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The Time Course of Graphic, Phonological, and Semantic Activation in Chinese Character Identification

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In reading, lexical *form–form* relations may be more reliable than *form–meaning* relations. Accordingly, phonological forms (activated by graphic forms) become actual constituents, rather than addenda, of word identification. These considerations suggest that access to phonological forms can precede meaning access in single-word reading in many circumstances. The time course of form and meaning activation during Chinese word reading was tested in 2 primed-naming experiments varying prime type and prime–target stimulus onset asynchrony (SOA). The results showed a sequence of facilitation over SOA: (a) graphic, (b) phonological, (c) semantic. Words with precise meanings produced more rapid semantic priming than words with vague meanings. Graphic prime facilitation at a 43-ms SOA gave way to inhibition at longer SOAs. The onset of graphic inhibition coincided with the onset of phonological facilitation, suggesting a single identification moment. The authors describe an interactive constituency model that accounts for the pattern of data.

Writing systems vary in how they represent the phonology of the language they encode. How are these differences reflected in visual word identification? Three classes of hypotheses have been proposed. According to the *universal direct access hypothesis,* word reading is accomplished by a visual route in all writing systems and in all orthographies. Phonological processing, to the extent that it occurs, is a product of individual reader and word characteristics (e.g., word frequency; Baluch & Besner, 1991; Besner, 1987; Sebastian-Galles, 1991; Tabossi & Laghi, 1992). In contrast, the *orthographic depth hypothesis* claims that the use of phonology is directly determined by properties of the orthography (Frost, 1994; Frost, Katz, & Bentin, 1987). When the grapheme–phoneme mappings of the orthography are consistent, as in Serbo-Croatian and Italian, reading involves a *shallow* orthography that allows a phonological process to convert written strings to phonemic strings (Feldman & Turvey, 1983; Frost et al., 1987; Katz & Feldman, 1983; Lukatela & Turvey, 1980). A third hypothesis is based on the *universal phonological principle* (UPP) proposed by Perfetti, Zhang, and Berent (1992) and further developed in Perfetti and Zhang (1995a). According to the UPP, encounters with printed words activate multiple levels of phonology in all writing systems. Features of the writing system may control the details of how various phonological levels are activated, but the phonological activation itself is fully general.

Chinese presents an interesting case for these ideas about writing systems, orthographies, and reading.[1] Chinese is usually considered a logography, a system in which the basic unit in writing associates with a unit of meaning, a morpheme. Because there is no unit of the writing system that encodes single phonemes, grapheme–phoneme mappings are impossible. The writing system, however, does provide some representation of speech at the syllable level. This fact places Chinese closer to the family of speech-based writing systems than is often assumed (DeFrancis, 1989; Mattingly, 1992) and clearly should caution against careless claims that Chinese reading involves only a meaning-based writing system. Nevertheless, because syllable information is both incomplete and nonsystematic, it is possible to maintain the view that reading Chinese is markedly different from reading English or any other orthography within the family of alphabetic writing systems. A Chinese reader can, in principle, read words, which consist of one or more characters, by going directly from writing units (characters) to meanings.

Both the orthographic depth hypothesis and the universal direct access hypothesis, which are very different in the role they give to phonology in alphabetic writing systems, suggest that reading Chinese is a visual form-to-meaning process. The universal phonological principle, however, suggests that whether phonology intervenes between visual form and meaning, it is an essential constituent of identification. The UPP emphasizes (a) the dependency of writing systems on spoken language, and (b) the preference of

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[1] We do not use *writing systems* and *orthographies* interchangeably. Writing systems are the abstract principles that control the orthography, which is the particular realization of the system. Thus, within an alphabetic writing system, orthographies can vary in how they map onto phonology and morphology.

human language processing and memory for speech coding. Thus, reading generally is a phonology-plus-meaning process.

Research has provided support for both the script-to-meaning view of Chinese reading (e.g., Baron & Strawson, 1976; Chen, Yung, & Ng, 1988; Hoosain & Osgood, 1983; Smith, 1985; Tzeng & Hung, 1978; Tzeng, Hung, & Wang, 1977; Wang, 1973; see, e.g., Hoosain, 1991, for a detailed review) and the phonology-plus-meaning view (Cheng & Shih, 1988; Lam, Perfetti, & Bell, 1991; Perfetti & Zhang, 1991, 1995b; Tan & Peng, 1991). According to one perspective, both views might be correct, with phonology merely added to the end of a script-to-meaning process. A more fundamental difference exists between the two views, however, in the role assigned to phonology. The phonology-plus-meaning hypothesis, based on the UPP, takes phonological word forms to be constituents of the word identification process, not some optional addendum to identification as implied by the script-to-meaning view.

The claim that phonological word forms are constituents of identification has some implications for reading. One is that the role of phonology may be both more powerful than simple mediation—which is the assumption that phonology is used for something else—and more important than merely "postlexical" processing. If there is a cognitive moment of word identification, this moment includes an explicit retrieval of phonological form as well as meaning, or some other category of word information. Furthermore, word identification must arise from graphic information. Thus, a moment of identification is the retrieval of a phonological form in some relation to both graphic and semantic information. This relationship might be one of briefly integrated information sources: For example, the object such that it is spelled *dog*, has the phonological form /dawg/ and means whatever it is that *dog* means. Thus, in English at least, a moment of identification suggests a short-lived integration—a simultaneous availability of graphemic, phonological, and semantic information. This integration reflects what van Orden and Goldinger (1994) referred to as coherence (resonance), as these information sources, through mutual activation, jointly determine a word identity. Although identification arises with the integration of various sources, the information from different sources may accumulate in overlapping time courses. Obviously, graphic information initiates the process, but phonological and semantic information can come very rapidly from the graphemic input. And because the graphemes are linked to phonemes, the activation of graphemic and phonological information might rise in synchrony. However, the excitation strengths of these types of information can be different at some time point of identification (e.g., Ferrand & Grainger, 1994; Perfetti & Bell, 1991). Indeed, it is possible that in alphabetic systems, a phonological word form may be available before the complete specification of a graphemic representation (Lukatela & Turvey, 1994; van Orden, 1987). Moreover, graphemic activation decays fast during word perception (e.g., Humphreys, Evett, Quinlan, & Besner, 1987).

The situation may be different in a nonalphabetic writing system. Whereas alphabetic writing systems encourage an explicit sublexical relationship between graphemic and phonological form, Chinese does not. Its graphic–phonological relationships are defined over lexical items at the syllable level rather at the grapheme–phoneme level (Cheng, 1982; Leong, 1997; Perfetti & Zhang, 1995a). This means that if the identification of a Chinese character includes phonology as a constituent, as argued earlier, then this phonology may not arise in synchrony with the processing of the constituent graphic units as it does in English. Instead, the character will have picked out its associated phonological and semantic information either as a whole or with the useful parts (semantic and phonetic components) that do not bear the same relationship to the character as letters do to English words. In either case, the kind of synchrony allowed by sublexical graphic–phonological connections may be lacking. This speculative difference between alphabetic and nonalphabetic systems in the synchrony of different information sources, at this point, is rather subtle. It can be characterized in other terms by saying that Chinese identification, the integration of phonological and semantic information, occurs *from* its graphic input (following a specification of its graphic input), whereas alphabetic writing systems allow word identification to occur *with* its graphic input (prior to complete specification of graphic input).

In this perspective, English and Chinese reading differ less in the use of phonology than in the use of orthography. In both English and Chinese, phonological forms may be especially reliable constituents of identification, rapidly and routinely activated as a part of word identification. This assumption may help explain the recent evidence suggesting that Chinese readers, just as readers of English, show a very rapid retrieval of phonological word forms, even more rapid than semantic information under some circumstances (Perfetti & Zhang, 1995b; Tan, Hoosain, & Peng, 1995). Perfetti and Zhang (1995b), for example, presented pairs of one-character words one at a time to native Chinese speakers for same–different judgments. The SOA between the onset of the first character and the onset of the second character was varied from 90 ms to over 310 ms. In one judgment, the decision was based on semantic information: Do the two words have the same meaning? In another judgment, the decision was based on phonological information: Do the two words have the same pronunciation? The critical cases were foil trials: For meaning decisions, a foil trial meant that the two words had the same pronunciation, and hence a "no" decision was required. For pronunciation decisions, a foil trial meant the two words had the same meanings, again requiring a "no" decision. Interference in each case was assessed by comparing these critical foil trials with control trials, in which the two words were completely unrelated. The result was that phonological interference was observed earlier, within a 90-ms SOA, than semantic interference. This result suggests that the name of a character is activated very quickly for a Chinese reader in a task for which it serves no purpose except to interfere with the task at hand.

Why might phonological forms be so rapidly available in Chinese, given a writing system that does not represent sublexical (phoneme-level) phonology? An explanation is available, if, as we have argued, phonology is a constituent of identification, even in Chinese, but one also needs an answer to the following question: Why should phonology be a constituent of identification? A general answer might be that writing systems, and thus reading, are speech dependent because of human biological preferences for speech. A narrower psychological explanation, suggested by Perfetti and Zhang (1995a), is that graphic and phonological forms, as opposed to meanings, are privileged constituents of identification. Specifically, Perfetti and Zhang argued that for writing systems in which form–form relationships are more deterministic than form–meaning relationships, graphic–phonological relationships are more reliable than graphic–meaning (or phonological–meaning) relationships in identification. For example, in English the meanings of *safe* are many and context dependent, whether one refers to basic denotation (*safe* at second base in baseball vs. *safe*—a place to keep valuables) or nuance of meaning (*safe* from physical harm vs. *safe* from uncertainty—a *safe* bet). By contrast, the phonological form associated with *safe* is unique: /seyf/. Unlike for meaning, there is no context issue in determining the phonological form. Thus a reader, on encountering *safe*, can be sure that it is /seyf/ without having secure knowledge of its context-dependent meaning. For words presented in isolation, this fact has a strong implication: Form–form connections are retrieved nearly deterministically;[2] form–meaning relations are retrieved only probabilistically, at least at the base morpheme level. This view of word meaning is consistent with the proposal that word meanings can be seen as a range of values filled in by context (Barsalou, 1982).

