

## Semantic Radicals Contribute to the Visual Identification of Chinese Characters

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In a character decision task, phonetic compound targets (composed of a semantic radical and a phonetic component) followed primes that shared (a) the target's radical and were semantically related (R+S+), (b) the target's radical and were not semantically related (R+S-), (c) no radical but were semantically related (R-S+), and (d) no radical and were not semantically related (R-S-). Target radicals also varied as to the number of compounds in which they appeared (i.e., combinability). When targets followed primes immediately (Experiment 1; SOA 243 ms), target latencies following R+S- primes were slowed relative to R-S- controls but those following R+S+ and R-S+ primes were facilitated equivalently. Increases in combinability significantly reduced decision latencies. When 10 items separated primes and targets (Experiment 2), facilitation was evident only after R+S+ primes. Results indicate that one type of component, the semantic radical, is processed in the course of Chinese character recognition and that orthographic similarity due to repetition of a radical is not an adequate account. © 1999 Academic Press

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Morphemic units reduce the arbitrariness of the relation between meaning and form that characterizes language. A large body of research has examined the role of a word's morphological structure in visual word recognition in alphabetic languages and has asked how skilled readers represent morphologically complex words in the mental lexicon. Among accounts that explicitly represent morphology, three positions have been articulated (see Feldman, 1994; Henderson, 1985). According to the *full listing hypothesis*, words are represented and accessed as full forms without reference to their constituents, and each word has a separate lexical entry in the internal lexicon (Butterworth, 1983). As an alternative, according to the *decomposition hypothesis* morphemes are units of representation in the mental lexicon. Recog-

nizing a word entails some type of analysis of its internal morphological structure, and morphologically complex word forms can be accessed only via morphemic access units (Taft & Forster, 1975). More recent accounts treat the morpheme as a unit of processing or as a principle of organization within the lexicon and do not insist on a prelexical locus (e.g., Feldman & Andjelković, 1992; Schreuder & Baayen, 1994). Some investigators have suggested a combination of these two options (Caramazza, Laudanna, & Romani, 1988; Caramazza, Miceli, Silveri, & Laudanna, 1985). Finally, according to accounts in which morphological structure is implicit in memory, the systematic variation between form and meaning is sufficient to account for effects of morphological relatedness, and morphemes need not be represented explicitly (Rueckl, Mikolinski, Raveh, Miner, & Mars, 1997).

The present study examines how Chinese characters are processed and organized in the mental lexicon and focuses on the processing of one type of character component, the semantic radical. Characters are the basic writing units and typically they correspond to morphemes

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and to syllables. Accordingly, the written characters that make up a word capture the meaning of each of the morphemes in the word and pronunciation of each of its syllables. Because the single Chinese character corresponds to one syllable and historically, syllables correspond to morphemes, Chinese is sometimes described as a morphosyllabic or morphophonological system (DeFrancis, 1989; Perfetti & Zhang, 1995).

### CHINESE CHARACTERS AS PRIMARY UNITS

Several attributes of written Chinese suggest that the character is the primary perceptual unit (see Hoosain, 1991). First, for the most part, Chinese characters as wholes map onto the morphemes rather than onto the subsyllabic phonological units (Perfetti & Zhang, 1995). Moreover, many single characters are free morphemes (and syllables) in modern-day usage. Chinese characters are not made visually more complex by the addition of inflectional markings to indicate the gender, number, case, and tense of verbs (Li & Thompson, 1981). These characteristics, collectively, may imply that the character could be the primary unit of perception. Second, characters are distinguished by fixed spaces in text and always occupy the same square area, irrespective of the number of strokes they possess. Therefore, a character is potentially identifiable as an independent unit based on spatial characteristics. Finally, although in modern Chinese there are many polysyllabic words, most of their single characters can be used as separate words. Interestingly, how to segment or assemble multicharacter words in a sentence is not straightforward, even for Chinese readers. This, too, may enhance the importance of single characters (Hoosain, 1991).

The characteristics of written Chinese described above have led some researchers to assume that characters are the primary units of visual recognition and mental representation (e.g., Cheng, 1981; Hoosain, 1991; Tzeng, Hung, & Wang, 1977; see also Morton, Sasanuma, Patterson, & Sakuma, 1992; Wydell, Butterworth, & Patterson, 1995). In a forced-choice task, for example, Cheng (1981) asked

subjects to identify which of two subcharacter components was previously presented in a context. A target component was embedded in a character (i.e., a single-character word), a pseudocharacter that looked like a real character, or a noncharacter context where the component occupied an impossible position. Components were identified better when they occurred in characters than in pseudocharacters, and components in pseudocharacter contexts were, in turn, identified better than in noncharacter contexts. This is a Chinese (single-character) analog of the word superiority effect. The outcome suggests that components of characters are not detected independently of or prior to the whole character in which they occur.

Researchers in the phonological processing of Chinese characters have also argued that the phonology of the character, but not the phonology of the phonetic component (sublexical phonology), contributes to character recognition (e.g., Perfetti, Zhang, & Berent, 1992; Tan, Hoosain, & Siok, 1996). More recently, this argument has been extended to the two-character word level phonology with Japanese kanji (Wydell et al., 1995), such that the phonology of a two-character kanji word but not of its constituents is activated (cf. Osgood & Hoosain, 1974).

### CHARACTER COMPONENTS AS PRIMARY UNITS

By emphasizing the primacy of whole characters, there is a tendency to minimize another systematic property of Chinese. The majority of Chinese characters are compound characters that consist of at least two components. More specifically, in modern-day usage, only a small number of characters are integrated ones that cannot be divided into components. Approximately 80% of characters are *phonetic compounds* that are made up of a phonetic component (the phonetic) and a semantic radical (the radical) (Zhou, 1978; Zhu, 1988). In principle, the phonetic is a cue to the pronunciation of the whole character, whereas the radical is a cue to its meaning. Researchers have suggested that the cueing value of phonetic components is quite low—only 26.3% of phonetic compounds

share a pronunciation identical with that of their phonetic (Fan, Gao, & Ao, 1984). Radicals tend to have semantic interpretations that are consistent with the semantics of the whole characters in which they appear (Fan, 1986). In a sense, they give cues to meaning (they are semantically transparent), although they typically indicate a general semantic category rather than a precise meaning for the character (Tan, Hoo-sain, & Peng, 1995). Occasionally, however, radicals have no clear semantic relationship with the characters that contain them (they are semantically opaque).<sup>1</sup>

