Journal of Experimental Psychology:
Learning, Memory, and Cognition
2004, Vol. 30, No. 2, 530–539

Copyright 2004 by the American Psychological Association, Inc.
0278-7393/04/$12.00 DOI: 10.1037/0278-7393.30.2.530

The Nature of the Mental Representation of Radicals in Chinese: A Priming Study

Guosheng Ding and Danling Peng
Beijing Normal University

Marcus Taft
University of New South Wales

Using a priming procedure, 4 experiments were carried out to investigate the effects of a short preexposure of a prime that was a radical or contained radicals identical to the target. Significant facilitation was found when the target contained the prime as a radical, although only for low-frequency targets which did not arise merely as a result of graphical similarity. Facilitation also occurred when the prime and target shared a radical in the same position but not when in different positions. When the prime and target had exactly the same radicals but in different positions, however, the priming effect was inhibitory. This set of results suggests that simple characters (radicals) and complex characters are represented at a different level.

The orthographic system of Chinese can be described at a number of different levels, that is, strokes, radicals, characters, and words. Words contain one or more characters, which, in turn, are composed of one or more radicals (e.g., the 口 and 斤 of the complex character 听),[1] which, in turn, are composed of one or more strokes. A radical can appear in different positions within a complex character; for example, 白 is found at the top of 皇, the bottom of 皆, to the left of 皑, and to the right of 柏. Left-hand radicals, usually termed *semantic* radicals, often give a clue to the meaning of the character (e.g., 白 means white, and 皑 means pure white), whereas right-hand radicals sometimes give a clue to the pronunciation of the character (e.g., 白 is pronounced *bai*2, and 柏 is pronounced *bai*3).[2]

The sublexical radical can often be used as a character in its own right. For example, both the 口 and 斤 of 听 are simple characters with their own pronunciation and meaning. In contrast, some radicals, such as the 亻 of 位 or the 讠 of 讲, can never be used as characters even though those radicals might carry some semantic information (e.g., 讠 often refers to speech-related characters). Furthermore, some radicals, which are called *compound* radicals, are actually a combination of more than one simple radical, and sometimes the compound radical can be used as a character. For example, the character 积 consists of the radicals 禾 and 只, both of which are characters in their own right. 只 is in turn composed of the radicals 口 and 八, which can also be characters.

The question can then be raised of whether there are specific representational units for radicals in lexical memory and, if there are, what the relationship is between these and the representations of their character versions. For example, are the radical and character versions of 斤 represented at different levels, or do they make use of a shared unit? If the former, how are the two representations related?

There is increasing evidence from a range of paradigms to suggest that reading a complex character involves the processing of its radicals (e.g., Lai & Huang, 1988; Peng, Yang, & Chen, 1994; Taft & Zhu, 1997; Taft, Zhu, & Peng, 1999; Li & Chen, 1999; Zhang, Perfetti, & Yang, 1999; Zhou & Marslen-Wilson, 1999). For example, Zhou and Marslen-Wilson (1999) obtained a facilitatory priming effect when a target was semantically related to the phonetic radical embedded in the prime, even though the prime itself was not semantically related to the target. Radical processing in Chinese character recognition also has been indicated by illusory conjunction effects (Li & Chen, 1999), as well as constituent frequency effects (Han, 1998; Taft & Zhu, 1997; Taft et al., 1999; Taft, Zhu, & Ding, 2000). Although there is evidence to suggest that radical processing is involved in Chinese character reading, the exact nature of radical representation in lexical memory is still a matter of debate.

The research of Taft and his colleagues, using the character decision task, provides more detailed information about the role of radicals in character recognition. Support for positional specificity of radical representation comes from the demonstration by Taft et al. (1999) that two characters that are composed of the same radicals (e.g., 呆 [dull], *dai*1 and 杏 [apricot], *xing*4) are not

Guosheng Ding and Danling Peng, School of Psychology, Beijing Normal University, Beijing, People's Republic of China; Marcus Taft, School of Psychology, University of New South Wales, Sydney, Australia.

This research was supported by the National PANDENG Project 95-Special-09 and Grant 30270462 from Chinese Natural Science Foundation to Danling Peng and a grant from the Australian Research Council awarded to Marcus Taft.

Correspondence concerning this article should be addressed to Danling Peng, School of Psychology, Beijing Normal University, Beijing, 100875, People's Republic of China. E-mail: PDL3507@bnu.edu.cn

[1] The term *radical* can be confusing because it is used as the English translation of two different Chinese words. On the one hand, there are the approximately 214 units (called 部首, *bu*4 *shou*3 in Chinese) that are used for indexing characters in a dictionary; on the other, there are approximately 541 units (部件, *bu*4 *jian*4) that include all components regardless of position. The second meaning is adopted here, being the more general use of the term.

[2] Numerals are used to indicate one of the four tones used in Mandarin.

confusable. That is, there is no delay in responses to either of these characters relative to another character matched on frequency. They suggested that the unit representing the radical 口 used at the top of a vertically structured character (e.g., 呆) was different from the unit representing the radical 口 used at the bottom of such a character (e.g., 杏) and that the same was true for the top and bottom radical versions of 木. Of course, the results of Taft et al. might alternatively be taken as evidence that characters are not recognized via their radicals at all, but such a conclusion would be incompatible with other research, mentioned above, that demonstrates an influence of radical processing on the recognition of the complex character in which the radical occurs.

Taft and Zhu (1997) found that radical frequency had an impact on character decision responses when character frequency was controlled but that the effect mainly occurred for right-hand radicals. It was further shown that the frequency of the right-hand radical that had the biggest impact was its frequency in that particular position (i.e., when used on the right-hand side of a character). This was also shown by Taft et al. (2000), who further found an effect of radical frequency when the frequency of the radical as a simple character was manipulated. Unlike Taft and Zhu, however, Taft et al. (2000) demonstrated the effect of a third radical-frequency measure, namely, frequency as a radical regardless of position.