In Chinese, the form–meaning relationship may be even more context dependent than in English. The number of Chinese characters in daily use is very limited, usually less than 4,000 according to the *Xiandai Hanyu Pinlu Cidian* [*Modern Chinese Frequency Dictionary*] (1986). With a limited functional character repertory, written Chinese uses characters to express the full range of potential meanings. At the same time, Chinese readers can build up strong graphic form–phonological form associations, which are quite deterministic. Although there is much homophony in Chinese—several characters share a given pronunciation (ignoring tone)—the pronunciation of most characters is uniquely determined, just as in English. Tan et al. (1995) have noted that Chinese readers can use pronunciations even when the meanings of characters are less determined. They found differences between vague and precise meanings (what they called "fuzzy" and "exact" meanings) in semantic masking effects, with vague meaning words providing weaker semantic effects than precise meaning words.

Semantic vagueness arises in at least two different ways, both derivative of the fact that meanings are context dependent. In one case, there is imprecise representation of a word's range of meanings; in the second case, the meanings are highly varied, ambiguous without a dominant meaning. Consider, for example, the words 表 (/biao/) and 态 (/tai/). These two characters have frequencies of 943 and 233 per million, respectively, according to the *Modern Chinese Frequency Dictionary* (1986). 表 (/biao/) has the 10 meanings ordered as follows by the *Modern Chinese Dictionary* (1992):

> 1. surface; 2. a kind of relative; 3. express, show, or demonstrate; 4. treating a cold or flu with sudorifics; 5. model, example; 6. a kind of ancient memorial to an emperor; 7. table, form, list; 8. an ancient pole to measure sun shadows; 9. meter, gauge; 10. watch.

Of these, 1, 3, 5, 7, 9, and 10 are frequently used, but it is not clear which, if any, meaning is the most frequent. More important, because there are several common and distinct meanings, no one meaning is dominant (i.e., represented in the majority of uses). By contrast, for 态 (/tai/), there are only two meanings given: 1. shape, state, form, condition, attitude. 2. voice (e.g., the active voice). The first meaning is dominant. Readers, however, have trouble reporting either meaning in isolation. Thus, we have two cases of vague meanings, one a very high frequency word with many meanings, but no dominant sense; and one of high frequency with two or fewer meanings, one dominant.

Informants provide judgments that agree with this analysis. We asked 10 native speakers of Mandarin Chinese (in Pittsburgh) to report the precise meanings of several characters, including the two described, within 10 s. For 表 (/biao/), despite its high frequency, only 5 of 10 informants could report any meaning, and each of these 5 participants reported a different meaning. For 态 (/tai/), 7 informants could not report any meaning, and 3 reported its first meaning. With 表 (/biao/) we observed uncertainty of meaning, with informants asking which meaning they should report. With 态 (/tai/), informants did not know the precise meanings, and 4 said it is too difficult to judge the meaning of that character in isolation. Thus, we see two slightly different cases of semantic uncertainty, one with many distinct meanings, thus showing standard polysemy, and the other with a meaning that seems very difficult to specify in isolation. Taken together, they illustrate a pervasive semantic uncertainty of isolated words in Chinese.

The role of semantic precision has been demonstrated in backward masking studies by Tan et al. (1995). Participants identified a briefly exposed target character, which was masked by a graphically, phonologically, or semantically similar character, or by an unrelated control character. When the target and mask were presented for 60 and 40 ms, respectively, a phonological mask affected high frequency target identification. More interestingly, a semantically related mask also facilitated identification of a target, provided it was a high frequency word with precise meaning. No effects were found for semantically vague words. These findings revealed that phonological activation precedes semantic activation and constituted evidence that the semantic vagueness of a word can affect semantic processing of word identification. A more recent study by Tan, Hoosain, and Siok (1996) with the backward masking procedure provides further support for these positions.

In summary, there is evidence that phonological forms of

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[2] English has only a handful of nondeterministic spellings: *wind, lead, bow*, and perhaps a dozen more.

characters are activated very rapidly in Chinese, more rapidly than meanings under some circumstances. And there is a partial explanation of this time course difference if phonological forms are constituents rather than addenda of word identification, an assumption that is strengthened by the greater degree of one-to-one mapping between graphic forms and phonological forms compared with graphic forms and meaning. From this argument arise two questions. One is whether we can obtain evidence that the time-course of semantic information depends on semantic precision, as our argument suggests. If the phonology-before-semantics result can be partly explained by this relative determinacy principle, then semantically precise words should show faster semantic activation than semantically vague words. The second question concerns a specific property of Chinese, which we suggested may differ more from English in its use of graphic information than in its use of phonological information. Our suggestion was that whereas phonology should be a constituent of reading in both writing systems, English and other alphabetic writing systems, but not Chinese, present the opportunity for graphic and phonological information to arise synchronously at the sublexical level. Thus, the cognitive moment of identification in Chinese may include some asynchrony in the integration of its constituents, with the graphic form being available as a unit before both its phonological form and meanings.

To address these questions, we turn to experiments using a naming task in which phonology but not semantic processing is necessary. By examining prime–target relationships in naming, one can observe the time course of graphic information (for graphic prime–target relationships), phonological (for phonologically related prime–target pairs), and semantic information (for semantically related prime–target pairs). These prime–target relationships can be exploited to the degree that relevant information from the prime is activated and used in the naming response. At very short prime durations, there is limited time to obtain information, and one might expect graphic similarity to facilitate priming more than phonological and semantic information. At longer prime durations, there is more time for all of the information from the primes to be used.

Nevertheless, given the results of Perfetti and Zhang (1995b) and Tan et al. (1995), which were based on semantic judgments and perceptual identification, respectively, we should expect early phonological effects in naming, which requires phonology, replicating the faster time course of phonological over semantic information. For semantic primes, the time course of semantic information should depend on the meaning precision of the primes. For graphic information, the expectation is less clear. One possibility is that visual similarity between prime and target aids the extraction of critical form information from the target. Perfetti and Zhang (1991) found such graphic priming effects on target identification at 50 ms; however, they found no effects on target naming speed when the prime was exposed for 180 ms. These results suggest that once a word has been identified (as a phonological or semantic object), its visual form may not be available (see also Humphreys et al., 1987).

Thus, we report below the results of primed naming experiments, modeled after Perfetti and Zhang (1991, Experiment 4), but with two additional important features. In Experiment 1, we vary the semantic vagueness of the prime to test the hypothesis that semantically precise primes show stronger priming than semantically vague primes. Experiment 2 examines the time course question by varying the SOA between prime and target.

Experiment 1

Experiment 1 tested the assumption that form–meaning relationships are less accessible than form–form relationships in naming. More specifically, if form–meaning relationships are variable in precision, then semantic priming effects should be dependent on the degree of semantic precision of a prime character. When a prime character is semantically vague, semantic priming should be less likely than when a prime character is semantically precise.

Experiment 1 also allows an across-task replication of Perfetti and Zhang's (1995b) and Tan et al.'s (1995) findings favoring phonology before semantics to single-character words. In addition, the experiment tests graphic effects as well as semantic and phonological effects. In previous primed naming research, Perfetti and Zhang (1991, Experiment 4) found both phonological and semantic priming effects in the absence of graphic effects with a 180-ms SOA between prime and target. This result was just the opposite to that obtained in masked identification with shorter 50-ms exposure duration, where graphic effects were obtained in the absence of phonological and semantic effects (Perfetti & Zhang, 1991, Experiment 1; Tan et al., 1995, 1996). It may be that shorter SOAs produce visual–graphic effects based on the activation of relevant visual form information, whereas at longer SOAs, visual form information, in the absence of relevant phonological or semantic information, has ceased to be accessible. For Experiment 1, we chose an SOA of 115 ms because it is less than the 180-ms SOA that produced semantic and phonological but not graphic priming in naming. On the basis of previous research, we assumed this SOA would be ample to show phonological priming and sufficient for semantic priming, at least in precise semantic conditions. (Perfetti & Zhang, 1995b, found a semantic effect at 140-ms SOA and a phonological effect at 90-ms SOA.)

For semantic vagueness, we collapsed across the two types of semantic uncertainty discussed previously. Here we refer to a general concept of vagueness, a measure of semantic uncertainty of single-character words in isolation. On one end of the vagueness dimension, native speakers rate the word as having a precise meaning. At the other end, they rate the word as having a vague meaning. Because previous research has shown that simple associative relationships influenced semantic processing of characters (Tan et al., 1996), we controlled for associative relationships between prime and target in this experiment. Thus, the semantic variable is realized as vagueness of meaning, not diffusion of association.