In Chinese psycholinguistics, several studies have examined the contribution of component-level information to character recognition, and some researchers have argued that stroke analysis and component decomposition are primary stages of printed character identification (Huang, 1986; Leong, Cheng, & Mulcahy, 1987; Taft & Zhu, 1997; Tan et al., 1995). These studies focus almost exclusively on whether visual complexity (i.e., number of strokes composing a character; see Tan & Peng, 1991) and sublexical phonology (e.g., Fang, Horng, & Tzeng, 1986) influence character recognition. Investigations into the role of semantic radicals are sparse. Two studies that examined the time course of orthographic and phonological similarity can be reinterpreted as providing evidence that semantic radicals also play a role in character recognition, however. Leck, Weekes, and Chen (1995) used a semantic categorization procedure and required subjects to decide whether a target character be-

longed to a prespecified semantic category. Orthographically similar items were created by repeating either the phonetic or the semantic. For phonetic compounds, the false positive response rate to foils (e.g., 猜) that shared the same semantic radical as the target (e.g., 狐) was higher than that to control foils, whereas the false positive response rate to foils that shared identical phonetic components to the target (e.g., 呱) was not different from that of the controls.

Ju and Jackson (1995) used a backward-masking paradigm in which they presented a target and a mask in succession. Each target-mask pair was preceded and followed immediately by a pattern mask. The mask was presented for 30 ms. The exposure duration of the target was adjusted for each individual so as to maintain a 40–60% target identification rate. In the graphic mask condition, more than 90% of the targets (e.g., 伯) shared a radical identical to that of the mask (e.g., 仿), and the masks facilitated target recognition relative to controls. Ju and Jackson explained their finding as revealing the role of graphic information. Given that the majority of graphically similar materials shared a semantic radical, results could also be interpreted as evidence that the presence of semantic radicals in masks and in targets influenced recognition of the target. In summary, both the Leck et al. (1995) and the Ju and Jackson (1995) results suggest that semantic radicals play a role in character categorization and that the effect cannot be attributed to graphic similarity alone.

The characteristics of Chinese characters described above invite a comparison between semantic radicals and the morphemes of alphabetic writing systems in that they both constitute meaningful orthographic units. In several languages, it has been demonstrated that morphemic structure plays an important part in word recognition (Bentin & Feldman, 1990; Burani & Laudanna, 1992; Drews & Zwitserlood, 1995; Feldman, 1994; Feldman & Andjelković, 1992; Feldman & Bentin, 1994; Feldman & Fowler, 1987; Feldman & Moskovljević, 1987; Fowler, Napps, & Feldman, 1985). Paralleling the morphological line of research, in the present study we asked

<sup>1</sup> Note that the definition of semantic transparency or opacity of a semantic radical depends on the character in which it appears. A radical can be semantically transparent in some characters and opaque in others. For example, the semantic radical 扌 that appears in 打 (meaning "to hit" or "to beat"), 拉 (meaning "to pull"), and 抱 (meaning "to embrace") is defined as semantically transparent in these characters. However, it is defined as semantically opaque when it appears in 捌 (meaning "eight"). Whereas the terms "transparent" and "opaque" capture ends of a continuum, note that the range of values for semantic transparency suggests that this variable is best treated as not dichotomous. Finally, there is a distinction between transparency of the semantic radical and semantic vagueness of the whole character (see Tan et al., 1995; 1996).

whether semantic radicals also play a role in the recognition of written Chinese. We adapted the methodologies of morphological processing to probe more directly the contribution of semantic radicals to the identification of phonetic compound characters in written Chinese. Accordingly, we used the primed character decision task in which participants were asked to decide whether a target item was a legal character. If semantic radicals are activated in the course of recognizing whole characters, we can ask whether the graphic or orthographic attributes of radicals provide an adequate account of character processing or whether the semantic attributes of radicals are implicated as well.

Previous investigations with simple or masked priming paradigms have demonstrated that the time course over which various types of similarity are active can differ. For example, when the prime is similar in (alphabetic) form to the target, it facilitates target recognition at the earliest processing stage, inhibits recognition at later stages, and has no effect at long lags when several items intervene between prime and target (e.g., Ferrand & Grainger, 1994; Lupker & Colombo, 1994; Stolz & Feldman, 1995). By contrast, the morphological relatedness of prime and target facilitates target processing both at shorter stimulus-onset asynchronies (SOA) and at longer lags (e.g., Fowler et al., 1985; Stolz & Feldman, 1995). In general, varying the interval between prime and target provides a means of isolating the contribution to recognition of various dimensions (orthographic, morphological, semantic) of similarity (e.g., Feldman, submitted for publication). Across experiments, we varied the interval between prime and target and within each experiment, we varied the semantic and orthographic similarity of characters that appeared as primes and as targets. Patterns of facilitation and type of prime were examined under short SOA (243 ms) and long lag (7–13 intervening items) conditions.

### EXPERIMENT 1

The goal of Experiment 1 was to demonstrate that Chinese character recognition entails processing of one type of component, the semantic radical. In addition, the relevance of various

attributes (i.e., orthographic, semantic) of semantic radicals was explored. There were four prime types. The first type of prime shared a semantic radical and was semantically related to the target (R+S+). In this condition, the meaning of the semantic radical was consistent with the meaning of both the target and the prime. That is, the radicals were semantically transparent. The second type of prime shared a semantic radical with the target but its meaning was semantically unrelated to the target (R+S-). Under these circumstances, the semantic radical of the prime could not provide any clue as to the prime's meaning; thus, it was semantically opaque. The third type of prime was semantically related to the target but did not share a radical (R-S+). Here, primes and targets were semantically related but only as whole characters. Finally, the fourth type of prime was a control that was neither semantically related nor shared any component with the target (R-S-).