It was argued that the independent influence of all three measures of radical frequency supported a model whereby a complex character (e.g., 枢 [pivot], *shu*1) was recognized via a position-specific radical unit (i.e., right-hand 区) and that this unit was activated via the representation for the simple character (i.e., 区 [region], *qu*1) along with the positional information (i.e., *right-hand*). This idea was incorporated into a hierarchical model and is depicted in Figure 1 (for detailed justification, see Ding, Taft, & Zhu, 2000; Taft et al., 2000, and Taft, in press). Here it can be seen that the simple-character unit 区, activated by stroke-based features, and the particular radical position, left or right (arbitrarily depicted by the symbols ‹ and ›, respectively) are only activated when that stroke combination is found in the relevant position of a presented complex character. When one of these positional units is activated in combination with other relevant feature units, a position-specific radical representation is activated. In other words, independent representations exist for the left-hand version of a radical (e.g., ‹) and the right-hand version (e.g., ›), as well as for top and bottom versions (if they exist in any characters).

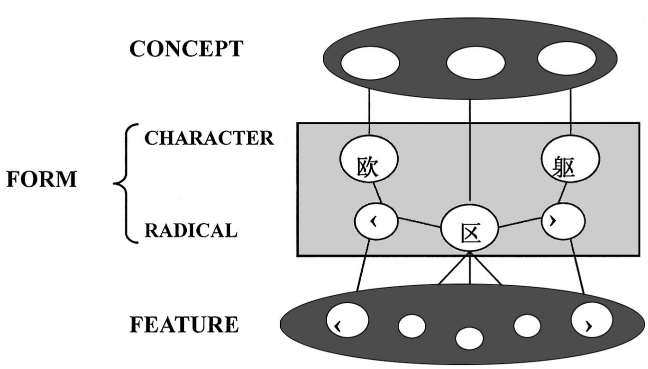

Figure 1. The model in which the radical representations are activated via simple-character representation.

The current research centers on the question of the relationship between the representation of radicals and characters and does so within a priming experiment. Priming investigates the relationship between lexical representations by revealing the effect of preexposure of one unit on another. The manipulation here was of the existence of the same radicals in the prime and target, where the radical might either be combined with another radical (to form a complex character) or constitute a character in its own right (as a simple character). The aim was to examine further whether the sort of conceptualization depicted in Figure 1 was helpful in understanding how Chinese characters are read.

Experiment 1

According to Figure 1, a complex character is recognized via the representation for its radical in simple character form. That is, the first step in recognizing 枢 is the activation of a unit representing 区 (as well as one for the left-hand 木 radical). Support for such a claim would come from the finding that recognition of a complex character (e.g., 枢) is facilitated by the prior presentation of the simple-character version of one of its radicals (e.g., 区). This was examined in Experiment 1.

Method

Materials. Forty-eight complex characters that contain more than one radical were used as targets (see Appendix A). Half of them were horizontally structured, and the other half were vertically structured. Half of them were high-frequency characters (>80 per million words, with a mean of 481 per million words) according to the *Modern Chinese frequency dictionary* (1985), and the other half were low-frequency characters (<80 per million words, with a mean of 16 per million). For each target, two kinds of priming condition were used: radical priming (in which the prime was a character that was a constituent radical of the target, e.g., 乏–砭, 夫–规) and unrelated priming (in which the prime was an unrelated character, e.g., 匆–砭, 舟–规). The radical primes appeared equally in the left, right, top, or bottom position of the target and were matched to the unrelated primes on character frequency and stroke number.

To determine whether the semantic relatedness of the primes and targets was the same across the different conditions, a rating task was given to a group of 11 native Chinese speakers who did not participate in the experiment. They were presented the prime and target characters side-by-side and were asked to judge on a scale from 1 to 5 how related each pair was in their meaning regardless of any overlapping radicals. There was no difference between any of the conditions (with mean ratings of 1.27 and 1.11 for the primed vs. control high-frequency items and 1.43 and 1.15 for the primed vs. control low-frequency items). An attempt was also made to match the conditions on phonological relatedness. To this end, for almost all of the pairs, there was no overlap between the prime and target either on their initial consonant or on their vowel (in which the vowel might include a terminal *n* or *ng*).[3]

To avoid the repeated exposure of the same target to the identical participant in different conditions, a counterbalanced design was adopted. The targets were divided into two lists. Each included half of the high-

[3] Overlap in tone was ignored in this analysis because it has been shown to have little impact in the judgment of phonological similarity between characters (see Taft & Chen, 1992).

frequency characters and half of the low-frequency characters, as well as half of the horizontally structured characters and half of the vertically structured characters. The participants were divided randomly into two groups. One group received the radical priming condition for the first subgroup of targets and the unrelated priming condition for the second subgroup, whereas the other group received the radical priming condition for the second subgroup of targets and the unrelated priming condition for the first subgroup.

In addition, forty-eight noncharacter items were constructed by combining parts of real characters together, with all radicals in their legal positions, generating images that could not be distinguished from the real characters on physical grounds alone. All of the primes for noncharacter targets were genuine simple characters. To avoid strategic effects, there were also two priming conditions for the noncharacter target: radical priming (in which the prime was a character that was a constituent radical of the noncharacter target) and unrelated priming (in which the prime was an unrelated character). The same counterbalanced design was used for the noncharacters as well.

Participants. Sixty undergraduates studying at the Beijing Normal University participated in this research, with a financial reimbursement for their participation. All of them had normal or corrected-to-normal vision. The participants were randomly divided into two groups, and each one received one target list as described above.

Procedure. A "+" was presented on a computer screen for 300 ms at the beginning of a trial, followed by a blank screen for 500 ms. Then came the prime, presented in the same position as the +, for 43 ms, followed by the target. So the stimulus onset asynchrony (SOA) was 43 ms. Participants reported that they could detect something flash quickly before the target but could not identify what it was. They were asked to ignore the flash and respond by keypress as to whether the target was a real Chinese character and to do this as quickly and as accurately as possible. As soon as the participant gave a response, the target disappeared. After an interval of 2 s, the next trial started. The targets were printed in Song font, while the primes were in Kai font. All the trials were conducted with a different random order for each participant.

