1999, and Zhou & Marslen-Wilson, in press, for evidence). This view may also apply to the sublexical semantic activation of phonetic radicals, although more studies are certainly needed to test this argument.

Lexical Representation in Chinese

The finding of automatic activation of semantic representations of phonetic radicals in reading complex characters puts constraints on the structure of lexical representation and lexical-processing models. A popular hierarchical model of visual word recognition in Chinese (Taft, Liu, & Zhu, 1999; Taft & Zhu, 1995, 1997; Zhu & Taft, 1994), which is along the lines of the interactive activation framework, assumes that reading Chinese characters begins with the activation of strokes. This activation at the basic orthographic level passes to radicals, which connect to character representations. The character representations connect to their corresponding syllable representations and to the whole-word orthographic representations, which in turn connect to concept or semantic representations. Because phonetic radicals are themselves characters and because most characters can also be words, this model may represent phonetic radicals three times—once at the radical level, once at the character level (to connect to phonology), and once at the word level (to connect to semantics). Moreover, the radical-level representations are position sensitive (Taft & Zhu, 1997; but see Feldman & Siok, 1997). Thus, if a radical can occur at either the left or right side of a character, this radical is represented twice (with position information) at the radical level. Although such an approach is obviously awkward (consider, e.g., a radical like 口, /kou[3]/, "mouth," which can occur on the left, right, top, or bottom or in the center of characters), it nevertheless can accommodate the findings in this study. Because activation is assumed to flow from lower levels to higher levels, the orthographic activation of phonetic radicals embedded in complex characters will eventually reach their semantic representations, resulting in the priming effects observed in this study. This model can also explain the phonological activation of semantic radicals that are characters on their own (Zhou et al., in press), as it assumes that all (simple) radicals are independently

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[5] For example, one way to teach children to learn characters, used by some parents and in some schools in mainland China, is to group together characters with the same phonetic radicals and ask children to pay special attention to the structure and composition of these characters.

[6] One common way for Chinese dictionaries to arrange characters is to group characters according to their orthographic structure and common components (usually semantic radicals). These components are then abstracted in indexes. To check specific characters in the dictionary, readers usually have to decompose the characters and use their critical components as cues to search the dictionary.

activated in the process of character recognition (Taft & Zhu, 1997). However, it is not clear how semantic radicals, which are not characters themselves, are represented in this model. By definition, they have no representations at the character level and hence have no direct connections with semantics, yet they do contribute to the semantic activation of whole characters (Feldman & Siok, 1999; Zhou & Marslen-Wilson, 1999).

Perfetti and Tan (1998) suggested that there are three interconnected "lexicons" in a multilexicon system: the character orthographic lexicon, the noncharacter component orthographic lexicon, and the phonological lexicon. Perfetti and Tan put phonetic and semantic radicals that are themselves characters into the character orthographic lexicon, which connects to the phonological lexicon, and the noncharacter components (a few phonetic radicals and many semantic radicals) into a separate lexicon. It is not clear in this suggestion, however, what the function of a "noncharacter lexicon" is in lexical processing and whether both phonological and semantic representations of phonetic radicals embedded in complex characters are automatically activated in reading complex characters.

Our preferred account for the sublexical semantic activation of phonetic radicals does not need to assume distinct levels or lexicons. Rather, we assume that, because of the distinctiveness of phonetic radicals in complex characters, their orthographic forms are extracted from the visual input of whole characters during the process of character recognition and mapped onto their own orthographic, phonological, and semantic representations, in parallel to the mapping for the whole characters. These different types of representation, whether for whole characters or for phonetic or semantic radicals, are each represented at the same levels. These representations can be viewed as either localist or distributed activation patterns. The activation of orthographic representations, whether they correspond to whole characters or to semantic or phonetic radicals, automatically leads to the corresponding activation in both semantic and phonological systems.