In summary, Experiment 1 varied semantic vagueness and prime type (graphic, semantic, and phonological) in a primed naming procedure with a 115-ms SOA. In addition to the three critical prime types, there were two kinds of controls, an unrelated single-character prime and the nonlinguistic number symbol (#). This control procedure allows a clear separation of facilitation from inhibition effects. An unrelated character that is partially identified may create a condition of inhibition, and any prime effects relative to the unrelated prime may be a reduction of inhibition.

Method

Participants

Twenty undergraduate students of South China (Guangzhou) Normal University participated in the experiment. All were native Mandarin speakers and had normal or corrected-to-normal vision.

Materials and Design

Vagueness ratings. Twenty-five students of the Beijing Electronic Industry Management College rated a list of 340 medium- or high-frequency characters (greater than 6 per million, according to the *Modern Chinese Frequency Dictionary*) on a 7-point vagueness scale. Informants were asked to assess the semantic vagueness of each character from *very vague* (*1*) to *very precise* (*7*). From the data provided by these informants, 48 semantically vague and 48 semantically precise characters were chosen as primes for the primed naming experiment. The rating for the vague-meaning primes ranged from 1.92 to 3.96, with an average of 2.97 ($SD = 0.59$). For the precise-meaning primes, the rating ranged from 5.51 to 7.00, with an average of 6.20 ($SD = 0.46$).

The selection of primes was based on the vagueness ratings in combination with the definition of prime types: graphic, semantic, phonological, and unrelated. Thus, the 48 vague primes and 48 precise primes were divided into groups of 12 of each prime type: *Graphic* primes were graphically similar to their targets but neither phonologically nor semantically similar. Of the graphic primes, 79% shared a component with their targets, whereas the remainder had high visual similarity without shared components. *Phonological* primes were homophonic (and identical in tone) to their targets, but neither semantically nor graphemically related. *Semantic* primes were semantically but neither phonologically nor graphemically related to their targets. Twenty additional Beijing Electronic Industry Management College undergraduate students rated the semantic similarity of all pairs on a 7-point rating scale (1 = *lowest meaning similarity,* 7 = *highest meaning similarity*). All pairs were rated as high in meaning similarity; no prime–target pair produced a mean rating of less than 5.5, and the mean ratings across the two sets of primes were not significantly different (5.80 vs. 6.11; $F < 1$). *Unrelated* primes had no relationship to their targets. The 96 prime–target pairs thus formed two lists of 4 prime–target relations in a 2 (vague/precise) × 4 (prime types) mixed factorial design. In addition, 12 characters served as targets primed by a neutral #. These 12 targets, matched to the main set of 96 on frequency and semantic vagueness, occurred in both lists. The size of the # was designed to be similar to the size of a character.

The primes and targets satisfied certain constraints. All primes and targets were greater than 30 per million in printed frequency; the semantic vagueness of the targets was matched across prime conditions; the number of strokes in both primes and targets was matched across primes types. The stimuli and their characteristics are listed in Appendixes A, B, and C. Key prime and target characteristics are given in Table 1.

Associative relatedness assessment. There was no associative relationship between primes, including semantic primes and targets, as assessed by 60 different informants, undergraduates at South China (Guangzhou) Normal University. In this assessment, 60 students were divided into two equal groups and asked to look at the meaning of a character and write down the first character that came to mind. One group was given a typed list of the 96 characters used as targets, and the other group given the 96 characters used as primes. They were encouraged to provide a single character as their response. Based on the participants' association responses, the 96 character prime–target pairs satisfied the constraint that no target and prime were associates. Specifically, of the 96 prime–target pairs, the associative strength of 94 pairs was zero, and the associative strength (i.e., percentage of informants giving a certain character as an associate) of the remaining 2 pairs was less than 3.4%.

Procedure

Each participant viewed 108 pairs, 96 prime–target pairs and 12 #-target pairs. Chinese characters were presented in white against a black background in 24-point, normal font. Each character was approximately 0.9 × 1.2 cm. Participants were seated approximately 50 cm from a screen controlled by a microcomputer.

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 prime was immediately presented for 115 ms and was immediately followed by a character target. The target remained on the screen until participants made a naming response. Participants were informed that there would be a very brief exposure of a first character, followed by a second character, and that their task was to pronounce the second character (i.e., the target) as quickly and accurately as possible. They were not told about any relationships that might exist between the two characters. A voice-activated microphone connected to the computer recorded the interval between the onset of the target and the onset of participants' oral

Table 1
Means of the Stroke Number and Semantic Vagueness of Primes and Targets in Each Condition

Prime type	Vague primes		Targets		Precise primes		Targets	
	Stroke	Vagueness	Stroke	Vagueness	Stroke	Vagueness	Stroke	Vagueness
Graphic	9.17	2.70	8.25	4.11	7.92	6.15	7.67	5.03
Homophonic	7.84	3.26	8.84	4.96	9.50	6.24	10.08	4.57
Semantic	8.67	2.98	7.50	4.40	8.17	6.08	8.92	4.99
Unrelated	8.50	2.95	9.17	4.36	8.50	6.33	8.92	4.44
# Primes							7.75	4.74

Table 2
Average Naming Latencies (in Milliseconds) and Error Rates for Targets as a Function of Prime Type and Prime Semantic Vagueness in Experiment 1

	Vague primes				Precise primes				
Results	Graphic	Homophonic	Semantic	Unrelated	Graphic	Homophonic	Semantic	Unrelated	# Primes
Latencies	640	550	569	635	634	543	529	632	626
Error rates	5.00	1.27	2.53	3.43	7.08	3.35	3.40	8.44	3.00

response. The maximum interval allowed was 2 s. If this interval was exceeded, a "no" response was automatically recorded by the computer, and after a 2-s pause, a new trial commenced.

Experimental stimuli were presented in random order. Prior to the formal experiment, each participant received 12 practice trials, 10 trials with characters as primes and 2 with # as primes. Character primes had no visual, phonological, or semantic similarities to targets in this warmup. Both targets and primes in these trials had high frequencies (no less than 30 occurrences per million).

Results

Reaction times greater than 1,200 ms and less than 200 ms (less than 3% of trials) were excluded from the analysis, as were the reaction times of incorrect responses. The mean reaction times of correctly pronounced targets and percentages of incorrect responses in each prime condition are shown in Table 2. The important results were that (a) both phonological and semantic prime types facilitated target naming, whereas graphic primes showed no effect; and (b) precise-meaning semantic primes produced more facilitation than vague-meaning semantic primes.

These conclusions are supported by analyses of variance for both subjects (F_1) and items (F_2): For prime type, $F_1(3, 57) = 81.34$, $p < .001$, $MSE = 102{,}236.67$; $F_2(3, 88) = 68.52$, $p < .001$, $MSE = 61{,}324.00$. For semantic vagueness, $F_1(1, 19) = 12.41$, $p < .002$, $MSE = 7{,}854.01$; $F_2(1, 88) = 5.26$, $p < .03$, $MSE = 4{,}704.00$. The effect of semantic vagueness was seen mainly for semantic primes. A planned comparison of vagueness for semantic versus unrelated primes showed that vagueness mattered only for semantic primes, $F_1(1, 19) = 9.34$, $p < .007$, $MSE = 6{,}845.00$; $F_2(1, 44) = 4.43$, $p < .05$, $MSE = 4{,}107.00$.[3]

To examine the pattern of priming effects among homophonic, semantic, and graphic primes, we carried out a separate series of planned comparisons, one for vague primes and one for precise primes. Because all effects were significant both relative to the unrelated primes and the # primes, we report all effects relative to the unrelated primes.

For vague primes, both homophonic primes and semantic primes facilitated target identification: For homophone primes, $F_1(1, 19) = 45.17$, $p < .001$, $MSE = 72{,}250.00$; $F_2(1, 22) = 52.28$, $p < .001$, $MSE = 43{,}350.00$. For semantic primes, $F_1(1, 19) = 38.58$, $p < .001$, $MSE = 43{,}560.00$; $F_2(1, 22) = 23.41$, $p < .001$, $MSE = 26{,}136.00$. Target identification times in the homophonic prime condition were nonsignificantly faster than in the semantic prime condition, $F_1(1, 19) = 2.40$, $p > .13$, $MSE = 3{,}610.00$; $F_2(1, 22) = 1.95$, $p > .17$, $MSE = 2{,}166.00$. By contrast, the analysis showed no effect of graphic primes, $F_1(1, 19) = 0.11$, $p = .75$, $MSE = 250.00$; $F_2(1, 22) < 1$. There was no difference between unrelated character primes and the # primes (both F_1 and $F_2 < 1$).

The same pattern of priming effects was obtained for the semantically precise primes: Facilitation by homophonic and semantic primes compared with both unrelated character primes and # primes. For homophone primes, $F_1(1, 19) = 71.01$, $p < .001$, $MSE = 79{,}299.02$; $F_2(1, 22) = 62.15$, $p < .001$, $MSE = 47{,}526.00$. For semantic primes, $F_1(1, 19) = 105.37$, $p < .001$, $MSE = 106{,}090.00$; $F_2(1, 22) = 86.13$, $p < .001$, $MSE = 63{,}645.00$. Although homophonic primes again produced faster naming than semantic primes, the difference was not significant, $F_1(1, 19) = 2.52$, $p > .12$, $MSE = 1{,}946.02$; $F_2(1, 22) = 1.54$, $p > .22$, $MSE = 1{,}176.00$. Again, there was no effect of graphic primes (F_1 and $F_2 < 1$), and there was, again, no difference between unrelated character primes and the # primes (both F_1 and $F_2 < 1$).