Results and Discussion

Table 1 contains the mean character decision times and error rates for the characters used in Experiment 1. In this experiment and all of the others reported here, for each participant, any response time (RT) that fell beyond a value that was 2 *SD*s from the mean was replaced by that value. Missing data, if there were any, were replaced by the averaged value of each condition for each person.

The main effect of frequency was significant for both RT, $F_1(1, 59) = 197.01$, $p < .001$; $F_2(1, 46) = 61.20$, $p < .001$; and error rate (ER), $F_1(1, 59) = 45.12$, $p < .001$; $F_2(1, 46) = 18.75$, $p < .001$. The main effect of priming was also significant for RT, $F_1(1, 59) = 10.3$, $p < .002$; $F_2(1, 46) = 4.87$, $p < .05$, but not for ER (both Fs < 1). The interaction effect between frequency and priming was significant in the participant analysis, although not in the item analysis, $F_1(1, 59) = 4.02$, $p < .05$; $F_2(1, 46) = 2.38$, $p = .13$. Further analysis showed that for low-frequency targets, the priming effect was significant for RT, $F_1(1, 59) = 8.27$, $p < .01$; $F_2(1, 23) = 4.52$, $p < .05$; although not for ER (both Fs < 1). There was a negative priming effect for high-frequency targets in the participant analysis of ER, $F_1(1, 59) = 5.09$, $p < .05$; $F_2(1, 23) = 3.03$, $p = .09$; but not for RT, $F_1(1, 59) = 1.82$, $p = .18$; $F_2(1, 23) = 0.99$, $p = .33$.

Thus, the preexposure of a simple character facilitates the recognition of a complex character that contains it as a radical. This is only true, however, when the complex character is of low frequency. For high-frequency complex characters, a possible inhibitory effect of the prime was observed. However, because there was a trade-off between RT and ER, it is hard to know whether this is meaningful. What is clear, though, is that there is no facilitatory effect arising from the preexposure of a simple-character prime to a high-frequency complex character that contains it as a radical. This suggests either that high-frequency characters are activated directly from the featural level without the intervention of radicals or that high-frequency targets are so quickly recognized that there is simply no room for facilitation. If the former were true, though, one might still have expected facilitation because many of the same features are activated in the prime and target.

Although the priming effect observed with low-frequency words suggests that the character version of a radical primes its radical version, it is alternatively possible that the effect arose purely from graphical similarity because the prime and target are obviously more graphically similar when they share a radical. Experiment 2 attempts to control for this.

In Experiment 2, a design similar to that used in Experiment 1 was adopted. However, only low-frequency targets were used because no priming was observed for high-frequency words in Experiment 1. In addition to the two priming conditions, there was another condition in which the prime was orthographically similar to the radical prime. For example, in the new condition, 砭 (*bian*3) was preceded by 之 (*zhi*1), which is only one stroke different to the radical prime 乏 (*fa*2). If the radical priming effect found in Experiment 1 came mainly from the orthographic similarity between prime and target, the new condition would also generate a facilitatory effect.

Table 1
Mean Reaction Times (ms) and Error Rates (%) for the Characters of Experiment 1

	Low frequency			High frequency		
Condition	Character	RT	% ER	Character	RT	% ER
Radical priming	乏-砭	590	10.0	夫-规	506	2.9
Unrelated priming	匆-砭	613	10.2	舟-规	515	1.0
Priming effect		23**	0.2		9	−1.9

Note. RT = reaction time; ER = error rate.
** $p < .01$.

Experiment 2

Method

The targets were the same low-frequency characters used in Experiment 1. However, added to the two priming conditions was another condition in which the prime was orthographically similar to the radical prime (e.g., 之–砭). This condition was matched with the other two in terms of rated semantic relatedness of the prime and target (with a mean of 1.27), as well as the lack of phonological overlap between prime and target. See Appendix B for the items.

The prime–target pairs in the three conditions were divided into three subgroups with eight pairs each, respectively, and three lists were generated with each consisting of three subgroups from different conditions. The participants were divided into three groups, and each group exposed one of the three lists, so that no individual saw the same target more than once and all targets were presented equally often with a prime of each type. The same procedure as was followed in Experiment 1 was adopted here.

Forty-two native Mandarin speakers participated in the experiment. All of them were undergraduates or postgraduates studying at the Beijing Normal University, who did not take part in Experiment 1. They were financially reimbursed for their participation. The participants were randomly divided into three groups, and each one received one target list as described above.

Results and Discussion

Table 2 contains the mean character decision times and error rates for the characters used in Experiment 2. The analysis showed that the main effect of conditions was significant for RT, $F_1(2, 82) = 13.09$, $p < .001$; $F_2(2, 46) = 5.02$, $p < .05$, although not on ER (all Fs < 1). Pairwise comparison showed that the radical facilitatory priming effect was significant for RT, $F_1(1, 41) = 9.39$, $p < .005$; $F_2(1, 23) = 3.65$, $p < .1$; thus replicating the priming effect observed in Experiment 1. It was further shown that this radical priming effect was not merely a result of graphical similarity, because similarity primes did not produce facilitation. Indeed, the effect was in the opposite direction and even significantly so in the participants analysis, $F_1(1, 41) = 4.66$, $p < .05$; $F_2(1, 23) = 2.05$, $p > .1$. A direct comparison between the effects of radical primes and similarity primes showed a significant difference for RT, $F_1(1, 41) = 27.64$, $p < .001$; $F_2(1, 23) = 11.88$, $p < .005$. There were no effects on ER.