In summary, the presence of a shared radical and semantic relatedness were manipulated to create four types of primes. One type of prime was unrelated both semantically and orthographically and it provided a baseline against which to evaluate the effect of the other three types of primes. Two types were semantically related to the target, although they differed as to whether the radical of the target was present in the prime. As a control for the contribution of the visual similarity of phonetic compounds and as a way of probing the effect of the semantic transparency of a radical to processing of the compound in which it occurs, we also included primes that shared a radical with the target but where the semantic interpretation of the radical was opaque in the prime. The semantic interpretation of the radical was transparent in all targets.

Among semantic radicals in Chinese, the size of the set of characters in which a particular radical appears can vary: Some radicals appear in a large set of characters, whereas others appear only in a small set. For example, the radical 身 (*body*) occurs only in 6 characters, while the radical 扌 (*relating to the action of hand*) occurs in 328 characters. Counts are based on the *Xiandai Hanyu Cidian [Modern Chinese Dictio-*

nary] (1992). We call this feature *radical combinability*. In a character decision task in which phonetic compounds were presented in isolation, we have previously demonstrated that components that entered into many combinations were recognized faster than components that entered into only a few (Feldman & Siok, 1997). Therefore, we manipulated combinability across radicals as a second variable in the study.

In Experiment 1, a prime character was exposed for 243 ms, followed immediately by a target. To anticipate, if radicals do not influence character recognition, then (a) the effects of R+S+ and R-S+ primes should be comparable, because the whole character primes are matched for semantic relatedness with the target, (b) the effect of R+S- primes should not differ from that of the controls, because neither shares semantic similarity with the targets, and finally (c) radical combinability should not affect response latency.

If semantic radicals do play a role in character recognition, then radical combinability should have an effect on target response latencies. Moreover, two outcomes are possible depending on whether only the orthographic properties of radicals or both their semantic and orthographic properties influence character identification times. If only the orthographic dimension of radicals is relevant, then target latencies following R+S+ primes will differ from those following R-S+ primes, and latencies following R+S- primes will differ from latencies associated with R-S- controls. Both contrasts entail manipulations of the presence or the absence of a radical with whole character relatedness (S+ or S-) of prime and target held constant. If radicals are processed as orthographic units, a critical prediction is that either facilitation or inhibition is plausible when prime and target share a radical but that the direction should not change with differences in semantic transparency.

Alternatively, differing target latencies following R+S- primes relative to R-S- controls in the absence of a latency difference between R+S+ and R-S+ primes could indicate that semantically opaque radicals pose special

problems. To anticipate, with controls for whole character relatedness, an outcome whereby semantically transparent radicals in primes facilitate target latencies whereas semantically opaque radicals in primes inhibit would suggest that an orthographic account of how radicals contribute to character identification is inadequate. This outcome would provide indirect evidence that the semantic attributes of radicals play a critical role in character recognition.

### Method

*Participants.* Sixty-four Beijing Normal University undergraduates participated in this study. All participants were native Putonghua (Mandarin) speakers, with normal or corrected-to-normal vision.

*Stimuli and design.* Sixty-four (phonetic compound) characters were chosen as targets, half had high-combinability radicals (radicals occurred in many characters) and the other half had low-combinability radicals (radicals occurred in few characters). See Appendix. For high-combinability radicals, their occurrence in the corpus of about 6000 characters listed in *Xiandai hanyu cidian [Modern Chinese dictionary]* (1992) was no less than 56, with an average of 197 (SD = 215). For low-combinability radicals, their occurrence was no more than 41, with an average of 22 (SD = 9). All target characters had semantically transparent radicals (the semantic interpretation of the radical is maintained in the character) with high or medium frequencies (no less than 10 occurrences per million), according to *Xiandai hanyu pinlu cidian [Modern Chinese frequency dictionary]* (1986). The average surface frequency of the targets was 246 (SD = 294) for those with high-combinability radical characters and 254 (SD = 273) for those with low-combinability radical characters. All primes had frequencies of no less than 4 occurrences per million. The average frequency of the four prime types did not differ significantly and the average frequency of each prime type was lower than the average target frequency. Figure 1 illustrates examples of primes and targets and describes their characteristics.

Prior to selecting primes for the R+S+ and

Attribute	R+S+	R+S-	R-S+	R-S-	Target
<b>High-combinability radical</b>					
Character	评	诸	述	竿	论
Radical	讠	讠	辶	竹	讠
Radical meaning	--say, talk	--say, talk	--travel	--bamboo	--say, talk
Character pronunciation	/ping/	/zhu/	/shu/	/gan/	/lun/
Character meaning	comment	some	speak	stick	review
Average frequency and SD of Characters in each cell	135 (207)	145 (158)	147 (160)	147 (167)	246 (294)
<b>Low-combinability radical</b>					
Character	翼	翠	膀	缘	翅
Radical	羽	羽	月	纟	羽
Radical meaning	--feather	--feather	--flesh	--textile	--feather
Character pronunciation	/yi/	/cui/	/bang/	/yuan/	/chi/
Character meaning	wing	green	wing	"yuan"	wing
Average frequency and SD of characters in each cell	136 (295)	155 (205)	145 (193)	145 (164)	254 (273)

FIG. 1. Attributes of experimental materials.

R+S- conditions, a rating study was conducted. Ten informants who were native Mandarin (Putonghua) speakers were asked to evaluate the semantic cueing value (SCV) of the semantic radicals in compounds. SCV measures the contribution of the semantic radical to the meaning of the full character and is thus a measure of semantic transparency. Informants were instructed to indicate their judgment by position on a 7-point scale, where 1 indicated very low and 7 indicated very high. Results revealed that, for the primes in the R+S+ condition, the SCV of all characters was no less than 5.0, with a mean of 5.7 (SD = 0.46), while

for the primes in the R+S- condition, the SCV was no higher than 1.8, with a mean of 1.1 (SD = 0.19).

