Journal of Experimental Psychology:
Learning, Memory, and Cognition
1997, Vol. 23, No. 3, 761–775

0278-7393/97/$3.00

Submorphemic Processing in Reading Chinese

Marcus Taft and Xiaoping Zhu
University of New South Wales

Three experiments are reported here to address the question of whether submorphemic information is involved in the recognition of Chinese characters. A character decision task was used in which frequency characteristics of the radicals within a character and radical status of the components within a noncharacter were manipulated. The frequency of the right-hand radical affected responses to 2-radical characters, whereas the radical status of both left and right components affected noncharacter responses. Furthermore, the impact of radical frequency was shown to be sensitive to radical position. For 3-radical characters, it appeared that the frequency of a compound radical (composed of 2 subradicals) had no effect on responses, whereas the frequency of the subradicals did. It is concluded that all simple radicals are independently activated in the process of character recognition. Compound radicals are not activated in this way despite their common occurrence. The results are considered within a multilevel interactive-activation framework incorporating position sensitivity.

In recent years, there has been considerable interest in the question of which orthographic components of a word are involved in the process of visually recognizing that word. Examples of components that have been examined in alphabetic scripts are morphemes (e.g., Henderson, 1985; Taft, 1985) and submorphemic units like bodies or rimes (i.e., that part of a monosyllabic morpheme that does not include the initial consonants, like the *EAM* of *STREAM;* for example, Bowey, 1990; Kay & Bishop, 1987; Taft, 1992; Treiman & Chafetz, 1987). In the study reported in this article we aimed to extend this research to a completely different orthography, namely, Chinese. The focus of the research was on submorphemic units, which in Chinese are physically distinguished within a morpheme (i.e., within a character).

Chinese Characters and Words

The bulk of research into the issue of sublexical processing has been carried out by using an alphabetic writing system such as English. However, the question can be raised as to whether theories based on studies using an alphabetic system are generalizable to other orthographic systems, the most dramatically different being Chinese.

Chinese words are composed of one or more characters. For example, 寸 (cùn) is a one-character word meaning *inch,* whereas 时候 (shíhòu) is a two-character word meaning *time.* According to the *Modern Chinese Frequency Dictionary* (1985), two-character words make up 74% of all words, and one-character words make up only 12%—though the vast majority of characters (82%) can be used as single-character words. The majority of Chinese characters form single morphemes (Chao, 1968; Hoosain, 1992; Zhang & Peng, 1992) because they mostly have a meaning in their own right even though this might not always be obvious from the words in which they occur. For example, the 候 (hòu) of 时候 (shíhòu) is used on its own to mean *wait* but occurs in a number of different words that are related to *waiting,* though not always transparently so (e.g., 候诊 = *wait to see the doctor* and 候补 = *be a candidate*).

In 96% of cases (*Dictionary of Chinese Character Information,* 1988), the characters themselves are composed of subunits that constitute particular groupings of strokes, usually placed either side by side (a horizontal character, for example, 时) or one above the other (a vertical character, for example, 昔). Take as an example the character 时, which has two distinct components, 日 and 寸, both of which can be characters in their own right. We call these components *radicals.* The left-hand radical is composed of four strokes (丨, 𠃍, 一, and 一), and the right-hand radical three (一, 亅, and 丶). A radical is defined in terms of the contiguity of its strokes on the one hand, and its recurrence in different characters on the other. For example, the two strokes making up the 丁 of 寸 are contiguous and therefore create a single unit, but because this unit is only ever found with the third stroke, 丶, the three strokes together form a single radical.

There are actually two different Chinese terms that can be translated into the word *radical,* making this word potentially confusing. First, there are the approximately 214 units, called *bùshǒu* (部首), that are used to look up a character in a dictionary. For horizontally structured characters these are often found on the left-hand side. This sense of the term *radical* has been used in a number of previous studies (e.g., Fang & Wu, 1989; Huang & Wang, 1992). Second, though there is the larger set of components, called *bùjiàn* (部件), that includes all components no matter where in the character they appear. According to the *Chinese Radical Position*

Marcus Taft and Xiaoping Zhu, School of Psychology, University of New South Wales, Sydney, New South Wales, Australia.

We thank Jishan Huang for her assistance in designing the items for Experiment 1. This research was supported by a grant from the Australian Research Council.

Correspondence concerning this article should be addressed to Marcus Taft, School of Psychology, University of New South Wales, Sydney, New South Wales 2052, Australia. Electronic mail may be sent via Internet to m.taft@unsw.edu.au.