Given that there was no obvious phonological or semantic relationship between the primes and targets in the radical priming condition, it seems that the facilitatory effect arises from the preactivation of a radical unit in the orthographic representation system, and not from low-level graphical similarity.

Table 2
Mean Reaction Times (ms) and Error Rates (%) for the Characters of Experiment 2

				Priming effect	
Condition	Character	RT	% ER	RT	% ER
Radical priming	乏-砭	678	9.8	31**	2.1
Similar priming	之-砭	738	12.8	−29*	−0.8
Unrelated priming	匆-砭	709	11.9		

Note. RT = reaction time; ER = error rate.
* $p < .05$. ** $p < .01$.

The finding of an inhibitory effect for the visually similar condition (although not significant in the item analysis) is consistent with previous observations of inhibition at 85-ms SOA when the prime and target are graphically similar (Chen & Shu, 2001; Perfetti & Tan, 1998). In these studies, the prime and target were graphically similar as a whole unit, sometimes sharing a radical and sometimes not. It seems that the inhibitory effect in those studies arose from the items that did not share a radical, given the results of the present study. In the case of the radical priming condition of both Experiments 1 and 2, if there was any inhibition arising from graphical similarity between prime and target, it must have been strongly counteracted by the preactivation of the radical unit of the target by the prime, because clear facilitation was observed.

The conclusion from the first two experiments is that the processing of a simple character overlaps in some way with the processing of a complex character that contains that simple character as a radical. According to Figure 1, this overlap arises because the initial stage of recognizing the complex character involves the activation of the unit that is used for recognition of the simple character. Thus, it is suggested that simple characters are represented at a lower level than the complex characters in the hierarchical processing system, as depicted in Figure 1. This concept can be reinforced by the finding that for the low-frequency characters, response latency is influenced by the number of radicals in the characters, even when the number of strokes is controlled (Wang & Peng, 1997). Such a result can be explained by the fact that the more radicals a character possesses, the more processing steps involved in its recognition, because complex characters are accessed via the representation of their constituent radicals, as described in Figure 1.

In this model, a position-specific radical representation mediates activation of the simple character and activation of the complex character. If this was so, then recognition of a complex character would be facilitated by the prior presentation of another complex character that shared the same radical. Moreover, such facilitation would only occur when the shared radical was in the same position. Experiment 3 tests this prediction.

Experiment 3

Facilitatory priming between two characters that share the same radical in the same position was shown by Feldman and Siok (1999a), by means of an SOA of 243 ms. They tested the left-hand radical, which provides a guide to the meaning of the character, and only found the facilitatory effect when the prime and target were semantically related. When the prime and target shared their semantic radical but were unrelated in meaning, there was actually an inhibitory effect. From this, they concluded that the function of the radical played a role in processing, which, if true, would need a modification to the form-based account depicted in Figure 1. However, Feldman and Siok (1999b) further showed that the inhibitory effect observed for the graphically similar but semantically unrelated primes and targets at a 243-ms SOA became facilitatory at a 43-ms SOA. Thus, purely form-based activation appears to occur at the early stages of processing, with higher level semantic information coming into play only at a later stage (see also Weekes, Chen, & Lin, 1998). From Feldman and Siok's (1999b) results, it is expected that facilitatory priming at a 43-ms

SOA will be observed when the prime and target share their nonsemantic (right-hand) radical (e.g., 躯, *qu*1 and 枢, *shu*1) and hence are unrelated in meaning (i.e., body and pivot, respectively).

According to the claim that radical representations are position specific (Taft & Zhu, 1997; Taft et al., 1999), radicals in different positions in the prime and target will not prime each other. For example, preexposure of 欧 (*ou*1) will not prime recognition of 枢 (*shu*1). On the other hand, if the left-hand and right-hand radicals have representations that involve the same processing, such a priming effect would be expected. Whether radicals in different positions do prime each other was tested in Experiment 3. In comparison with control (unrelated) items, the prime and the target contained the same radical, and the relative position of the radical was manipulated.

Method

Materials. Fifteen complex Chinese characters with horizontal structure were used as targets. All of them were of low frequency. For each target, there were three priming conditions: (a) same-position priming (SP), in which the prime and the target contained the same radical in the same position (e.g., 躯–枢); (b) different-position priming (DP), in which the prime and the target contained the same radical in a different position (e.g., 欧–枢); (c) unrelated priming (UP), in which the prime bore no systematic relationship to the target (e.g., 坷–枢). The three conditions were again matched on the rated semantic relatedness of prime and target (with means of 1.22, 1.12, and 1.10, respectively). Whereas the pronunciation of the prime and the pronunciation of the target were different for all three conditions (even when the two characters shared a right-hand radical), there was a somewhat greater phonological overlap for the SP and DP conditions than for the UP condition: The vowel was shared in four of the SP and three of the DP pairs, but in none of the UP pairs. All items are found in Appendix C.

The apparatus and procedure were the same as in Experiment 1. The design was the same as that of Experiment 2, with the prime–target pairs being divided into three lists, each including all three conditions. Three groups of participants received the different priming conditions within each different list.

Participants. With no overlap in materials between Experiments 1 and 3, the same 60 individuals who took part in Experiment 1 were tested in Experiment 3.

Results and Discussion

Table 3 contains the mean RTs and ERs for the characters used in Experiment 3. For RTs, there was a significant facilitatory effect for the SP condition compared with the control condition, $F_1(1, 59) = 4.40$, $p < .05$; $F_2(1, 14) = 3.53$, $p < .1$, but the DP condition generated no significant priming (both Fs < 1.41). For ERs, neither condition showed priming (all Fs < 1.52). Direct comparison between the SP and DP conditions showed no significant difference, $F_1(1, 59) = 1.2$, $p = .28$; $F_2(1, 14) = 2.74$, $p = .12$.