Likewise, another 10 informants were asked to assess, on a 7-point rating scale with 1 representing lowest and 7 highest, the semantic similarity of each prime-target pair in the R+S+ and R-S+ conditions. The rated semantic relatedness for the 64 targets and their R+S+ primes ranged from 5.0 to 6.8, with a mean of 5.8 (SD = 0.51). For the same targets and their corresponding R-S+ primes, the rated semantic relatedness ranged from 5.0 to 6.8, with an average of 5.9 (SD = 0.51). In

addition, the number of strokes in a target and in all four of its primes was matched. Finally, for R+S+ and for R-S+ primes, it was sometimes the case that the combination of prime and target formed a bimorphemic word either as a prime-target or as a target-prime combination. The number of bimorphemic words was matched across R+S+ and R-S+ conditions.<sup>2</sup>

Each participant saw all four types of primes in a counterbalanced design. In other words, each participant viewed a target, preceded by one of the four primes, and each experimental list included all four types of primes. Moreover, across lists, each target followed all four types of primes. The participants' task was to judge whether each target was a real Chinese character. Each experimental list contained 64 character-character pairs and 64 character-noncharacter pairs (in the simplified script). All targets were preceded by real character primes. All noncharacter targets were constructed either by taking real characters and changing one or more strokes or by combining two components that did not co-occur. By using two types of non-character formations we avoided having participants focus either on strokes or on the appropriateness of a particular combination. All noncharacter targets looked like real characters but had no meaning nor pronunciation.

*Procedure.* Experimental materials were presented on one of three IBM 386/33 microcomputers in white 24-point against a black background. Each item was approximately  $0.9 \times 1.2$  cm (width  $\times$  height). Participants were seated approximately 50 cm from the screen. Participants were instructed to make a character/non-

character decision by pressing one of two buttons as quickly as possible. The dominant hand was always used for the "CHARACTER" responses and the other hand for the "NON-CHARACTER" responses.

Trials began with the presentation of a fixation cross at the center of the screen for 1000 ms. A prime was then exposed for 243 ms, followed immediately by a target.<sup>3</sup> The target remained on the screen until participants responded or until 2000 ms had elapsed. The computer automatically measured the interval between the presentation of the target and the key press response. The stimuli were presented to participants in an identical pseudo-random order.

Prior to presentation of the experimental materials, 16 practice trials were presented. The structural features, radical combinability, and character frequency of the practice stimuli were similar to those of the test stimuli. The experiment lasted about 15 min. Participants took a 3-min break after viewing half of the stimuli.

### Results

Only response times to real characters were analyzed. Reaction times more extreme than 3 SD (fewer than 3.5% of trials) were excluded from the analysis, as were the reaction times of incorrect responses. No participants were excluded because of high error rates. Six items were eliminated from the analyses due to the ambiguous role of their phonetic.<sup>4</sup> The mean reaction times and percentage of errors to target characters in each prime condition are summarized in Table 1.

<sup>2</sup> Prime and target appeared in the same spatial location. As a result, a contribution of low-level graphemic similarity cannot be excluded.

<sup>3</sup> Prime and target appeared in the same spatial location. As a result, a contribution of low-level graphemic similarity cannot be excluded.

<sup>4</sup> Within phonetic compounds, the phonetic may vary in its phonological transparency. Variation in phonological transparency creates a difficulty in classifying some characters as phonetic compounds, especially if historical phonology and dialectal variation are ignored (see DeFrancis, 1984). In the present study, all the targets contained one (transparent) semantic radical, although the function of the other component was not necessarily fully phonologically transparent. As a result, it was sometimes difficult, especially for the nonlinguist, to ascertain whether the function of the second component was, in fact, phonetic. Accordingly, we deleted six items.

<sup>2</sup> For R+S+ primes (e.g., 评) followed by targets (e.g., 论), 5/30 with high combinability radicals and 5/30 with low combinability radicals were meaningful when combined in the forward fashion (e.g., 评论, COMMENT). For R-S+ primes followed by targets, 5/30 with high combinability radicals and 4/30 with low combinability radicals were meaningful when combined in the forward fashion. For R+S+ primes (e.g., 膀) preceded by targets (e.g., 翅), 4/30 with high combinability radicals and 3/30 with low combinability radicals were meaningful when combined in the backward fashion (e.g., 翅膀, WING). For R-S+ primes preceded by targets, 4/30 with high combinability radicals and 5/30 with low combinability radicals were meaningful when combined in the backward fashion.

TABLE 1

Mean Response Latencies (ms) and Error Rates (%) for Targets as a Function of Radical Combinability and Prime Type in Experiment 1

	Prime type			
	R+S+	R+S-	R-S+	R-S-
Combinability				
High				
Mean	530	578	528	554
Error rate	2.9	7.9	2.1	5.5
Low				
Mean	548	590	550	574
Error rate	7.3	14.1	7.1	9.1
Combined				
Mean	539	584	539	564
Error rate	5.1	11	4.6	7.3
Facilitation RT	25*	-20*	25*	
Facilitation error	2.2	-3.7*	2.7*	

\*  $p < .05$ .

Prime Type (R+S+, R+S-, R-S+, and control (R-S-))<sup>5</sup> and Radical Combinability were factors in an analysis of variance with repeated measures for target reaction times.  $F$  values are reported by subjects ( $F_1$ ) and by items ( $F_2$ ). The effects of Prime Type [ $F_1$  (3,189) = 24.35,  $p < .0001$ ,  $MSE = 2489$ ;  $F_2$  (3,168) = 8.14,  $p < .0001$ ,  $MSE = 3227$ ] and Radical Combinability [ $F_1$  (1,63) = 25.4,  $p < .0001$ ,  $MSE = 1524$ ;  $F_2$  (1, 56) = 3.13,  $p < .08$ ,  $MSE = 8904$ ] were significant. The Prime Type  $\times$  Radical Combinability interaction was not significant [both  $F_1$  and  $F_2 < 1$ ].

Posthoc multiple comparisons between different prime types collapsed over levels of radical combinability showed the following: Both R+S+ primes and R-S+ primes produced equivalent facilitation relative to control primes (+25 ms) ( $p < .0001$  by subjects and  $p < .05$  by items). R+S- primes inhibited response latencies relative to control primes (-20 ms) ( $p < .005$  by subjects and  $p < .06$  by items).

With the accuracy measure, the effect of

<sup>5</sup> Prime type was treated as one variable with four levels so that the effectiveness of the three types of related primes (R+S+, R+S-, R-S+) could be evaluated with respect to the same control (R-S-).