One way of modeling this is in a connectionist framework, in which orthographic, phonological, and semantic representations of the complex characters and radicals are constructed as activation patterns distributed over large numbers of simple processing units (e.g., Seidenberg & McClelland, 1989). The weights connecting these units are derived through exposure to orthographic input and encode statistical regularities within and between domains, such as the phonological relations between radicals and whole characters (Y. Chen & Peng, 1994). Because phonetic radicals are characters in isolation and because they are used in many different characters, these radicals form their own activation patterns at orthographic, phonological, and semantic levels, and these representations interact with each in lexical processing. In recognition of a complex character, although the mapping between orthography, phonology, and semantics establishes stable lexical activation at these levels for the whole characters, the distinctive properties of the embedded phonetic radicals allow them to establish subpatterns at the same levels (Rueckl, Mikolinski, Raveh, Miner, & Mars, 1997; Zhou & Marslen-Wilson, 1998a). Although conventional connectionist modeling using "blending" techniques may not be very effective in representing distinctive semantic or phonological patterns corresponding to whole characters and phonetic radicals (see Gaskell & Marslen-Wilson, in press), temporal-binding or space-binding techniques (e.g., Hummel & Biederman, 1992; Shastri & Ajjanagadde, 1993; Smolensky, 1990) may allow connectionist networks simultaneously to achieve and retain such unrelated activation patterns.

In conclusion, whatever the appropriate underlying theoretical frameworks for capturing the data, we have shown here that sublexical processing of phonetic radicals in reading Chinese involves activation of semantic properties corresponding to the radicals. There are no fundamental differences between sublexical processing of phonetic radicals and lexical processing of simple and complex characters.

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Appendix

Primes and Targets Used in Experiments 1 and 3

Characters in column 2 are semantic primes, which are also used as phonetic radicals in complex primes. Characters in column 3 are complex primes, which are homophonic to the phonetic radicals embedded in these primes (in the regular group), have the same rhyming parts as the phonetic radicals (in the rhyming group), or have no phonological relations with the phonetic radicals (in the irregular group). Characters in column 4 are control primes, and characters in the last column are targets. The positions of complex primes and targets in the irregular group were reversed in Experiment 3, and a new set of control primes were selected. Items marked with an asterisk (*) were not included in Experiment 3.

Table A1
Primes and Targets Used in the Regular Group (Experiment 1)