For error rates, there were main effects of semantic vagueness, $F_1(1, 19) = 6.12$, $p < .03$, $MSE = 4.32$; $F_2(1, 88) = 5.43$, $p < .05$, $MSE = 6.71$, and prime type, $F_1(3, 57) = 10.21$, $p < .001$, $MSE = 11.43$; $F_2(3, 88) = 15.83$, $p < .001$, $MSE = 12.41$, and an interaction of Semantic Vagueness × Prime Type, $F_1(3, 57) = 7.89$, $p < .001$, $MSE = 3.98$; $F_2(3, 88) = 5.15$, $p < .005$, $MSE = 6.50$. Graphic primes produced more errors than unrelated # primes, and precise-meaning primes produced more errors than vague-meaning primes. Homophonic and semantic primes produced fewer errors relative to the unrelated character-prime control type, but only for precise meaning primes and only relative to the unrelated character prime. No other significant difference among the conditions was found. As can be seen in Table 2, the most visible error effect was an increase in errors with unrelated character primes when primes' meanings were precise.

Discussion

With 115 ms of prime exposure, both homophonic and semantic primes facilitated target naming, but graphic primes did not reliably affect target identification. These

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[3] Because each prime condition contained different items, item characteristics such as frequency varied across conditions. An analysis of covariance, with prime and target frequencies as covariates, produced the same pattern of significance as the results of the ANOVAs reported here. This is true for the main ANOVAs and for the specific condition comparisons both in Experiment 1 and Experiment 2.

findings provide a perfect replication of the naming results of Perfetti and Zhang (1991) in the 180-ms SOA condition. Our findings, together with Perfetti and Zhang's, suggest that the phonological and semantic information of Chinese characters was activated within 115 ms, although in a priming procedure it is always possible that some of the effect arises after the onset of the target. If one assumes that it requires about 200 ms for conscious processing (cf. Neely, 1977), our results suggest that both phonological and semantic information occurs automatically at an early stage of character processing when naming is required.

The failure to observe graphic effects in Experiment 1 is puzzling at first glance. Graphic information of Chinese characters appears to be activated completely at threshold of character identification (Tan et al., 1996), which is considerably less than the 115 ms of Experiment 1. The implication of these facts is that the graphic code has been accessed much earlier than phonological and semantic codes and has reached an inactive state by 115 ms.

Also interesting is that semantically precise primes facilitated target processing more than semantically vague primes when there was a semantic relationship between prime and target, as illustrated by the significant interaction of Semantic Vagueness × Semantic versus Unrelated Primes. This result suggests that the semantics of precise-meaning characters are likely to be activated earlier and more strongly than those of vague-meaning characters. Target characters were named, on average, 40 ms faster when primed with a precise-meaning semantic prime than when primed with a vague-meaning semantic prime. Relative to the unrelated primes, the semantically vague semantic primes produced a 66-ms advantage (55 ms relative to the # controls); the semantically precise semantic primes produced a 103-ms advantage relative to unrelated primes and a 97-ms advantage relative to # controls. Thus, the cost to processing facilitation for semantic vagueness for a semantic prime was around 40 ms (37 or 42 ms, depending on the no-prime comparison condition).

Semantic vagueness showed little or no effect when there was a nonsemantic relationship between prime and target (7 ms for phonological and 6 ms for graphic primes). Apparently, the semantic precision of the primes mattered only when there was a meaning relation between prime and target. In general terms, this is an intuitively reasonable result: The meaning of a prime, whether precise or vague, is not related to that of the target in the phonological and graphic prime trials. However, a closer consideration of lexical activation mechanisms makes clear that semantic effects are possible, even when the nominal prime–target relationship is phonological. In particular, if a character's precise-meaning constituents are critical in the initial identification process, then a precise-meaning prime, regardless of its eventual relationship to a target, should have some advantage over a vague-meaning prime. Thus, the failure for semantic precision to affect priming in the phonological case suggests that precise meaning is not a constituent of the initial identification of the prime. Instead precise meanings are constituents of contextualized patterns of meaning activation that depend on more than one word. Thus, only on the appearance of a following word that could be semantically related does the prime's meaning precision become important, at least when naming is required.

A remaining question is whether we might observe graphic effects in shorter SOA, as we have suggested. More generally, it is of interest to discover the time course of graphic, phonological, and semantic activation in this paradigm. Experiment 2 was designed for that purpose.

Experiment 2

Previous research has demonstrated the facilitative effects of graphic as well as homophonic and semantic masks on target identification in the backward masking paradigm (e.g., Perfetti & Zhang, 1991; Tan et al., 1995). These studies showing graphic effects used SOAs shorter than those that produced no priming in Experiment 1. However, Perfetti and Zhang (Experiment 4) found no graphic priming in a naming task with 180-ms SOA. The 115-ms SOA of Experiment 1 was intermediate to the 50- and 60-ms SOA of the identification experiments and the 180-ms SOA of the naming experiment. What is needed is a range of shorter SOAs that might be sensitive to the rapid activation (Ferrand & Grainger, 1994; Perfetti & Bell, 1991) and decay of visually based graphic information in characters.

In addition, there is evidence for asynchronous activation of phonological and semantic information in nonnaming tasks (e.g., Perfetti & Zhang, 1995b; Tan et al., 1996). In naming, one might also expect that phonological information, because it can be used directly in the task, might be used more quickly than semantic information. At shorter SOAs, we might observe greater phonological priming than semantic priming. Moreover, the advantage of semantic precision might take some time to develop. To examine these time course issues, Experiment 2 used three short SOAs of 43, 57, and 85 ms.

Method

Participants

Fifty-four undergraduate students of South China (Guangzhou) Normal University participated in the experiment. All were native Mandarin speakers and had normal or corrected-to-normal vision. Twenty, 18, and 16 participants were randomly assigned to one of the three SOAs, respectively. None of these individuals had taken part in the previous experiment.

Design, Materials, and Procedure

The stimuli and design were the same as in Experiment 1. The same procedure as in Experiment 1 was adopted, except that the SOAs between the onset of the primes and the onset of the targets were shortened to 43, 57, or 85 ms.

Results

Table 3 presents the mean identification times of correctly pronounced targets (trimmed as in Experiment 1) and error rates. A few items produced unusually high error rates. To reduce the impact of these items (which would produce

Table 3
Average Naming Latencies (in Milliseconds) and Error Rates for Targets as a Function of Prime Type, Prime Semantic Vagueness, and Stimulus Onset Asynchrony (SOA) in Experiment 2

	SOA					
Condition	43 ms	Error	57 ms	Error	85 ms	Error
Vague primes						
Graphic	545	4.58	688	4.63	710	11.58
Homophonic	630	2.15	540	7.11	530	5.24
Semantic	634	0.00	632	2.82	630	4.37
Unrelated	641	4.64	637	7.01	629	7.37
Precise primes						
Graphic	555	2.58	688	8.88	701	14.81
Homophonic	638	2.54	538	5.09	540	5.26
Semantic	636	0.00	635	3.26	550	2.14
Unrelated	639	5.42	640	3.29	633	8.47
# Primes	627	4.05	631	4.21	635	4.74

unstable mean reaction times for correct items), any item producing more than a 60% error rate was eliminated in the analyses. This procedure resulted in the elimination of 2 items from the 43- and 85-ms conditions, and 3 items from the 57-ms condition.

The key results are as follows: Prime type effects were observed at all SOAs, but the pattern of effects depended on SOAs and semantic vagueness. (a) At the shortest SOA, graphic primes facilitated identification, but semantic and homophonic primes did not. (b) At longer SOAs, graphic priming effects reversed, becoming inhibitory. (c) Homophonic effects were observed before semantic priming effects regardless of semantic vagueness. (d) Semantic priming effects were observed at shorter SOAs for precise primes than for vague primes. These descriptions of the results are supported by the analysis of variance reported here. F values are reported by participants (F_1) and by items (F_2).

Identification Times

There was a main effect of prime type, $F_1(3, 153) = 66.22, p < .001, MSE = 135{,}492.39$; $F_2(3, 81) = 47.21, p < .001, MSE = 79{,}643.15$. SOA was significant only by items, $F_1(2, 51) = 2.26, p = .115, MSE = 4{,}735.02$; $F_2(2, 169) = 3.76, p < .04, MSE = 8{,}426.31$. Semantic vagueness was not significant, $F_1(1, 51) = 1.15, p > .29, MSE = 2{,}586.01$; $F_2(1, 81) = 2.12, p > .10, MSE = 6{,}073.34$. SOA interacted significantly with prime type, $F_1(6, 153) = 64.27, p < .001, MSE = 131{,}503.89$; $F_2(6, 169) = 47.21, p < .001, MSE = 84{,}697.12$. The SOA × Semantic Vagueness interaction was significant by participants, $F_1(2, 51) = 3.63, p < .04, MSE = 8{,}170.63$, but not by items, $F_2(2, 169) = 1.73, p > .15, MSE = 3{,}521.10$. The interaction of Semantic Vagueness × Prime Type was significant by participants, $F_1(3, 153) = 3.12, p < .03, MSE = 6{,}821.17$, not by items, $F_2(3, 81) = 1.56, p > .16, MSE = 2{,}854.25$. Most important, the three-way interaction of SOA × Prime Semantic Vagueness × Prime Type was significant, $F_1(6, 153) = 2.64, p < .02, MSE = 5{,}764.46$; $F_2(6, 169) = 2.31, p < .03, MSE = 4{,}001.41$.