Prime Type was significant by subjects [ $F_1$  (3,189) = 10.54,  $p < .0001$ ,  $MSE = 103$ ] and by items [ $F_2$  (3,168) = 8.00,  $p < .0001$ ,  $MSE = 53.8$ ]. The effect of Radical Combinability was also significant [ $F_1$  (1,63) = 28.54,  $p < .0001$ ,  $MSE = 104$ ;  $F_2$  (1, 56) = 4.90,  $p < .05$ ,  $MSE = 223$ ]. The Prime Type  $\times$  Radical Combinability interaction was not significant (both  $F_1$  and  $F_2 < 1$ ).

Posthoc analyses on the error data showed that R+S+ primes marginally facilitated target identification relative to unrelated control primes ( $p < .07$ , by subjects and  $p < .08$  by items). Accuracy following R-S+ primes was worse than that following controls ( $p_1 < .005$  and  $p_2 < .05$ ). Finally, accuracy rates following R+S+ and R-S+ primes did not differ.

Noncharacter trials were not counterbalanced across prime types. Therefore, analyses would not be meaningful and negative decisions latencies are not presented.

### Discussion

Many researchers have assumed that, in written Chinese, characters are the primary unit of visual recognition (e.g., Cheng, 1981; Hoosain, 1991; Liu, 1988). The results of Experiment 1 provide evidence that one type of component, the semantic radical, is processed in the course of character recognition and that an account based on whole character processing is not adequate. In Experiment 1, we presented a prime for 243 ms, followed immediately by a target. When the prime shared a radical with the target but was not related in meaning to the target (R+S-), the prime inhibited target recognition. Past research in Chinese in which a prime was exposed for less than 100 ms has generally revealed that orthographically similar primes facilitated target recognition in the perceptual identification (Perfetti & Zhang, 1991) and character decision tasks (Tan & Peng, 1991). The present experiment demonstrated an inhibitory rather than a facilitative orthographic effect following R+S- primes. In the semantically opaque (R+S-) condition, where primes and targets are orthographically similar, 20 ms of inhibition (collapsed over combinability) was observed relative to the R-S- condition. It is



likely that the stimulus onset asynchrony influences the direction as well as the magnitude of orthographic priming (Feldman & Siok, 1998). In addition, based on findings with alphabetic writing systems, the frequency of the prime relative to that of the target may also be relevant (Segui & Grainger, 1990).

For semantically related prime–target pairs, target facilitation was evident whether (R+S+) or not (R–S+) primes shared an identical radical with that of the target. An effect of semantic relatedness replicates what researchers have found under a variety of experimental conditions in many different writing systems (e.g., Neely, 1977). It suggests that compound characters with similar meanings are associated in the mental lexicon of the Chinese reader. With latencies, the magnitude of R+S+ facilitation was comparable to that in the R–S+ condition, although only the former was visually similar to the target. It follows that the 25-ms facilitation (collapsed over combinability) in the R+S+ condition cannot be predicted from the joint effects of orthographic similarity due to a shared radical and semantic relatedness between whole characters. That is, at an SOA of 243 ms, there was no evidence that orthographic similarity altered the magnitude of facilitation among semantically related forms.

To reiterate, orthographic similarity and whole character relatedness are inadequate to account for the present results. If semantic radicals were processed as orthographic units during the course of character recognition then, when prime and target share a radical, the direction of the effect (facilitation or inhibition) should not change with manipulations on semantic relatedness of the prime and target. By contrast, while target latencies following R+S+ and R–S+ primes did not differ, latencies following R+S– primes were significantly slower than those following R–S– controls.

If there is no distinct effect of orthographic similarity in the present experiment and if R+S+ facilitation and R–S+ facilitation both reflect effects of whole character relatedness then how can we account for slowed target recognition following R+S– primes? We propose that R+S– inhibition reflects semantic

processing of the radical and that the semantic transparency of radicals constitutes another influence on the processing of Chinese characters. Perhaps semantic opacity in the prime impairs target recognition because the semantic contribution of the radical to the prime and to the target differ. That is, the inconsistent meaning of the semantic radical (e.g., 讠 meaning SAY, TALK) relative to the whole character in an opaque prime (e.g., 诸 meaning SOME) causes the meaning of the radical to be inhibited some time after the initial activation of the prime. As a result, when a target (e.g., 论 meaning REVIEW) that contains the same radical is presented subsequently, processing of the target is impaired. No analogous target inhibition occurs following transparent primes (e.g., 评 meaning COMMENT) because the meaning of the radical relative to that of the whole character is consistent. Admittedly, based on the present experiment alone, the contribution to character identification of a radical's semantic and orthographic attributes are not fully distinguishable and resolution of this issue must await the publication of further research.

We have described three potential influences on target decision latencies in the character decision task when primes are presented for durations of 243 ms. These include (1) the semantic relatedness between whole characters as well as similarity due to the (2) orthographic and (3) semantic transparency of radicals. In isolation, comparing the magnitude of facilitation for semantically related items with and without a shared radical provided little compelling evidence for the claim that radicals play a part in character recognition. Semantically related characters facilitated each other and an orthographic effect due to a shared radical was absent. The potential effect of a shared radical within semantically related pairs warrants further investigation, however. In particular, we could ask whether differences would be reliable with semantically less precise targets (see Tan et al., 1996) or under temporally more constrained processing conditions (i.e., shorter SOAs). In summary, in the present study, it is the absence of orthographic inhibition due to a shared radical following R+S+ primes in con-

junction with the inhibition following R+S—primes that constitutes the critical evidence that orthographic processing of the radical along with whole character semantic relatedness do not constitute an adequate account.

Finally, radical combinability influenced character decision latencies in Experiment 1. Specifically, with controls for frequency, responses to targets formed from characters with high-combinability radicals were faster than to characters with low-combinability radicals. Radical combinability influenced character identification so that recognition latencies varied as a function of the number of compound character combinations its radical can enter into. Accordingly, processing of a compound must be constrained by identification of its radical. From a reciprocal activation point of view (see Andrews, 1989), radicals that enter into many combinations receive more reciprocal activation, or feedback, from their “neighbors” and hence would be identified earlier. Therefore, magnitude of activation appears to vary as a function of the number of compounds that can be formed from a particular radical.

In conclusion, in Experiment 1, we demonstrated that semantic radicals play a role in Chinese character identification. This finding was not consistent with the (exclusively) whole-character hypothesis (e.g., Cheng, 1981; Hoo-sain, 1991). Moreover, an orthographic account of radical processing in conjunction with whole character semantic relatedness was inadequate to account for the pattern of results. We proposed that the semantic analysis of radicals is central to the identification of Chinese characters.