Item no.	Prime type			Target
	Semantic	Complex	Control	
1	安 /an(1)/	鞍 /an(1)/	醚 /mi(2)/	危 /wei(1)/
2	半 /ban(4)/	拌 /ban(4)/	拟 /ni(3)/	倍 /bei(4)/
3	表 /biao(3)/	裱 /biao(3)/	啮 /nie(4)/	钟 /zhong(1)/
4	宾 /bin(1)/	缤 /bin(1)/	妞 /niu(1)/	客 /ke(4)/
5	岛 /dao(3)/	捣 /dao(3)/	赌 /du(3)/	海 /hai(3)/
6	刀 /dao(1)/	叨 /dao(1)/	泣 /qi(4)/	剑 /jian(4)/
7	耳 /er(3)/	饵 /er(3)/	跷 /qiao(4)/	眼 /yan(3)/
8	分 /fen(1)/	吩 /fen(1)/	绅 /shen(1)/	合 /he(2)/
9	风 /feng(1)/	枫 /feng(1)/	柿 /shi(4)/	雨 /yu(3)/
10	官 /guan(1)/	棺 /guan(1)/	搪 /tang(2)/	民 /min(2)/
11	黑 /hei(1)/	嘿 /hei(1)/	桶 /tong(3)/	白 /bai(2)/
12	黄 /huang(2)/	磺 /huang(2)/	涡 /wo(1)/	绿 /lu(4)/
13	见 /jian(4)/	舰 /jian(4)/	鸭 /ya(1)/	看 /kan(4)/
14	巨 /ju(4)/	矩 /ju(3)/	淹 /yan(1)/	大 /da(4)/
15	雷 /lei(2)/	镭 /lei(2)/	坷 /ke(3)/	电 /dian(4)/
16	离 /li(2)/	漓 /li(2)/	佬 /lao(3)/	分 /fen(4)/
17	里 /li(3)/	鲤 /li(3)/	殷 /yin(1)/	外 /wai(4)/
18	林 /lin(2)/	琳 /lin(2)/	隅 /yu(2)/	树 /shu(4)/
19	龙 /long(2)/	珑 /long(2)/	陨 /yun(3)/	凤 /feng(4)/
20	马 /ma(3)/	码 /ma(3)/	铮 /zheng(1)/	牛 /niu(2)/
21	美 /mei(3)/	镁 /mei(3)/	蛀 /zhu(4)/	丑 /chou(3)/
22	苗 /miao(2)/	描 /miao(2)/	综 /zong(1)/	禾 /he(2)/
23	末 /mo(4)/	沫 /mo(4)/	袄 /ao(3)/	尾 /wei(3)/
24	南 /nan(2)/	楠 /nan(2)/	粑 /ba(1)/	北 /bei(3)/
25	宁 /ning(2)/	柠 /ning(2)/	镐 /gao(3)/	静 /jing(4)/
26	禽 /qin(2)/	擒 /qin(2)/	碴 /cha(2)/	兽 /shou(4)/
27	青 /qing(1)/	蜻 /qing(1)/	搓 /cuo(1)/	紫 /zi(3)/
28	丘 /qiu(1)/	蚯 /qiu(1)/	嗒 /da(1)/	山 /shan(1)/
29	柔 /rou(2)/	揉 /rou(2)/	隙 /xi(4)/	弱 /ruo(4)/
30	叔 /shu(1)/	淑 /shu(1)/	碇 /ding(4)/	婶 /shen(3)/
31	同 /tong(2)/	桐 /tong(2)/	跺 /duo(4)/	异 /yi(4)/
32	弯 /wan(1)/	湾 /wan(1)/	讽 /feng(3)/	直 /zhi(2)/
33	文 /wen(2)/	纹 /wen(2)/	耕 /geng(1)/	武 /wu(3)/
34	星 /xing(1)/	惺 /xing(1)/	鸿 /hong(2)/	月 /yue(4)/
35	凶 /xiong(1)/	汹 /xiong(1)/	圾 /ji(1)/	恶 /e(4)/
36	秀 /xiu(4)/	锈 /xiu(4)/	祸 /huo(4)/	美 /mei(3)/
37	虚 /xu(1)/	墟 /xu(1)/	抠 /kou(1)/	实 /shi(2)/
38	羊 /yang(2)/	佯 /yang(2)/	馍 /mo(2)/	马 /ma(3)/
39	益 /yi(4)/	溢 /yi(4)/	晾 /liang(4)/	利 /li(4) /
40	婴 /ying(1)/	缨 /ying(1)/	燎 /liao(2)/	童 /tong(2)/
41	云 /yun(2)/	耘 /yun(2)/	颅 /lu(2)/	风 /feng(1)/
42	主 /zhu(3)/	拄 /zhu(3)/	诀 /jue(2)/	仆 /pu(2)/

(Appendix continues)

Table A2

Primes and Targets Used in the Rhyming Group (Experiment 1)