To describe the time course data, we report additional ANOVAs carried out separately for each SOA. Once again, because there were no differences between unrelated character and # primes, only comparisons relative to unrelated primes are reported, except as noted.

SOA = 43 ms. In a pattern opposite to that of Experiment 1, only graphic primes showed facilitation. This pattern held for both semantically vague primes and semantically precise primes. For vague primes, $F_1(1, 19) = 23.94, p < .001, MSE = 92{,}256.02$; $F_2(1, 22) = 28.47, p < .001, MSE = 55{,}296.00$; for precise primes, $F_1(1, 19) = 37.17, p < .001, MSE = 70{,}560.00$; $F_2(1, 20) = 25.87, p < .001, MSE = 44{,}476.86$. Homophonic and semantic primes did not affect target identification (all $Fs < 1$). Although # primes produced 14 ms faster identification times than unrelated primes, this difference was not significant.

SOA = 57 ms. Graphic primes produced inhibition, homophones produced facilitation, and semantic primes showed no reliable effects. First, for semantically vague primes: Graphic primes inhibited target identification, $F_1(1, 17) = 17.02, p < .001, MSE = 23{,}205.44$; $F_2(1, 21) = 9.10, p = .008, MSE = 15{,}518.61$; homophonic primes facilitated target identification, $F_1(1, 17) = 31.25, p < .001, MSE = 84{,}681.00$; $F_2(1, 22) = 11.91, p < .002, MSE = 33{,}078.38$; and semantic primes did not affect target identification (F_1 and $F_2 < 1$). The target identification times in the homophonic prime condition were significantly faster than those in the semantic prime condition, $F_1(1, 17) = 36.94, p < .001, MSE = 76{,}176.00$; $F_2(1, 22) = 9.54, p = .005, MSE = 38{,}773.38$.

For the semantically precise primes, the pattern was the same: Graphic primes again inhibited target identification, $F_1(1, 17) = 26.57, p < .001, MSE = 21{,}073.36$; $F_2(1, 20) = 10.10, p < .005, MSE = 14{,}730.49$. Homophonic primes again facilitated target identification times, $F_1(1, 17) = 48.53, p < .001, MSE = 93{,}636.00$; $F_2(1, 22) = 35.44, p < .002, MSE = 63{,}448.17$; and semantic primes had no effect. The reaction times to the targets in the homophonic condition were significantly faster than those in the semantic condition, $F_1(1, 17) = 47.64, p < .001, MSE = 84{,}648.00$; $F_2(1, 22) = 37.50, p = .005, MSE = 56{,}454.00$.

SOA = 85 ms. Graphic primes produced inhibition, homophone primes produced facilitation, and semantic primes produced facilitation only when they were semantically precise. For semantically vague primes, graphic primes inhibited target identification, $F_1(1, 15) = 22.38, p < .001, MSE = 44{,}625.78$; $F_2(1, 22) = 34.48, p < .001, MSE = 39{,}366.00$; homophonic primes facilitated target identification, $F_1(1, 15) = 60.95, p < .001, MSE = 88{,}620.50$; $F_2(1, 22) = 59.71, p < .001, MSE = 58{,}905.04$; and semantic primes did not affect target recognition (F_1 and $F_2 < 1$).

For the semantically precise primes, graphic primes again inhibited target identification, $F_1(1, 15) = 29.53, p < .001, MSE = 37{,}950.12$; $F_2(1, 20) = 24.74, p < .002, MSE = 27{,}264.40$. Homophonic primes again facilitated target identification, $F_1(1, 15) = 136.12, p < .001, MSE = 69{,}192.0$; $F_2(1, 22) = 55.78, p < .001, MSE = 61{,}610.67$. Semantic primes, in contrast to the vague primes, also facilitated target recognition, $F_1(1, 15) = 44.43, p < .001, MSE = 55{,}112.0$; $F_2(1, 22) = 48.77, p < .001, MSE = 40{,}672.67$, and this facilitation was not significantly different from that produced by homophone primes, $F_1(1, 15) < 1$; $F_2(1, 22) = 1.97, p > .17, MSE = 2{,}166.00$.

In all these conditions, the target recognition differences between the unrelated character primes and the # primes were not significant (F_1 and $F_2 < 1$).

Error Data

Error rates were affected by prime type, $F_1(3, 153) = 6.61, p < .001, MSE = 9.01$; $F_2(3, 81) = 27.41, p < .001, MSE = 64.54$, and SOA, $F_1(2, 51) = 10.63, p < .001, MSE = 12.91$; $F_2(2, 169) = 4.21, p < .05, MSE = 6.93$. Semantic vagueness was not significant, $F_1(1, 51) = 1.15, p = .29, MSE = 2{,}586.01$; $F_2(1, 81) < 1$. No interactions approached significant levels.

At 43-ms and 57-ms SOAs, planned comparisons showed no significant differences among conditions. In the 85-ms SOA condition, the graphically similar primes with precise semantic meanings produced more errors, relative to both the unrelated character-prime controls, $F_1(1, 15) = 9.30, p < .008, MSE = 6.12$; $F_2(1, 20) = 6.13, p = .02, MSE = 11.73$, and the #-prime controls, $F_1(1, 15) = 11.67, p < .005, MSE = 13.78$; $F_2(1, 20) = 7.81, p < .02, MSE = 19.84$. The semantic primes with precise meanings produced fewer errors relative to the unrelated character-prime controls, $F_1(1, 15) = 4.66, p < .05, MSE = 4.50$; $F_2(1, 22) = 6.19, p < .03, MSE = 6.00$, but not relative to the #-prime controls (F_1 and $F_2 < 1$). There were no other significant differences among the conditions.

Discussion

The results of Experiment 2 suggest interesting timing asynchronies in the activation of the graphic, phonological, and semantic constituents of identification. At 43-ms duration, graphic primes facilitated target recognition, but neither homophonic nor semantic primes showed any effect. With the increase of the SOA to 57 ms, homophonic primes showed significant facilitation, but semantic primes still had no effect. When the SOA was extended to 85 ms, homophonic primes, as well as semantic primes with precise meanings, facilitated target identification, whereas semantic primes with vague meanings did not influence processing of targets. In addition, at the 57-ms and 85-ms SOAs, graphic primes inhibited, rather than facilitated, target processing, with a slight increase of inhibitory effects with the growth of SOA.

To see the growth of effects in single-character word identification over 115 ms, we combine these results with the findings of Experiment 1 in Figure 1, which show facilitation and inhibition effects over four SOAs, separately for each prime type. In each case, a comparison of vague- and precise-meaning primes can be seen.

These data can be interpreted as indicating the time course of activation and inhibition—or more generally, the net accessibility—of graphic, phonological, and semantic information. Phonological information was found to be accessible before semantic information, regardless of whether the primes had semantically vague or semantically precise meanings. This is in line with Tan et al.'s finding (1996) with the backward masking procedure. Only the accessibility of semantic information was a function of semantic vagueness: The semantic information of precise-meaning primes was accessible, or at least useful in priming, before that of vague-meaning primes.

The dramatic changes of graphic effects from facilitation to inhibition to null effect show a high temporal sensitivity of graphic information. One account of these changes is as follows: There is a rapid extraction of graphic features that is not quite complete at 43 ms; the character has not been identified, so there is no effect of its phonological or semantic properties. The graphic facilitation arises from the activation of visual–graphic cohorts as part of the incomplete identification process. When the following target turns out to be among that cohort, there is some facilitation. This graphic facilitation effect is similar to the graphic effect found in subthreshold backward masking (Perfetti & Zhang, 1991; Tan et al., 1995). Graphic facilitation, however, turns to inhibition by 57 ms at the same time that phonological facilitation effects emerge. This locking of the onset of graphic inhibition to the onset of phonological facilitation may be more than a coincidence. The two effects may be the result of the same cognitive moment, the identification of a character as a word that includes a specific phonological constituent. The activation of this phonological form facilitates naming a character that has this same form (phonological priming) but inhibits the naming of a character with a different pronunciation if that character is from the same set of partially activated graphic cohorts (graphic inhibition).

A careful analysis of errors made by participants adds evidence to this account. In Experiment 2, the error rates increased with SOA, especially under graphically similar prime situations. Furthermore, during the experiment, we noticed that errors often arose because participants named primes instead of targets. We calculated the percentages of prime naming in the graphic, semantic, and unrelated character prime conditions. (Of course, it is impossible to identify prime naming in the homophonic condition.) As shown in Table 4, participants named graphic primes more than unrelated or semantic primes, especially at 85-ms SOA.

Because the SOAs were short and the percentage of homophone primes was modest (22%), we think that a conscious homophone expectation or guessing strategy is very unlikely to account for either the facilitation or inhibition effects. Instead, the effects reflect a rapid, automatic character identification processes. The competition between automatically activated phonological forms of primes and those of the targets occasionally lead to prime naming instead of target priming when the name of the prime, through its visual similarity to the target, remains available as a competitor. Note that a general name interference hypothesis is insufficient because the inhibition occurred only for graphically similar primes.