## EXPERIMENT 2

Like morphemes in English, Chinese radicals are typically orthographic units as well as semantic units, although they differ from morphemes in that they do not necessarily have a phonological form. In Experiment 1, it was difficult to unequivocally distinguish the effects produced by semantic characteristics of radicals from those produced only by their orthographic characteristics because, when primes and targets are presented in close temporal succession,

effects of orthographic similarity are anticipated. That is, a short lag priming procedure necessarily is sensitive to the effects of orthographic similarity.

One method of minimizing the orthographic priming effect is to extend the interval between the onset of a prime and the onset of a target. There have been a number of studies that failed to show orthographic influences when many items intervened between prime and target (Bentin & Feldman, 1990; Burani & Laudanna, 1992; Drews & Zwitserlood, 1995; Feldman, 1994; Feldman & Andjelković, 1992; Feldman & Bentin, 1994; Feldman & Fowler, 1987; Feldman & Moskovljević, 1987; Fowler, Napps, & Feldman, 1985). A frequently replicated finding is that when there are no intervening items between prime and target (i.e., 0 lag), morphologically related primes (e.g., CARS) facilitate target processing (e.g., CAR), whereas formally similar primes (e.g., CARD) tend to inhibit target processing. When there are 7 to 13 intervening items between prime and target (i.e., long lags), however, morphologically similar primes facilitate target recognition, whereas formally similar primes have no effect (e.g., Feldman, submitted for publication; Feldman & Fowler, 1987; Feldman & Moskovljević, 1987; Grainger, Cole, & Segui, 1991; Hanson & Wilkenfeld, 1985; Laudanna, Badecker, & Caramazza, 1992; Murrell & Morton, 1974; Napps & Fowler, 1987; Segui & Grainger, 1990; Stolz & Feldman, 1995). At long lags, the absence of orthographic effects concurrent with the maintenance of morphological effects has been interpreted to mean that orthographic similarity alone cannot account for facilitation between morphological relatives in alphabetic writing systems (e.g., Dutch, German, Hebrew, Italian, and Serbian).

Morphological facilitation can also be distinguished from effects of semantic relatedness at long lags. Bentin and Feldman (1990) found significant facilitation to target decision latencies in Hebrew when there was a pure semantic relation between prime and target and they were presented in immediate succession, but not when many items separated them. In contrast to semantic priming, however, facilitation due to

morphological relatedness between prime and target was not reduced at long lags relative to the immediate condition. For the semantically and morphologically related (SM) prime and target pairs, the magnitude of the facilitation in the immediate priming condition was similar to that of pure semantic relatedness and greater than that of morphological relatedness alone. At long lags, however, the magnitude of facilitation in the SM condition was similar to that produced by a pure morphological relationship. The outcome of this study demonstrated that repetition of a morpheme facilitates word identification, whether or not the morphologically complex forms are semantically related (see also Frost, Forster, & Deutsch, 1997). Moreover, the long lag procedure may be better suited to the study of morphological effects because it minimizes the influence of semantic relatedness.

By analogy with the work on morphological processing, we reasoned that by increasing the interval between presentation of prime and target in the present study, it would be possible to eliminate effects of orthographic similarity and whole character semantic relatedness. In Experiment 2, we extended the interval between the presentation of the prime and the target in an attempt to better understand the processing of semantic radicals in visual word recognition.

### Method

**Participants.** Sixty South China (Guangzhou) Normal University undergraduates participated in Experiment 2. All participants were native speakers of Mandarin Chinese (Putonghua) and fluent readers of simplified Chinese characters, with normal or corrected-to-normal vision. They were paid for taking part in the experiment. None of these individuals had taken part in Experiment 1.

**Stimuli, design, and procedure.** The types of primes and the distribution of materials across experimental lists were the same as those in Experiment 1. In Experiment 2, lags of 7–13 items separated primes and targets. The experimental materials consisted of the same 64 character targets, 64 noncharacter targets, and 64 critical primes. Because participants had to

TABLE 2

Mean Response Latencies (ms) and Error Rates (%) for Targets as a Function of Radical Combinability and Prime Type in Experiment 2

	Prime type			
	R+S+	R+S-	R-S+	R-S-
Combinability				
High				
Mean	548	556	557	564
Error rate	2.1	2.1	2.7	2.5
Facilitation	16*	8	7	
Low				
Mean	546	554	568	565
Error rate	1.5	4.0	4.6	4.0
Facilitation	19*	11	-3	
Combined				
Mean	548	555	562	564
Error rate	1.9	2.9	3.6	3.2
Facilitation	16*	9	2	

\*  $p < .05$ .

make a judgment both to the target and to the prime, an additional 64 noncharacters were introduced into the experimental list so that half of all responses were "yes" and half were "no." Moreover, to maintain adequate lags, 40 characters and 40 noncharacters were introduced. Overall, an experimental session in Experiment 2 contained 336 trials. Each character was presented visually and remained on the screen until participants made a response. The entire experiment lasted about 30 min. Participants took a 5-min break after viewing half of the items.

### Results

Only characters were analyzed in Experiment 2. Reaction times more extreme than 3 SD (less than 3.2% of trials) were excluded from the analysis, as were the reaction times of incorrect responses. Six items were deleted from the analyses, as in Experiment 1. The mean reaction times and percentage of errors to target characters in each prime condition are summarized in Table 2.

Prime Type (R+S+, R+S-, R-S+, and control (R-S-)) and Radical Combinability were main factors in an analysis of variance.

There was a main effect of Prime Type [ $F_1(3,177) = 4.39, p < .005, MSE = 5735; F_2(3,168) = 6.17, p < .001, MSE = 6300$ ]. The effect of Radical Combinability did not approach significance (both  $F_1$  and  $F_2 < 1$ ) nor did the interaction of Prime Type  $\times$  Radical Combinability [ $F_1(3,177) = .88, p = .45, MSE = 521; F_2(3,168) = 1.55, p = .20, MSE = 1586$ ].