Item no.	Prime type			Target
	Semantic	Complex	Control	
1	单 /dan(1)/	蝉 /chan(2)/	傍 /bang(4)/	双 /shuang(1)/
2	登 /deng(1)/	橙 /cheng(2)/	贬 /bian(3)/	爬 /pa(2)/
3	弟 /di(4)/	梯 /ti(1)/	踩 /cai(3)/	妹 /mei(4)/
4	敢 /gan(3)/	瞰 /kan(4)/	赐 /ci(4)/	怕 /pa(4)/
5	干 /gan(1)/	刊 /kan(1)/	扶 /fu(2)/	湿 /shi(1)/
6	高 /gao(1)/	犒 /kao(4)/	湛 /zhan(4)/	低 /di(1)/
7	谷 /gu(3)/	俗 /su(2)/	彼 /bi(3)/	稻 /dao(4)/
8	贵 /gui(4)/	溃 /kui(4)/	挎 /kua(4)/	贱 /jian(4)/
9	鬼 /gui(3)/	愧 /kui(4)/	辣 /la(4)/	神 /shen(2)/
10	果 /guo(3)/	裸 /luo(3)/	礁 /jiao(1)/	菜 /cai(4)/
11	后 /hou(4)/	垢 /gou(4)/	杜 /du(4)/	前 /qian(2)/
12	惠 /hui(4)/	穗 /sui(4)/	碟 /die(2)/	恩 /en(1)/
13	加 /jia(1)/	咖 /ka(1)/	蚪 /dou(3)/	减 /jian(3)/
14	皆 /jie(1)/	谐 /xie(2)/	淡 /dan(4)/	全 /quan(2)/
15	今 /jin(1)/	吟 /yin(2)/	浩 /hao(4)/	古 /gu(3)/
16	君 /jun(1)/	裙 /qun(2)/	憾 /han(4)/	臣 /chen(2)/
17	狂 /kuang(2)/	逛 /guang(4)/	凛 /lin(3)/	傲 /ao(4)/
18	难 /nan(2)/	滩 /tan(1)/	脖 /bo(2)/	易 /yi(4)/
19	朋 /peng(2)/	绷 /beng(1)/	砸 /za(2)/	友 /you(3)/
20	全 /quan(2)/	拴 /shuan(1)/	哧 /chi(1)/	齐 /qi(2)/
21	少 /shao(3)/	抄 /chao(1)/	浸 /jin(4)/	多 /duo(1)/
22	十 /shi(2)/	汁 /zhi(1)/	旷 /kuang(4)/	百 /bai(3)/
23	田 /tian(2)/	佃 /dian(4)/	沦 /lun(2)/	地 /di(4)/
24	易 /yi(4)/	踢 /ti(1)/	绵 /mian(2)/	难 /nan(2)/
25	蚤 /zao(3)/	搔 /sao(1)/	橱 /chu(2)/	虫 /chong(2)/
26	造 /zao(4)/	糙 /cao(1)/	姆 /mu(3)/	建 /jian(4)/
27	斩 /zhan(3)/	惭 /can(2)/	谱 /pu(3)/	杀 /sha(1)/
28	真 /zhen(1)/	慎 /shen(4)/	绒 /rong(2)/	假 /jia(4)/
29	止 /zhi(3)/	耻 /chi(3)/	梢 /shao(1)/	停 /ting(2)/
30	奏 /zou(4)/	凑 /cou(4)/	悟 /wu(4)/	唱 /chang(4) /

Table A3
Primes and Targets Used in the Irregular Group (Experiment 2)