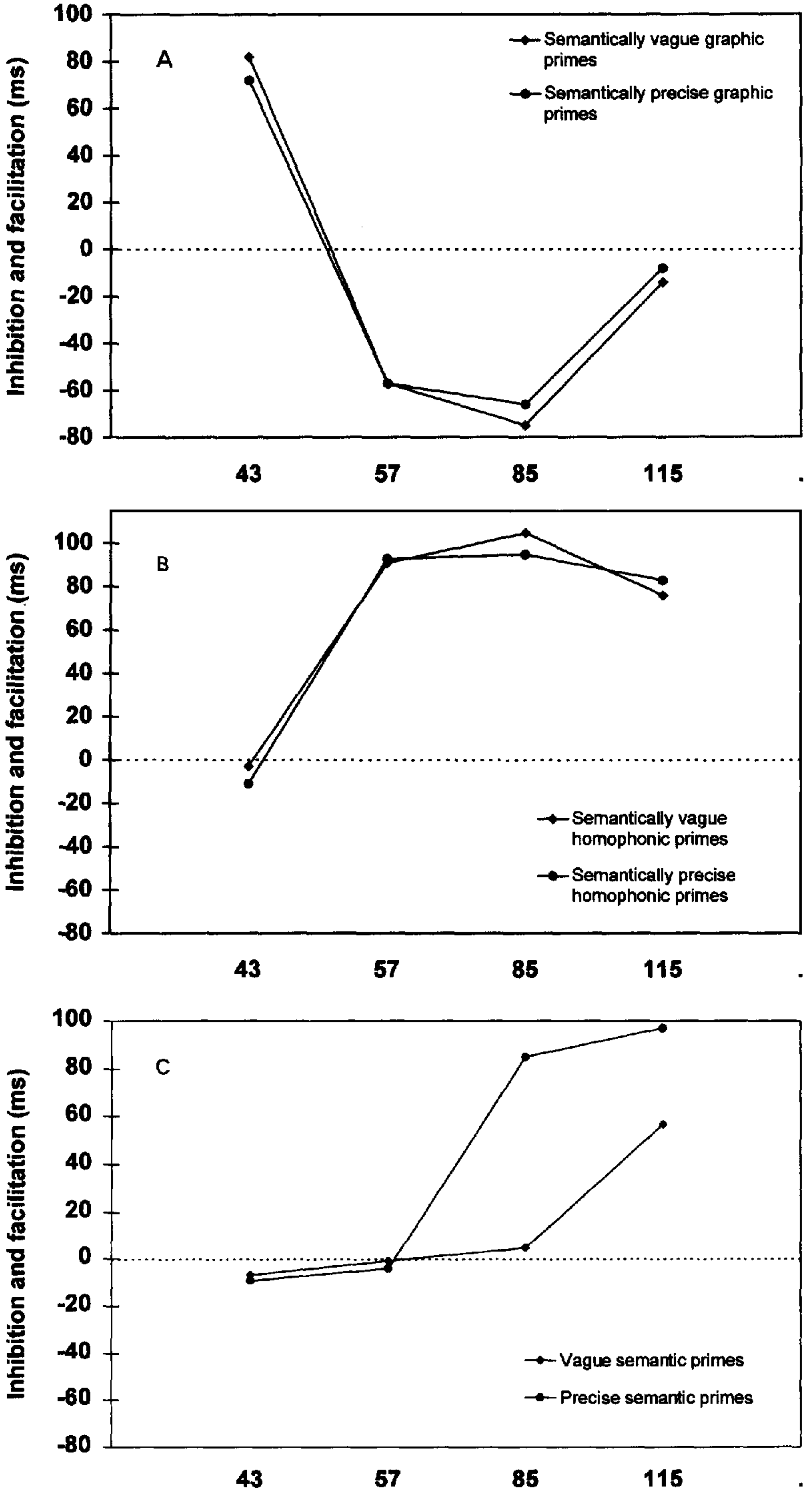
A
Inhibition and facilitation (ms)
100
80
60
40
20
0
-20
-40
-60
-80
43
57
85
115
Semantically vague graphic primes
Semantically precise graphic primes
B
Inhibition and facilitation (ms)
100
80
60
40
20
0
-20
-40
-60
-80
43
57
85
115
Semantically vague homophonic primes
Semantically precise homophonic primes
C
Inhibition and facilitation (ms)
100
80
60
40
20
0
-20
-40
-60
-80
43
57
85
115
Vague semantic primes
Precise semantic primes

Table 4
Mean Percentages of Naming Primes in Graphic, Semantic, and Unrelated Prime Conditions as a Function of Prime Semantic Vagueness and Stimulus Onset Asynchrony (SOA)

Condition	SOA 43 ms	57 ms	85 ms	115 ms
Vague primes				
Graphic	0.83	2.31	5.26	1.25
Semantic	0.00	0.47	0.55	0.84
Unrelated	0.83	1.43	1.05	0.43
Precise primes				
Graphic	0.86	1.40	8.47	4.20
Semantic	0.00	0.47	0.53	0.43
Unrelated	0.83	0.95	1.59	0.42

General Discussion

The effectiveness of semantic primes at longer SOAs demonstrates the activation of character meanings as part of character naming. The usefulness of this activation, however, was found to be a function of semantic vagueness. Because the meaning of semantically vague primes is less accessible, it requires more time to show a priming effect than does a semantically precise prime. This differentiation of priming effectiveness as a function of meaning, coupled with the earlier effectiveness of phonological primes, is consistent with the assumption that form–form relationships are privileged over form–meaning relationships in isolated word identification. Vague-meaning characters illustrate the high degree of indeterminacy in single word meanings. Precise-meaning characters, although also indeterminate in the strict sense, have, relatively speaking, specifiable meanings. Accordingly, these meanings are more accessible and more useful in priming a word to be named, provided that word is semantically related to it.

Equally important, the experiments provide more general information on the time course of graphic, phonological, and semantic information activation in Chinese character identification. Although different targets were used in different priming conditions, statistical analyses with target frequency and target visual complexity as covariates have shown clear-cut results: Graphic information was activated first, within 43 ms, followed by phonological information within 57 ms and by semantic information within 85 ms. This order of activation—(a) graphic, (b) phonological, (c) semantic—is theoretically compelling but not logically inevitable. Certainly, the processes that extract basic visual information must occur first; all subsequent processing depends on the information available at this first stage. Less obvious is the earlier availability of phonological information compared with semantic information. A script-to-meaning view would expect to see meaning activation first. The assumption that form–form relationships are privileged because of their more deterministic one-to-one mapping, however, predicts the phonology-before-semantics result, as well as the observed dependency of semantic effects on meaning precision.

It is prudent not to generalize the time course results to other tasks. Because naming was required, phonological information ought to have been more useful than in a nonnaming task. Indeed, one possibility that must be considered is whether the phonological effect observed here was less one of facilitation than of release from competition. It might be that the naming requirement caused participants to prepare phonological outputs (names) for the primes that would then compete with the name of the target. The phonological primes, alone among prime types, would have the same onset (as well as the same syllable) as the target; other primes would not have even the same onsets as the target. Forster and Davis (1991) found in forward masked priming that prime names interfered with target names, and that this interference was reduced when primes and targets shared onsets. That raises the possibility that our phonological priming might have been primarily a release-from-interference effect mediated through output phonology; that is, homophone primes might have protected the target from naming competition. However, although some naming competition occurred in our experiments, it appears to have been selective. If naming interference were general, then we should have found slower naming times when targets were preceded by unrelated character primes compared with # primes. In fact, this did not occur in any condition. Furthermore, the only condition to suggest such a difference—14 ms at 43 SOA—is also the only one to produce no phonological priming. There is no doubt that these experiments created conditions that enable interference at some level, as evidenced by the fact that participants occasionally (2.9% over all conditions of the experiments) produced prime names rather than target names. However, these errors were concentrated within the category of graphically similar primes, especially at 85-ms SOA (see Table 4). The interference effect appears to have depended less on simple output phonology (which would have produced general interference across prime types) than on a stage of processing in which visually similar forms are activated and competing for identification.

Finally, we note again the shifting effects of graphic primes, from facilitation at 43-ms SOA to inhibition at 57 and 85 ms, and finally disappearing at 115 ms. The discovery of graphemic inhibition in Chinese joins similar observations in alphabetic word recognition (Colombo, 1985, 1986; Forster & Davis, 1984, 1991; Grainger & Ferrand, 1994; Lupker & Colombo, 1994; Segui & Grainger, 1990). The

Figure 1 (*opposite*). The time course of (A) graphic, (B) phonological, and (C) semantic activation for words with vague meanings and precise meanings. The graphs show the changes in net facilitation and inhibition produced by primes on target naming, relative to an unprimed (#) control. SOA = stimulus onset asynchrony.

phasing pattern of graphic facilitation followed by inhibition, which then decreases, however, appears not to have been observed in alphabetic systems, although Perfetti and Bell (1991), in an identification paradigm, did observe inhibition at about 45 ms of prime exposure for unrelated primes and a reduction of graphemic facilitation effects by 65 ms.

Our explanation for the oscillating phasing in this present study has two parts. First, the early facilitation phase arises from the visual components of incomplete word identification, as partial products of identification processes activate words consistent with the graphic information. A similar mechanism may be expected to underlie facilitation effects in graphemic masking (Perfetti & Bell, 1991) and priming (Forster & Davis, 1984; Perfetti & Bell, 1991) in English. Second, the inhibition phase, which coincides with the onset of phonological priming, arises when the prime character reaches its threshold of identification. There is, on this account, a single cognitive moment of word identification. The same identification event that allows facilitation from identical phonology produces inhibition from the combination of similar graphic form and different phonology.