Planned comparisons between different prime types collapsed across levels of radical combinability showed that latencies following R+S+ primes were significantly faster than following control primes ( $p < .05$ , both by subjects and by items) and that the latency difference for targets following R+S+ and R-S+ was significant ( $p < .005$ , both by subjects and by items). No other differences approached significance.

With the accuracy measure, the effect of Prime Type was not significant [ $F_1(3,177) = 2.26, p < .10, MSE = .50; F_2(3,168) = 1.79, p = .15, MSE = 1.20$ ]. The effect of Radical Combinability was significant by subjects [ $F_1(1, 59) = 4.04, p < .05, MSE = 1.01$ ], but not by items [ $F_2(1, 56) = 2.91, p = .10, MSE = 4.91$ ]. The Prime Type  $\times$  Radical Combinability interaction was not significant. Posthoc analyses showed that target accuracy following R+S+ primes was significantly better than following controls ( $p < .05$  by subjects and  $p < .08$  by items).

### Discussion

In contrast to Experiment 1 where primes and targets were presented in immediate succession, in Experiment 2 primes and targets were separated by an average of 10 items. Results provided no evidence of facilitation at long lags between semantically related characters (R-S+) relative to unrelated controls (R-S-). This finding is important because it is sometimes suggested (e.g., Frost, Forster, & Deutsch, 1997) that the long lag repetition priming task is contaminated by strategic effects and a large proportion of items that are highly semantically related is a likely basis for a strategy. Similarly, in Experiment 2, characters that were orthographically similar but semantically unrelated

(R+S-) had no significant effect on targets. These findings are consistent with the claim that neither orthographic (Feldman & Moskovljević, 1987) nor semantic (Bentin & Feldman, 1990) similarity produces effects that endure over an average of 10 intervening items.

Concurrent with the failure to find either orthographic or semantic effects, R+S+ primes produced significant facilitation to targets relative to the control condition. This finding is consistent with our intuition that facilitation due to repetition of a transparent semantic radical in prime and target could be differentiated from the effects of simple orthographic similarity or whole character semantic relatedness. However, we observed no evidence of facilitation following R+S- primes. Insofar as repetition of a semantic radical is analogous to repetition of a base morpheme, this outcome was not anticipated. In Hebrew, long-term effects of morphological relatedness in the absence of semantic relatedness have been observed. Further research must probe more directly the appropriateness of comparing radicals and morphemes.

Finally, although isolated characters (Feldman & Siok, 1997) and characters presented in close succession (Experiment 1) revealed effects of combinability, there was no effect of radical combinability when long lags separated characters that shared a radical. Moreover, radicals that entered into many (high combinability) or few (low combinability) compound character combinations produced equivalent facilitation. However we come to understand radical combinability, we have demonstrated that it is a variable that affects the identification of isolated targets and targets that immediately follow their prime.

### GENERAL DISCUSSION

Until recently, the general consensus has been that characters, or (multicharacter) words, are the primary perceptual units in Chinese (e.g., Cheng, 1981; Hoosain, 1991; Liu, 1988; Morton, Sasanuma, Patterson, & Sakuma, 1992; Wydell, Butterworth, & Patterson, 1995). Results of two recent studies (Leck et al., 1995; Ju & Jackson, 1995) can be reinterpreted as consistent with the claim that semantic radicals also

are analyzed in character identification. In addition, effects of semantic radical combinability on single character decision latencies have been documented (Feldman & Siok, 1997). The purpose of the present study was to investigate more systematically the role of semantic radicals in visual character recognition. Semantic radicals are distinctive because, unlike words or most morphemes, they do not necessarily have a phonological interpretation. That is, semantic radicals are primarily semantic and orthographic units and only incidentally do they have a pronunciation (*viz.*, when they can appear as free characters). Using the primed lexical decision task, we demonstrated the contribution of semantic radicals to Chinese character recognition.

Results suggested that, when a target followed a prime at an SOA of 243 ms (Experiment 1), the presence of a shared semantic radical influenced target recognition. In particular, when prime and target were formed from the same semantic radical and when the meaning of a radical was consistent with the meaning of a whole prime character, repetition of the radical facilitated target identification. When the meaning of a radical was opaque as to the meaning of a whole prime character, repetition of the radical retarded target character processing. When primes and targets were separated by an average of 10 items (Experiment 2), semantically transparent primes formed from the same radical facilitated target processing. Other types of primes had no effect, either facilitatory or inhibitory, on target processing.

Clearly, the present findings are not consistent with the claim that Chinese characters are processed exclusively as holistic units and that their internal structure is not psychologically relevant. The patterns of facilitation and inhibition among compound characters in the present study suggested at least three influences on target processing. They differed with respect to the dimension of similarity (orthographic or semantic) and to the participating unit, either radical or whole character. Equivalent target facilitation following R-S+ and R+S+ primes at short lags was interpreted as reflecting semantic relatedness of whole characters (Experiment 1).

R+S+ facilitation also persisted when many items intervened between prime and target (Experiment 2). Whereas the results of Experiment 2 could indicate that the effect of whole character semantic relatedness persists at long lags if it is supported by orthographic similarity such as the repetition of semantic radical, it was the case that neither effects of whole character semantic relatedness nor orthographic similarity alone were observed at lags of 10 intervening items. Importantly, this finding is not restricted to Chinese materials. The failure to observe effects of semantic as well as orthographic similarity at long lags has been reported in Hebrew (Bentin & Feldman, 1990) and in English (Feldman, 1998). Sustained facilitation to targets following R+S+ primes at long lags appears to reflect the consistent contribution of the semantic radical to the meaning of the prime and the target. More compelling evidence for semantic processing of the radical comes from the short term priming task, however.

Target inhibition following R+S- primes at short lags (Experiment 1) could reflect a detrimental effect of orthographic similarity (based on repetition of a radical) in the absence of whole character relatedness. Such an interpretation might be motivated from analogous effects in alphabetic writing systems (Grainger et al., 1991; Stolz & Feldman, 1995) although, at least under some experimental conditions, the magnitude of facilitation due to morphological relatedness was enhanced by orthographic similarity (Rueckl et al., 1997; Stolz & Feldman, 1995). A severe weakness of this account is that there was no evidence that the effect of orthographic similarity and whole character semantic relatedness were offsetting each other when whole characters were semantically related and presented at an SOA of 243 ms. The magnitude of facilitation was equivalent following R+S+ and R-S+ primes, although only R+S+ primes shared a component and therefore were visually similar. Instead, we interpret inhibition following R+S- primes as a reflection of the opaque semantic relation of the semantic radical to the meaning of the prime or to the inconsistent meaning of the radical in the prime relative to its meaning in the target.