Table 3
Mean Reaction Times (ms) and Error Rates (%) for the Characters of Experiment 3

				Priming effect	
Priming condition	Character	RT	% ER	RT	% ER
Same position	躯-枢	606	10.6	23*	4.0
Different position	欧-枢	618	13.2	11	1.4
Unrelated	坷-枢	629	14.6		

Note. RT = reaction time; ER = error rate.
* $p < .05$.

In this experiment, it was found that the relationship of a radical's position between prime and target is important for the observation of a priming effect. When the radical is in the same position, there is a significant facilitatory priming effect, but not when it is in a different position. This suggests that the radicals with identical form but different position might be represented differently. However, this conclusion is mitigated by the lack of a significant difference between the two priming conditions. Furthermore, even though the priming effect of the DP condition was not significant, there was still a trend. It is possible, then, that facilitation arising from the shared features of differently positioned radicals does occur, but only very weakly.

In Figure 1, this facilitation could arise either from the shared activation at the feature level or from the shared simple-radical unit that precedes the activation of the relevant position-sensitive radical unit. In the DP condition, the prime shared only one radical with the target. Perhaps if the prime were to share both of its radicals with the target, albeit in different positions, a significant priming effect could be revealed because there would be more features in common between prime and target and they would activate the same two simple-radical units.

As was pointed out earlier, however, Taft et al. (1999) demonstrated that such transposable characters (e.g., 呆 and 杏) are not confused with each other despite the fact that they share so many features. It therefore seems that positional information plays an extremely important role in overriding the shared features. It may even be the case that there are inhibitory links between different radical units that are activated via the same features. If this were true, then rather than transposable characters showing an increased facilitation when used as prime and target (e.g., 呆–杏), they may show an inhibitory priming effect.

Before moving on to an examination of this possibility, consideration must be given to the possibility that radical function may have played some role in this experiment. As mentioned earlier, a left-hand radical often provides some semantic information about the character, whereas the right-hand radical provides some phonetic information. It might therefore be argued that when a radical is presented in a different position, its function is also potentially different and that any difference in responses to SP and DP items might arise from this factor. Indeed, Feldman and Siok (1997, 1999a, 1999b) claim a role for radical function in the processing of characters. However, it seems very unlikely that function played a role in the present experiment because the prime and target pairs were deliberately chosen to be low on semantic relatedness, even when sharing their left-hand radical, and low on phonological similarity, even when sharing their right-hand radical. Thus, there was little relationship in the function of the radicals used in the primes and the targets in this experiment, suggesting that any effects of shared radical are purely based on structural information.

Experiment 4

In this experiment, an examination is made of the impact of priming a character with another character that shares both its radicals but in a different position. As indicated earlier, inhibition between the representations of the same radical in different positions might well generate an inhibitory effect under these conditions.

Method

Materials. Twenty-six transposable character pairs were selected to be used as materials. Because the relative frequency between the two members of a transposable pair may be an important factor in influencing the priming effect, half of the pairs used the high-relative-frequency member as the target, and the other half of the pairs used the low-relative-frequency member as the target. Two lists were generated so that the same pair was presented with its relatively high frequency character as the target in one list and its relatively low frequency character as the target in the other. For each target, then, there were two priming conditions: transposed, in which the prime and the target were two members of a transposable pair (e.g., 呆–杏, 珀–皇) and unrelated, in which the target was the same, but the prime bore no relation to the target (e.g., 垂–杏, 桂–皇). The rated semantic relatedness of the prime and target was matched between conditions (with means of 1.36 and 1.11 for the related and unrelated high-frequency pairs and 1.19 and 1.10 for the related and unrelated low-frequency pairs). Whereas most of the pairs had no phonological overlap, it is apparent that the transposed items tended to have greater overlap than the unrelated items, with both consonantal onset and vowel being matched for three of the low-frequency, and two of the high-frequency transposed pairs but none of the unrelated pairs. Appendix D lists the items. The procedure was the same as in the other experiments, with an SOA of 43 ms.

Participants. The participants were the same 60 individuals who took part in Experiments 1 and 3, but the materials of those two experiments were entirely different than those used in Experiment 4.

Results and Discussion

Table 4 contains the mean character RTs and ERs for the characters used in Experiment 4. The main effect of frequency was significant for both RT, $F_1(1, 59) = 17.30$, $p < .001$; $F_2(1, 25) = 3.83$, $p < .1$; and ER, $F_1(1, 59) = 133.91$, $p < .001$; $F_2(1, 25) = 6.0$, $p < .05$. The main effect of priming was significant for RT, $F_1(1, 59) = 4.26$, $p < .05$; $F_2(1, 25) = 4.51$, $p < .05$; but not for ER, $F_1(1, 59) = 1.16$, $p = .29$; $F_2(1, 25) = 2.30$, $p = .14$, whereas the interaction between frequency and priming was significant for RT, $F_1(1, 59) = 2.86$, $p < .1$; $F_2(1, 25) = 7.37$, $p < .05$, but not for ER (both Fs < 1). Further analysis showed that the transposed priming effect was significant when the targets were the relatively low frequency ones, $F_1(1, 59) = 6.0$, $p < .05$; $F_2(1, 12) = 8.70$, $p < .05$, but this was inhibitory rather than facilitatory. There was no significant effect for the relatively high frequency targets (both Fs < 1). No significant effects for ERs were observed, although there was a trend in the item analysis for high-frequency targets, $F_1(1, 59) = 2.30$, $p > .1$; $F_2(1, 12) = .28$, $p > .1$, for low frequency targets, and $F_1(1, 59) = .17$, $p > .1$, $F_2(1, 12) = 4.03$, $p < .1$, for high-frequency targets.

The inhibitory effect obtained in this experiment suggests that there is competition taking place between the prime and target (as also is observed to some extent in Experiment 2 with visually similar primes and target radicals). In particular, when two different units that have considerable physical similarity are activated, there appears to be competition between them.