This single-moment mechanism is less likely to hold for an alphabetic writing system, where the graphic and phonological information are tightly connected on the subword level. There, one expects graphemic and phonological effects to be more in phase, even if time-lagged, in contrast to the out-of-phase results for Chinese. Indeed, graphemic and phonemic effects in English backward masking and priming show a strong temporal locking over a range of 25–65 ms in perceptual identification tasks (Perfetti & Bell, 1991). In a lexical-decision task, using a different method to separate graphemic and phonemic similarity of alphabetic words, Ferrand and Grainger (1994) found an early phase in which only graphemic effects and not phonemic effects were observed. However, there does not seem to be evidence in any alphabetic study of phase-incompatible graphemic and phonemic effects. Obtaining such evidence would depend on manipulating the very rare disassociation of spelling and phonology in alphabetic systems. For all of the imperfect associations between its spelling and pronunciation, English and other alphabetic systems have few or no examples that approximate the Chinese case. The design of the alphabetic writing system encourages the accumulation of graphemic and phonological information in overlapping phases.

A Model of Visual Chinese Character Identification

In this section, we describe a heuristic model of visual Chinese character identification that accounts for the time course effects we have observed, following the basic assumptions of interactive-activation models (McClelland & Rumelhart, 1981; cf. Grainger & Ferrand, 1994). The model, the interactive constituency model, assumes three separate lexicons: the orthographic lexicon, the phonological lexicon, and the meaning system, as shown in Figure 2.[4]

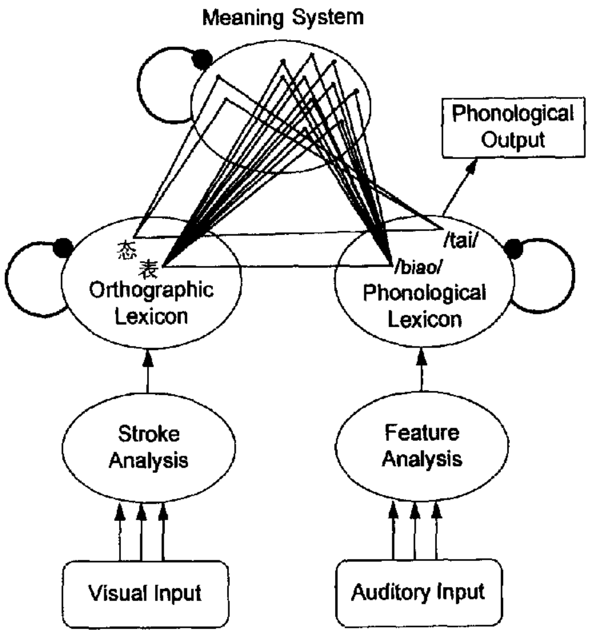

Figure 2. Schematic model of Chinese single-character identification. Early information from graphic components (strokes and their spatial relationships) activates a cohort of orthographic units (not shown) in the orthographic lexicon. At threshold, the identification of an orthographic character immediately retrieves its name from the phonological lexicon and activates meaning nodes in the meaning lexicon. A key representational assumption is that a given orthographic unit typically connects to one phonological unit but to many meaning nodes, allowing for an earlier retrieval of phonological names compared with meaning.

Each lexicon consists of a set of representation units or nodes. A node whose activation value exceeds its threshold excites other nodes with which it is consistent and inhibits nodes with which it is not consistent. Feature analysis is the first stage of visual character recognition. In Chinese, character strokes represent the basic features that characters possess; thus, the feature analysis is termed *stroke analysis.* During an encounter with a visually presented character,

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[4] We are concerned here with the representation and processing of characters. The issue of how to organize the information of subcharacter (e.g., phonetic components and semantic radicals) is important but beyond what we address. For a model that depicts one possibility for connecting whole character and subcharacter representations, see Taft and Zhu (1997) who proposed three hierarchical levels of representation from strokes through components (radicals) and whole characters. Alternatively, Tan and Perfetti (1995) proposed a model for component representation in a multi-lexicon system containing three interrelated lexicons: the character orthographic lexicon, the noncharacter component orthographic lexicon, and the phonological lexicon. These two models differ in that the Tan and Perfetti model represents those phonetics and semantic radicals that are themselves legal characters directly in the character orthographic lexicon and restricts the noncharacter orthographic lexicon to those components (a few phonetics and many semantic radicals) that are not independent characters. A fragment of a lexical model that captures phonetic and semantic relations among components across characters is also presented in Perfetti and Zhang (1995a). The model presented in our article excludes this issue of component representation to more clearly expose the character-level representation assumptions. The full model would include the noncharacter representation levels of Tan and Perfetti (1995).

each stroke and its positional relationship with other strokes is detected. Detected features begin sending activation to the orthographic units (characters). When an orthographic unit exceeds threshold, it sends activation to the phonological units and the meaning lexicon simultaneously, leading to the activation of phonological units or relevant meaning representations, or both. The activation threshold of orthographic units is determined by the frequency of occurrence of printed characters in daily usage. The threshold of phonological units is determined by the frequency of access to the phonological form associated with the character, both through speech and print–speech experience. Activated phonological units also send activation to the meaning system and send feedback to the orthographic units.

The model assumes that meaning is represented and organized in terms of semantic properties. Each property has a meaning node, and the meaning of a character consists of a set of meaning nodes. The more meanings a character has, the more property nodes it has, and the more complex the links among the nodes. The activation threshold of a specific meaning node relies on the frequency of encounter with this meaning. Because the activation from the orthographic units is fixed, for characters with many meanings and no dominant one (e.g., the character 表 /biao/ with 10 distinct meanings), each meaning node gets less activation, compared with characters having fewer meanings. Moreover, due to fewer independent occurrences of some characters in modern-day usage (e.g., 态 /tai/), their threshold is relatively higher.

In addition, the model assumes that the activation of graphic information in the orthographic lexicon decays faster than does the activation of phonological units in the phonological lexicon or the activation of semantic nodes in the meaning system. Identification depends on the integration of the pattern of activation over all of the nodes, reflecting the constituent integration assumption. When two units have the same excitatory strength, there is strong competition between them, leading to recognition or decision difficulty.

Explanation of the Time Course Results

The Facilitation and Inhibition Effects of Graphic Primes

In the priming procedure, an encounter with a prime leads to activation of the corresponding relevant orthographic units. For example, exposure to a character 酒 (pronounced /jiu/, meaning "wine" or "liquor") excites the orthographic unit 酒 and other units that share common strokes, stroke sequences, and visual shapes, such as 西 (/xi/), 酉 (/you/), 洒 (/sa/), 栖 (/qi/), and so on. When the SOA is too brief for complete identification of a character, such as at the 43-ms SOA of Experiment 2, the orthographic units connecting to the prime are activated, but below the threshold level necessary to pass activation on to the corresponding phonological and meaning nodes. Thus, there is no facilitation to a target word that happens to share these inactivated phonological and semantic units. The situation changes when the target word is graphically similar to the prime. During processing of the prime, the target character's orthographic units begin to be activated, along with others in the cohort of graphically similar characters. Accordingly, the threshold of the target's orthographic unit is decreased, and target identification is facilitated. In effect, the briefest exposure creates a very brief window during which a purely visual form priming can occur (Forster & Davis, 1984).

As the SOA increases a bit (SOA = 57–85 ms), the orthographic unit of a prime can gain strong activation and exceed its threshold, at which point it sends activation to its corresponding phonological unit and meaning nodes synchronously. This causes the phonological unit to exceed threshold, which in turn causes the phonological units connected with members of the visually similar cohort, including the target, to be inhibited. The consequences of this are longer reaction times for the target and, occasionally, the production of the name of the prime rather than the target.

As the SOA is further extended (115-ms SOA or longer), the inhibition of graphic primes diminishes. One possibility is that activation of the orthographic units of a prime decays with additional above-threshold exposure, thus eliminating the inhibition that resulted from their activated state. In effect, this reduces the competition of prime units and target units that share graphic similarity, and visual overlap between prime and target now has no effect. The exposure of visually dissimilar characters continues to benefit from phonological and semantic activation initiated by the prime because that activation is no longer specifically dependent on visual form.

Activation of Phonological and Semantic Information

When SOA is very brief, orthographic units remain below threshold, making the phonological unit and the meaning nodes inaccessible; thus, homophonic primes and semantic primes do not affect target identification. As SOA increases (SOA = 57 ms), the orthographic unit of a prime can exceed activation threshold, sending activation to the phonological lexicon and meaning nodes simultaneously, producing identification. Because commonly used characters such as those in this study have more than one meaning, their meaning nodes have to share received activation. For the phonological units, on the other hand, there is a fixed one-to-one relationship between a character and its pronunciation. Thus, for a limited amount of activation from the orthographic unit, the corresponding phonological unit can achieve higher activation than a given semantic node. This would lead to the advantage of phonology over meaning when the prime duration is just above threshold.

With the further extension of SOA (85 ms), a prime character is more fully processed, and each semantic node gets more activation from the orthographic units (and some feedback from the phonological unit, which, however, must be shared among many orthographic units and semantic nodes). This greater activation can move some semantic nodes above threshold, but whether this occurs now depends on character semantic vagueness: If the prime has semantically precise meaning with less semantic uncertainty (either few meanings or one dominant meaning), its (fewer) meaning nodes receive a fuller share of the activation, pushing some to threshold. (Equivalently, when precision is a matter of a word having a highly dominant meaning despite having many possible meanings, its advantage is one of a higher level of resting activation or lower threshold.) Once activated, the meaning nodes send activation to the phonological unit, which may facilitate naming of a target. Because of the sharing of activation among semantic nodes, this facilitation can occur only if the target follows a precise-meaning prime.