In essence, the effects of orthographic similarity due to the presence of a shared radical and whole character relatedness were not sufficient to accommodate the present pattern of results in the short term priming task. Therefore, we argued that the semantic attributes of radicals provide another source of activation in the present task. This claim was motivated by the way in which semantic transparency of the radical influenced target recognition. When prime and target were presented in immediate succession (SOA 243 ms) and the mapping between form and meaning of radical in prime and in target was not consistent, inhibition was observed. When the mapping was consistent, facilitation was observed.

Our emphasis on the semantic transparency of the radical and the critical role it plays in Chinese character identification should not be interpreted to mean that the orthographic attributes have no role. In fact, we have reported that, under the appropriate temporal constraints, both the semantic and the orthographic characteristics of radicals produce significant and differentiable effects (Feldman & Siok, 1999; Siok & Feldman, unpublished manuscript). In that study, as SOA increased, we saw a shift from facilitation to inhibition for targets that followed a prime whose shared semantic radical was opaque (R+S-). In addition, facilitation following primes with shared opaque and with visually similar radicals was comparable at very short but not at longer SOAs. Specifically, primes with opaque radicals and primes with visually similar radicals facilitated target latencies at short SOAs (viz. 43 ms). Opaque primes inhibited at longer SOAs (viz. 72 and 243 ms), whereas visually similar primes had no significant effect. Admittedly, from the present study alone, the possibility that the pattern of results following R+S- primes could be interpreted with as reflecting a complexity in processing related to the interaction of orthographic similarity with the absence of whole character semantic relatedness cannot be totally dismissed.

However, manipulations of SOA reveal that the effects of semantically opaque and visually similar radicals are distinct at an SOA of 243 ms. It is the goal of future research to elaborate on the underlying mechanism. What is evident at present is that semantic analysis of radicals must play a role in the visual recognition of Chinese characters.

To conclude, we have demonstrated that sublexical structure influences word recognition in a non alphabetic script where tradition stresses processing of the character as a whole. Evidence that the sublexical components of Chinese characters influence performance has been reported previously, although most of that work focused on the phonetic. In the present study, we demonstrate sublexical processing of the semantic and discuss the inadequacy of an orthographic account. Likewise effects of combinability have been interpreted to mean that the components of characters are processed in the course of recognizing a character. For both semantics as well as phonetics, with controls for surface frequency, characters with components that enter into many combinations (to form characters) are recognized more quickly than those with components that enter into only a few (Feldman & Siok, 1997). Results of the present study extend the processing advantage of high combinability semantic components into the priming paradigm. Most important, we show that sublexical processing can be semantic in focus. Finally, semantic similarity can be specified at the character level or the component level and that the two are not necessarily redundant. This attests to the variety of ways in which isolated words can be similar in meaning. It is important to note that the intricacies of semantic similarity between words and their components are not specific to Chinese and that the present findings may be relevant for accounts of semantic processing of the components of morphologically complex and compound words across a variety of languages and writing systems.

## APPENDIX

Radical	Target	R+S+	R+S-	R-S+	R-S-
<b>High Combinability</b>					
讠	论	评	诸	述	竿
扌	扔	投	捌	弃	沾
艹	芽	蕾	艺	嫩	徒
犭	流	泻	演	移	官
彳	狼	狐	猜	虎	案
宀	恼	愤	猜	怒	迹
纟	室	寓	惯	屋	确
纟	绳	线	字	束	脸
钅	铲	线	统	除	混
疒	疗	疾	镇	医	蛙
衤	袖	裤	痕	服	座
飠	饥	饿	裕	渴	钓
足	跑	跳	饰	奔	鉴
刂	刻	削	躁	描	伏
竹	筐	篮	剂	袋	挫
辶	远	遥	笨	距	呵
月	肥	胖	遮	沃	控
土	堵	填	胜	闷	淀
口	吸	呼	坏	排	补
山	峰	岗	唯	丘	笔
女	妈	婆	岁	母	桌
马	驶	婆	妨	奔	磁
火	烧	炼	骄	焦	影
心	念	恩	烂	记	取
木	枝	杈	怨	茎	临
目	瞧	瞪	杜	望	驻
禾	秧	稻	冒	苗	姐
虫	虾	蟹	私	海	畅
日	晚	暗	虹	迟	刮
酉	醉	酣	旷	迷	垫
贝	资	财	配	款	欺
巾	帆	帆	赋	篷	

## APPENDIX-Continued

Radical	Target	R+S+	R+S-	R-S+	R-S-
Low Combinability					
彳	冷	冰	冶	抖	叨
子	孩	孙	孔	童	棋
匸	匿	匪	匪	箱	逃
雨	霜	雾	零	凝	货
灬*	煮	煎	熊	炒	讨
犛*	牧	接	特	饲	触
皿	盆	盒	盟	杯	准
糸	紧	累	紫	捆	济
隹	雉	雏	雅	鸡	碰
穴*	窑	窝	究	洞	袭
爪*	采	觅	妥	寻	熟
殳	毁	毳	殿	坏	辣
耒	耕	耙	耗	犁	债
豸*	豺	豹	貌	兽	匠
犮*	将	状	妆	师	嘲
弓	弛	张	弥	松	鸭
户*	房	所	肩	宅	郁
见	观	览	规	盯	罚
父*	爸	爹	斧	伯	徒
水	站	浆	杳	银	替
立	战	竖	竭	挺	置
戈	装	戮	戏	征	序
衣	闻	裳	衷	饰	轻
耳	赶	聆	耻	讯	船
走	驱	赴	趣	驱	季
身	辞	躬	射	体	搅
舌	魔	舒	乱	词	搞
鬼	斩	魂	魏	俱	恒
斤*	翅	断	新	砍	沫
羽	歼	翼	翠	膀	缘
歹	切	残	殊	伤	询
刀		剪	券	除	邻

\* Item excluded from analysis.



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