One way to consider this is to suggest that there are inhibitory links hardwired between units that are activated via similar features. One possibility is that there are inhibitory links between the position-sensitive radical representations that are activated via the same simple-character unit (*radical competition*). Having both radicals of a character inhibited in this way is enough to counteract the potential facilitation arising from the preactivation of the simple-character representation used in the recognition of each radical, so that inhibition occurs. When only one radical has been inhibited, the counteracting effect only goes as far as neutralizing any facilitation (as observed in the DP condition of Experiment 3). However, this claim does not account very well for the inhibitory effect observed in Experiment 4. For example, if radical competition occurred, both high- and low-frequency targets would be affected equally by the preexposure of the transposable prime, but the result showed that the inhibitory effect was restricted to low-frequency targets only. Of course, it can be suggested that the character representation for complex high-frequency targets requires minimal lower level information to be activated to recognition threshold and, therefore, that the impact of inhibition at these lower levels has negligible impact. However, there is also some difficulty in accounting for the facilitatory trend in the different-position condition of Experiment 3, because there would be an inhibitory effect by this claim.

Another possibility is that the inhibition observed in Experiment 4 arises from the compound-character-representation level rather than radical-representation level (*character competition*). That is, there are inhibitory links between the compound-character representations that partly share the same features (or radicals) with each other. The more similar the characters are, the stronger the inhibitory links are. In this case, the asymmetrical inhibitory effect between different-frequency transposable pairs can be accounted for by the different access time to different-frequency characters. Because the SOA is so short (43 ms), the character-level representation for a low-frequency prime is not fully accessed, therefore exerting little effect on the relatively high frequency target. Suc-

Table 4
Mean Reaction Times (ms) and Error Rates (%) for the Characters of Experiment 4

	Relatively low frequency target			Relatively high frequency target		
Condition	Character	RT	% ER	Character	RT	% ER
Transposed-radical priming	呆-杏	620	24.0	珀-皇	574	2.9
Unrelated priming	垂-杏	591	25.3	桂-皇	576	5.4
Priming effect		−29**	1.3		2	2.5

Note. RT = reaction time; ER = error rate.
** $p < .01$.

cessful activation of the character representation for high-frequency primes means that low-frequency targets are more affected. By this account, the facilitatory effect found in Experiment 3 can be explained by the activation of the low-level radical representation shared by the primes and targets, perhaps as along with the simple-character version of the radical. When the radical (as well as the simple character) is activated, it will facilitate the activation of all words that include it. The ultimate priming effects are determined by the combination of the inhibitory effect from other compound-character units at the same level and the facilitatory effect from the radical units as well as the simple-character version at a lower level (and maybe a facilitatory effect from the feature level). Because the similarity between the targets and the primes in Experiment 3, which shared one identical radical, is much less than that in Experiment 4, which shared two identical radicals, the inhibitory effect in the former case will be less than in the latter case and, therefore, would not be as strong as the facilitatory effect from the lower level units. So a facilitatory effect results.

In fact, inhibitory links cannot exist at the character level only. This is because Taft et al. (1999) observed no confusion between a nonsense character and a real character that was formed by transposing the radicals of that nonsense character. If the lack of confusion arose through inhibitory mechanisms, these would have to be at the level of the radical rather than the character because nonsense characters have no representation. What is possible, though, is that there are inhibitory links both between radical units and between character units.

Finally, note that the results obtained in this experiment cannot be explained in terms of any greater phonological overlap between prime and target under the transposed conditions than the unrelated conditions. Although there was a tendency for such an imbalance in phonological overlap, it is hard to see how greater phonological similarity could lead to inhibition as opposed to facilitation. Furthermore, there was little difference between the high- and low-frequency transposed pairs in terms of phonological similarity, yet there was an interaction between frequency and the amount of priming.

General Discussion

In this research, the representation of Chinese radicals that can also be used as characters was investigated by means of a priming procedure. It was found that the preexposure of a character that is also a constituent radical of another character facilitates the recognition of the latter (Experiment 1) and that this effect does not arise from the formal similarity between the primes and targets (Experiment 2). It was also found that positional information is represented in lexical memory because primes with a radical in the same position as the target have an impact on the processing of that target, whereas those with a radical in a different position do not (Experiment 3). This finding was reinforced by the results of Experiment 4, in which there was no facilitation when the prime and the target shared the same two radicals but in different positions. The fact that it was actually an inhibitory effect was explained in terms of there being inhibitory links between units that are activated via shared features, with the complex-character units being the most likely locus.

The four important implications for models of the Chinese orthographic processing system are that (a) simple characters and complex characters are represented at a different level, with the former being lower than the latter; (b) the representation of a radical as a radical and the representation of that radical as a character are linked; (c) there are different radical representations for the radical when it occurs in different positions; and (d) there is an inhibition device existing within the character-recognition mechanism (with inhibitory links between either the character units or the radical units) that is activated via shared features. This is concluded from the findings that activation of a simple character facilitates activation of the complex characters that include a radical version of the former (Experiments 1 and 2) and that activation of a radical within a complex character facilitates activation of that same radical only if it is found in the same position within the other character (Experiments 3 and 4).

The second and the third implications above can be illustrated in the model presented in Figure 1. For example, it incorporates position-sensitive radical representations, and furthermore, these are activated via their simple-character version. The first and the fourth implications, however, are not specifically incorporated into that model. Figure 2 extends the model by adding some new features.