Presentation of a homophonic target following the prime results in its orthographic unit and phonological unit quickly exceeding activation thresholds, independent of the prime's meaning precision. The target's phonological unit has already been activated by the prime, effectively lowering the threshold of the phonological unit associated with the orthographic unit of the target character.

As SOA extends further (115 ms), semantic precision becomes less relevant. The continued activation from the orthographic unit (and feedback from its phonological unit) increases the activation of all meaning nodes, so that the difference between a precise- and vague-meaning prime diminishes.

This model, restricted to character naming, appears to give an adequate account of the asynchronies observed in these experiments. It accounts for semantic vagueness essentially by the multiple form-to-meaning mappings that lead to a diffuse activation across meaning units: more precision, fewer nodes to share fixed activation. It accounts for the phonology-before-meaning asynchrony in the same way: nearly one-to-one mappings from orthographic to phonological units. It accounts for the graphic shifts by the outcome of orthographic activation, which must be above threshold for semantic and phonological activation to occur, producing graphic inhibition just at that point.

Conclusion

In primed target naming of Chinese words, there are asynchronous phases in the access of graphemic, phonological, and semantic information that relate prime and target. We have observed a pattern of priming facilitation and inhibition that suggests access to lexical information is ordered: (a) graphic, (b) phonological, (c) semantic. Moreover, patterns of facilitation for phonological and semantic information, although time-lagged, were phase-compatible (i.e., phonological and semantic information could be used at the same SOA [83 and 115 ms]). By contrast, access to graphic information was found to be phase-incompatible with access to phonological and semantic information. The onset of phonological facilitation coincided with the onset of graphic inhibition. Although this alternating phasing property might have some other explanation, it is consistent with the occurrence of a psychological moment of identification that simultaneously relinquishes visually based codes as it seizes on phonological and semantic codes. Or, more mechanistically, it suggests a moment of character identification defined by the access of a single orthographic–phonological form pair and the inhibition of all competing pairs from the same orthographic cohort.

The discovery of earlier access to phonological than to semantic information is consistent with data from other tasks in Chinese (e.g., Perfetti & Zhang, 1995b; Tan et al., 1995, 1996). Nevertheless, we caution against strong generalization across tasks. Because the naming task specifically requires phonological forms, it can produce complex patterns of phonological facilitation and interference at the output as well as the identification levels (Forster & Davis, 1991). It is likely that tasks will differ in the kinds of asynchronies between meaning and phonology that they allow.

Finally, we conclude that the data are consistent with a relatively simple assumption about form–form and form–meaning relationships in reading. When writing systems have a relatively high degree of determinacy (nearly one-to-one mapping) of orthographic forms and phonological forms, then we should expect that phonological information is more quickly available than at least some semantic information. At the single-word level, form–meaning relationships are almost always indeterminate, specifically less deterministic than form–form relationships. The results of these Chinese experiments show a pattern of results consistent with a prediction of this assumption: that the onset of semantic priming depends on the meaning precision of the prime word. If our indeterminacy idea is correct, then, with contexts that highly constrain meanings, one might expect to observe semantic processes that temporally overlap the otherwise more rapid phonological processes.

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(Appendix follows on next page)

Appendix A

Stimuli From Experiment 1: Primes With Vague Meanings

Prime			Target		
Character	Frequency	Vagueness	Character	Frequency	Vagueness
Graphically similar primes and targets					
何	419.8	2.39	向	1,446.8	2.72
突	284.8	2.64	实	1,695.7	3.16
拢	47.0	3.50	扰	34.8	4.52
司	188.0	2.16	可	3,435.1	2.20
促	92.4	3.16	捉	69.1	5.80
斯	50.3	2.48	期	617.2	3.68
般	318.0	2.08	船	561.9	6.96
席	462.9	3.76	度	1,092.9	3.20
豁	34.3	3.12	割	87.9	6.24
锦	37.1	2.28	绵	32.6	3.96
亦	36.6	2.92	示	316.9	3.80
巴	170.9	1.92	已	1,172.5	3.16
Homophonic primes and targets					
其	841.2	3.88	齐	120.0	3.72
统	564.1	2.91	筒	47.0	5.28
委	419.8	2.60	伟	326.9	4.28
况	404.3	2.32	矿	186.4	6.04
素	209.6	3.13	诉	348.4	5.04
模	219.6	3.72	磨	120.0	4.60
梁	87.4	3.97	良	132.2	5.52
艺	356.7	3.68	宜	71.3	3.12
竟	223.4	2.68	静	307.5	6.20
仗	81.3	3.93	胀	38.2	4.80
凡	80.2	3.40	烦	90.7	5.16
互	165.4	2.96	户	169.8	5.72
Semantically similar primes and targets					
究	859.8	2.61	查	265.5	5.64
济	566.3	3.08	助	283.7	4.44
态	232.8	3.87	状	184.7	3.04
宣	180.3	3.38	说	5,755.2	6.40
概	169.2	2.36	总	928.6	2.80
漫	65.8	3.48	遍	164.3	3.60
什	2,260.9	1.96	多	3,127.6	6.24
第	982.2	2.72	序	90.7	4.32
番	50.9	2.48	次	982.8	3.60
彼	41.5	3.64	那	4,029.6	5.00
历	501.1	3.20	过	3,639.2	4.33
切	626.6	2.96	析	82.4	3.40
Control primes and targets					
程	501.1	2.74	披	52.5	5.36
企	140.5	2.52	阅	43.1	5.55
胡	121.1	3.04	份	93.5	4.43
贯	73.6	2.70	荣	92.9	3.88
荷	59.7	3.52	械	101.8	3.52
稍	70.8	3.20	控	112.3	4.60
任	715.7	3.52	染	131.6	5.88
阀	35.9	3.32	野	230.6	4.48
了	17,060.9	1.96	并	40.4	3.48
岂	33.7	2.28	梦	47.6	2.52
偶	48.1	2.63	逐	163.7	4.29
舒	87.4	3.96	触	90.1	4.36

Appendix B

Stimuli From Experiment 1: Primes With Precise Meanings

Prime			Target		
Character	Frequency	Vagueness	Character	Frequency	Vagueness
		Graphically similar primes and targets			
村	456.8	6.43	材	271.6	5.12
旧	289.3	6.48	伯	115.0	6.08
贪	29.9	5.72	贫	79.6	6.57
优	182.0	6.20	伏	75.8	3.88
织	425.3	6.24	纪	274.3	2.92
狼	58.1	6.40	狠	80.2	5.88
宫	58.6	5.75	官	207.4	5.84
旱	48.1	6.40	早	610.0	6.48
汁	17.1	6.20	计	658.1	3.41
酒	35.9	6.96	洒	35.9	4.76
拔	93.5	5.51	拨	48.7	4.72
掌	184.7	5.56	裳	31.5	4.80
		Homophonic primes and targets			
讲	576.8	6.30	奖	51.4	5.80
低	413.7	6.22	滴	65.3	4.88
暗	219.6	5.88	按	261.0	3.80
塔	40.4	6.46	他	8,872.8	6.52
甜	53.6	6.84	填	34.8	4.72
姓	131.1	5.78	幸	163.2	2.96
瓶	77.4	6.34	评	261.6	5.04
疯	75.2	5.88	封	247.8	3.80
肺	41.5	6.92	费	214.6	3.44
剪	30.4	5.92	检	209.6	4.12
妻	41.5	6.68	漆	56.4	5.20
铅	45.9	5.60	签	55.3	4.60
		Semantically similar primes and targets			
妈	1,114.4	7.00	母	422.0	6.20
脸	573.0	6.65	面	2,629.3	4.28
林	227.3	5.79	松	167.6	4.30
卖	311.4	6.84	销	81.9	3.54
币	40.9	6.00	款	73.6	4.56
瞪	47.0	5.92	视	300.9	4.64
峰	64.7	5.80	颠	33.7	3.24
岁	294.2	5.92	年	3,190.1	5.88
迟	79.6	6.08	晚	438.0	6.00
坏	348.4	5.92	劣	32.1	5.44
驰	34.3	5.52	奔	104.5	5.68
首	328.0	5.51	头	2,389.8	6.08
		Control primes and targets			
喝	227.9	6.20	弄	204.6	3.48
巧	102.9	5.52	唯	162.0	3.72
猪	51.4	6.96	控	112.3	4.40
妹	160.4	6.84	招	129.4	4.56
富	195.2	5.79	鲜	147.7	5.64
怨	39.3	5.80	免	122.2	4.36
米	471.2	7.00	列	175.9	3.80
雨	348.4	7.00	刷	87.9	5.22
抄	44.8	6.21	祝	56.4	4.84
液	141.0	6.00	剧	101.8	4.60
茶	139.9	6.60	疾	49.2	4.56
厅	44.2	6.00	讨	175.6	4.08

(Appendixes continue)

Appendix C

Stimuli From Experiment 1: Targets Following # Primes

Character	Frequency	Vagueness
注	271.0	3.24
付	100.7	4.20
妄	34.0	3.64
弃	43.7	5.56
依	206.3	2.92
衰	58.6	5.58
喘	48.1	5.66
胖	37.1	6.57
功	251.1	4.28
斜	62.5	5.56
吹	153.3	6.04
处	982.8	3.60

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