Item no.	Prime type			Target
	Semantic	Complex	Control	
1	罢 /ba(4)/	摆 /bai(3)/	超 /chao(1)/	免 /mian(3)/
2	白 /bai(2)/	泊 /po(1)/	僧 /seng(1)/	黑 /hei(1)/
3	百 /bai(3)/	陌 /mo(4)/	浩 /hao(4)/	千 /qian(1)/
4	车 /che(1)/	阵 /zhen(4)/	诉 /su(4)/	船 /chuan(2)/
5	虫 /chong(2)/	浊 /zhuo(2)/	媒 /mei(2)/	鸟 /niao(3)/
6	出 /chu(1)/	拙 /zhuo(1)/	贬 /bian(3)/	进 /jin(4)/
7	寸 /cun(4)/	付 /fu(4)/	淡 /dan(4)/	尺 /chi(3)/
8	呆 /dai(1)/	保 /bao(3)/	块 /kuai(4)/	傻 /sha(3)/
9	刀 /dao(1)/	初 /chu(1)/	姐 /jie(3)/	叉 /cha(1)/
10	对 /dui(4)/	树 /shu(4)/	块 /kuai(4)/	错 /cuo(4)/
11	分 /fen(1)/	盼 /pan(4)/	肝 /gan(1)/	离 /li(2)/
12	风 /feng(1)/	飒 /sa(4)/	谍 /die(2)/	雨 /yu(3)/
13	工 /gong(1)/	杠 /gang(4)/	捍 /han(4)/	农 /nong(2)/
14	瓜 /gua(1)/	弧 /hu(2)/	炯 /jiong(3)/	果 /guo(3)/
15*	关 /guan(1)/	联 /lian(2)/	桥 /qiao(2)/	开 /kai(1)/
16	鬼 /gui(3)/	魄 /po(4)/	蠕 /ru(2)/	神 /shen(2)/
17	黄 /huang(2)/	横 /heng(2)/	补 /bu(3)/	绿 /luu(4)/
18	击 /ji(1)/	陆 /lu(4)/	粗 /cu(1)/	打 /da(3)/
19	急 /ji(2)/	隐 /yin(3)/	摔 /shuai(1)/	慢 /man(4)/
20	斤 /jin(1)/	斩 /zhan(3)/	逆 /ni(4)/	两 /liang(3)/
21	巨 /ju(4)/	柜 /gui(4)/	伴 /ban(4)/	大 /da(4)/
22	开 /kai(1)/	研 /yan(2)/	根 /gen(1)/	关 /guan(1)/
23	乐 /le(4)/	烁 /shuo(4)/	邦 /bang(1)/	笑 /xiao(4)/
24	马 /ma(3)/	冯 /feng(2)/	汪 /wang(1)/	牛 /niu(2)/
25	木 /mu(4)/	休 /xiu(1)/	临 /lin(2)/	草 /cao(3)/
26	那 /na(4)/	挪 /nuo(2)/	姥 /lao(3)/	这 /zhe(4)/
27	内 /nei(4)/	纳 /na(4)/	押 /ya(1)/	外 /wai(4)/
28	牛 /niu(2)/	件 /jian(4)/	孩 /hai(2)/	羊 /yang(2)/
29	欠 /qian(4)/	坎 /kan(3)/	仆 /pu(2)/	缺 /que(1)/
30	青 /qing(1)/	猜 /cai(1)/	骑 /qi(2)/	紫 /zi(3)/
31	犬 /quan(3)/	伏 /fu(2)/	绕 /rao(4)/	狗 /gou(3)/
32	人 /ren(2)/	队 /dui(4)/	决 /jue(2)/	兽 /shou(4)/
33	舌 /she(2)/	括 /kuo(4)/	培 /pei(2)/	嘴 /zui(3)/
34	生 /sheng(1)/	姓 /xing(4)/	借 /jie(4)/	死 /si(3)/
35	市 /shi(4)/	肺 /fei(4)/	拦 /lan(2)/	县 /xian(4) /
36*	水 /shui(3)/	冰 /bing(1)/	楼 /lou(2)/	土 /tu(3)/
37	思 /si(1)/	腮 /sai(1)/	锤 /chui(2)/	想 /xiang(3)/
38	寺 /si(4)/	待 /dai(4)/	歌 /ge(1)/	庙 /miao(4)/
39	西 /xi(1)/	洒 /sa(3)/	扰 /rao(3)/	东 /dong(1) /
40	先 /xian(1)/	洗 /xi(3)/	犯 /fan(4)/	后 /hou(4)/
41	兄 /xiong(1)/	况 /kuang(4)/	抗 /kang(4)/	弟 /di(4)/
42	友 /you(3)/	拔 /ba(2)/	谋 /mou(2)/	敌 /di(2)/
43	有 /you(3)/	贿 /hui(4)/	鞍 /an(1)/	无 /wu(2)/
44	云 /yun(2)/	坛 /tan(2)/	捐 /juan(1)/	雾 /wu(4)/
45	争 /zheng(1)/	净 /jing(4)/	滚 /gun(3)/	斗 /dou(4)/
46	主 /zhu(3)/	往 /wang(3)/	流 /liu(2)/	次 /ci(4)/
47	走 /zou(3)/	徒 /tu(2)/	洲 /zhou(1)/	跑 /pao(3)/
48*	足 /zu(2)/	捉 /zhuo(1)/	唤 /huan(4)/	脚 /jiao(3) /

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