As seen in Figure 2, simple and complex characters are represented at a different level in the processing system, and the radical units mediate them. Furthermore, there are inhibitory links between the complex-character units, which are modulated by the similarity between the characters and (or) radicals. In this framework, when the complex character 枢 is presented, there is first activation of the simple-character version and the position-specific radical units. These then send their activation to the relevant complex-character unit with any units for similar characters, such as 躯 and 欧, being inhibited. The results of the present experiments can be explained by this model (i.e., Figure 2). The presentation of a simple character (e.g., 乏) leads to activation of its corresponding simple unit, so that the recognition of the target 砭 is facilitated by the preactivation of that unit, thus handling the results of Experiments 1 and 2. The coeffects of both inhibition

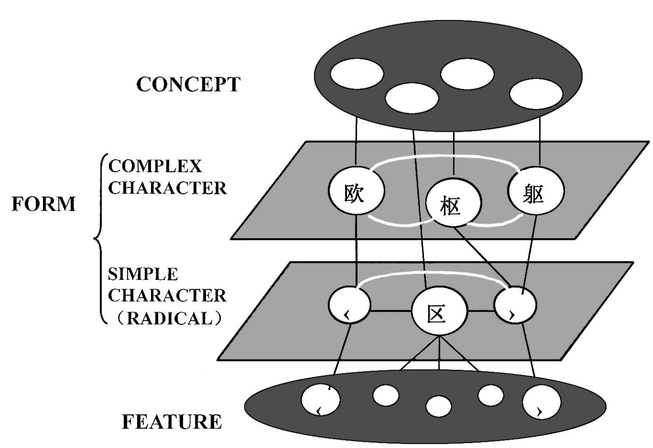

Figure 2. The extended model that radical representations are activated via the simple-character representation.

between the complex characters and the facilitation from the radical units determines the final priming effects in Experiments 3 and 4, thus handling the results of these two experiments.

The facilitatory trend for the DP condition in Experiment 3 can be accounted for by the same simple-character unit being activated by both the prime and target. However, because the radical units are different, the facilitatory effect is limited and cannot overwhelm the inhibitory effect arising from the complex units, as can the items in the SP condition. When the prime and the target share both radicals but in a different position, the facilitatory effect is still limited, but now the inhibitory effects are very strong owing to the much more visual similarity between primes and targets leading to an overall inhibitory outcome. Of course, this explanation strongly relies on the hypothesis that the inhibitory effect increases much more rapidly than the facilitatory effect from the common feature when more radicals overlap the primes and the targets.

Furthermore, the results reported by Taft et al. (1999) are in keeping with the model depicted in Figure 2. For example, Taft et al. (2000) found that position-insensitive radical frequency had an influence on the recognition of complex characters that contained that radical and that this could only happen if the complex character was activated via a unit that was used for all positioned radical units. Such is the case in Figure 2, where the simple-character version of the radical mediates activation of all position-sensitive radical units.

Note that the recognition of characters (like 积) that include a compound radical (i.e., 只 composed of the subradicals 口 and 八) adds a complexity to the model that has not been addressed. A further level may need to be added to the hierarchy in such cases because the compound radical must be activated by its subradicals taking positional information into account. Alternatively, though, it may be that the compound radical has no representation independent of its component subradicals (see Taft & Zhu, 1997), in which case the positional specificity of the radicals would have to be more complex than has been considered here. Clearly, the representation and processing of compound radicals need further research.

Finally, something needs to be said about radicals that are not free-standing characters. For example, the right-hand radical 卩 in 叩 is not a character in its own right and, therefore, one can ask how the radical representation for 卩 can be activated if activation is mediated through a simple-character version of the radical. This concern was addressed by Taft et al. (2000), who argued that an orthographic representation exists for the simple version of such radicals (e.g., 卩), but unlike existing characters, there are simply no links from this representation to semantics or to pronunciation. In support of this position, Taft et al. demonstrated considerable difficulty in rejecting noncharacters such as 卩 in a character-judgment task relative to parts of real characters that are not radicals (e.g., the 与 of 写). The model depicted in Figure 2 explicitly focuses on the relationship between a radical and its use as a free-standing character. As a result, all of the radicals used in the current studies could stand alone as real characters, so whether the model can be successfully extended to those radicals that cannot serve as real characters still needs substantiation.

In conclusion, the present experiments demonstrate through priming effects or a lack thereof, that complex-character recognition takes place via an orthographic processing system whereby sublexical radicals are represented in association with positional information. The activation of such a radical representation is mediated via the character version of that radical. In addition, when two characters are competing with each other, activation in the inappropriate competitor unit needs to be inhibited by the appropriate competitor. The fiercer the competition, the greater the inhibition required.

References

Chen, H.-C., & Shu, H. (2001). Lexical activation during the recognition of Chinese characters: Evidence against early phonological activation. *Psychonomic Bulletin & Review, 8,* 511–518.

Ding, G., Taft, M., & Zhu, X. (2000). The representation of radicals that can be used as characters. *Acta Psychologica Sinica, 32*(Suppl), 21–26.

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

Feldman, L. B., & Siok, W. W. T. (1999a). Semantic radicals contribute to the visual identification of Chinese characters. *Journal of Memory and Language, 40,* 559–576.

Feldman, L. B., & Siok, W. W. T. (1999b). Semantic radicals in phonetic compounds: Implications for visual character recognition in Chinese. In J. Wang, A. W. Inhoff, & H.-C. Chen (Eds.), *Reading Chinese script* (pp. 19–35). Mahwah, NJ: Erlbaum.

Han, B. (1998). The frequency effect of character constituents in the recognition of Chinese character. *Psychological Science China, 21,* 193–195.

Lai, C., & Huang, J. T. (1988). Component migration in Chinese characters: Effects of priming and context on illusory conjunction. In I. M. Liu, H.-C. Chen, & M. J. Chen (Eds.), *Cognitive aspects of Chinese language* (Vol 1, pp. 57–67). Hong Kong: Asian Research Service.

Li, H., & Chen, H. C. (1999). Radical processing in Chinese character recognition: Evidence from illusory conjunction. *Psychological Science China, 22,* 213–217.

Modern Chinese frequency dictionary. (1985). Beijing, People's Republic of China: Beijing Language Institute Press.

Peng, D., Yang, H., & Chen, Y. (1994). Consistency and phonetic-independency effects in naming tasks of Chinese phonograms. In Q. Jing, H. Zhang, & D. Peng (Eds.), *Information processing of the Chinese language* (pp. 26–41). Beijing, People's Republic of China: Beijing Normal University Press.

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

Taft, M. (in press). Processing of characters by native Chinese readers. In P. Li (Ed.), *Handbook of East Asian psycholinguistics. Vol. 1: Chinese.* Cambridge, England: Cambridge University Press.

Taft, M., & Chen, H. C. (1992). Judging homophony in Chinese: The influence of tones. In H. C. Chen, & O. Tzeng (Eds.), *Language processing in Chinese* (151–172). Amsterdam: North-Holland/Elsevier.

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

Taft, M., Zhu, X., & Ding, G. (2000). The relationship between character and radical representation in Chinese. *Acta Psychologica Sinica, 32*(Suppl.), 3–12

Taft, M., Zhu, X., & Peng, D. (1999). Positional specificity of radicals in Chinese character recognition. *Journal of Memory and Language, 40,* 498–519.

Wang, C., & Peng, D. (1997). Basic processing unit of Chinese character recognition: Evidence from stroke number effect and radical number effect. *Acta Psychologica Sinica,* 29, 8–16.

Weekes, B. S., Chen, M. J., & Lin, Y. B. (1998). Different effects of phonological priming on Chinese character recognition. *Reading and Writing, 10,* 201–222.

Zhang, S., Perfetti, C. A., & Yang, H. (1999). Whole word, frequency-general phonology in semantic processing of Chinese character. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 25,* 858–875.

Zhou, X., & Marslen-Wilson, W. (1999). The nature of sublexical processing in reading Chinese characters. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 25,* 819–837.

Appendix A

Materials Used in Experiment 1

Low frequency targets				High frequency targets			
Radical priming		Unrelated priming		Radical priming		Unrelated priming	
Primes	Targets	Primes	Targets	Primes	Targets	Primes	Targets
女	妍	火	妍	夫	规	乡	规
角	斛	弟	斛	又	欢	工	欢
王	琉	午	琉	禾	秋	舟	秋
虫	虬	安	虬	句	够	古	够
九	旭	万	旭	日	时	斗	时
马	驿	片	驿	弓	强	冈	强
干	轩	山	轩	子	好	么	好
员	殒	表	殒	豆	短	毕	短
乐	铄	充	铄	己	配	反	配
页	颀	呈	颀	只	积	分	积
乏	砭	匆	砭	斤	析	户	析
台	殆	父	殆	也	地	为	地
上	忐	飞	忐	西	要	东	要
大	夯	个	夯	白	皇	并	皇
九	旮	万	旮	此	些	场	些
水	沓	见	沓	田	思	充	思
非	韭	兵	韭	丘	兵	甘	兵
亚	晋	尔	晋	八	分	土	分
月	肾	内	肾	贝	贫	丙	贫
口	吝	山	吝	十	早	义	早
手	挛	本	挛	心	忽	方	忽
几	亢	之	亢	可	奇	会	奇
有	肴	来	肴	犬	哭	尼	哭
云	昙	矛	昙	寸	寺	巾	寺

Appendix B

Materials Used in Experiment 2

Radical priming		Similar priming		Unrelated priming	
Primes	Targets	Primes	Targets	Primes	Targets
女	妍	文	妍	火	妍
角	斛	用	斛	弟	斛
王	琉	干	琉	午	琉
虫	虬	中	虬	安	虬
九	旭	几	旭	万	旭
马	驿	乌	驿	片	驿
干	轩	于	轩	山	轩
员	殒	页	殒	表	殒
乐	铄	东	铄	充	铄
页	颀	员	颀	呈	颀
乏	砭	之	砭	匆	砭
台	殆	合	殆	父	殆
上	忐	止	忐	飞	忐
大	夯	天	夯	个	夯
九	旮	几	旮	万	旮
水	沓	木	沓	见	沓
非	韭	丰	韭	兵	韭
亚	晋	业	晋	尔	晋
月	肾	目	肾	内	肾
口	吝	日	吝	山	吝
手	孪	于	孪	本	孪
几	亢	九	亢	之	亢
有	肴	目	肴	来	肴
云	昙	去	昙	矛	昙

Appendix C

Materials Used in Experiment 3

Same-position priming		Different-position priming		Unrelated priming	
Primes	Targets	Primes	Targets	Primes	Targets
贱	贬	坝	贬	狙	贬
辟	辞	辣	辞	辐	辞
皖	皓	柏	皓	轨	皓
俗	豁	欲	豁	埂	豁
咕	桔	颉	桔	诧	桔
靖	蜻	静	蜻	旗	蜻
枢	躯	欧	躯	坷	躯
竭	飒	垃	飒	焕	飒
浃	陕	烦	陕	谗	陕
埧	椹	勘	椹	烽	椹
髀	骰	猬	骰	魏	骰
韵	歆	黯	歆	檀	歆
趼	妍	邢	妍	畅	妍
权	奴	欢	奴	诀	奴
耻	址	歧	址	玲	址

Appendix D

Materials Used in Experiment 4

Relatively low-frequency targets				Relatively high-frequency targets			
Transposed priming		Unrelated priming		Transposed priming		Unrelated priming	
Primes	Targets	Primes	Targets	Primes	Targets	Primes	Targets
吧	邑	法	邑	帛	帕	龀	帕
呆	杏	垂	杏	柑	某	饵	某
防	邡	创	邡	吟	含	邦	含
岂	屺	并	屺	珀	皇	桂	皇
吞	吴	齿	吴	椎	集	谍	集
音	昱	穿	昱	另	加	负	加
呗	员	杠	员	垠	垦	栋	垦
叨	召	扒	召	栖	栗	祷	栗
垩	垭	忿	垭	垅	垄	殆	垄
杳	杲	吝	杲	冕	晚	釜	晚
桉	案	敝	案	售	唯	崇	唯
部	陪	理	陪	粞	粟	剐	粟
贺	勋	宾	勋	翊	翌	陛	翌

Received February 16, 2003
Revision received July 9, 2003
Accepted July 31, 2003 ■