Frequency Dictionary (1984), there are 541 such radicals. It is this general bùjiàn meaning of radical that is adopted here because the right-hand component is examined as well as the left-hand one and because the radical norms used to develop the items (*Chinese Radical Position Frequency Dictionary,* 1984) are presented in terms of bùjiàn.[1]

Many radicals can be used as characters in their own right with their own pronunciation and meaning, but there are 238 radicals listed in the *Chinese Radical Position Frequency Dictionary* (1984) that are not actual characters, having no pronunciation and not always conveying any meaning. For example, in 候, neither the left part 亻 nor the right part 矦 is a real character. Actually, the right part of 候 is itself composed of two radicals, namely, ⺈ and 矢 (in which only the latter can be used as an isolated character). Thus we can say that characters can include compound radicals that are composed of two (or more) simple radicals. Compound radicals, like simple radicals, may or may not be characters in their own right.

Most radicals and compound radicals have their own fixed or typical position in a character. For example, the radicals 忄, 刂, 艹, and 灬 always occur in the left, right, top, and bottom positions, respectively. About 66% of all simple radicals (calculated from the *Chinese Radical Position Frequency Dictionary,* 1984) have this positional property. There are no statistics available for compound radicals, but they can also be position specific. It should be noted that although some radicals can occur in different positions in a character, it is also commonly the case that they will adopt a different shape depending on their position. For example, 牜 and 牛 are variations of the same radical, with the former only occurring on the left side of a character (e.g., 牺) and the latter only on the right side (e.g., 件). There are other radicals that change their form completely when in different positions. For example, 水 is the character for *water* and takes the same form when used as a right-hand radical (as in 冰) but is transformed into 氵 when used on the left (as in 河). In considering orthographic processing, such markedly different forms will be taken to be different radicals, whereas variations that only involve a change to one stroke will be considered to be the same radical.

A further important characteristic of radicals is their semantic and phonetic cuing functions. A radical often provides a guide to the meaning or pronunciation of the character in which it occurs. For horizontally structured characters (the most common structure), the semantic cuing function is usually provided by the left radical (the *semantic radical,* which is almost always a bùshǒu), while the phonetic cuing function is provided by the right radical (the phonetic radical). For example, 叮 is pronounced "dīng" and means *bite,* while its right-hand radical 丁 is also pronounced "dīng" and its left-hand radical refers to *mouth*-related concepts. However, the relationship between characters and their radicals or compound radicals is not always so transparent. The relationship between the meaning of a semantic radical and the meaning of the character can be quite obscure (e.g., 法 means *law* but 氵 refers to *water*), whereas phonetic radicals have identical pronunciations to the characters that contain them in only 26% of cases (Fan, Gao, & Ao, 1984), often varying in their tone, vowel, or initial consonant.

We now turn to the literature on the lexical processing of Chinese characters.

Research on Chinese Character Processing

Each Chinese character occupies a constant, square-shaped area and is separated from other characters in text by a space. Different characters might vary in number of strokes, number of radicals, and manner of construction but not in their overall character size. The fact that the physical boundaries of all characters are reliably the same regardless of their complexity might lead one to suppose that holistic processing would be the most efficient approach to the recognition of Chinese characters (see H. C. Chen, 1992); such a view was supported by M. J. Chen and Yung (1989) and Yu, Feng, Cao, and Li (1990).

M. J. Chen and Yung (1989) based their support for holistic processing on their finding that stroke number was irrelevant in performing a lexical-decision task, no matter how disoriented the stimulus characters were. However, an effect of stroke number has consistently been found in many other studies using different paradigms—in patterns of eye fixation in reading (Just, Carpenter, & Wu, 1983, cited in Just & Carpenter, 1987), in a character–digit coding task (Wen, 1990), in a lexical-decision task (Tan & Peng, 1989, 1990), in a naming task (Leong, Cheng, & Mulcahy, 1987; Yu & Cao, 1992b; Zhu, 1991; however, see Guo, Peng, & Zhang, 1985), and in a tachistoscopic identification task (Cao & Shen, 1963; Cheng, 1981; Cheng & Fu, 1986; Yeh & Liu, 1972). These findings indicated that component processing occurs, at least in relation to strokes, before the character-level representation is activated.

In relation to the processing of radical components, Yu et al. (1990) claimed that the fact that Chinese characters with horizontally structured radicals were not named any faster than those with vertically structured radicals was indicative of holistic processing. However, in a model in which radicals are activated whenever (and wherever) they occur, it is not obvious why the nature of the radical structure should have influenced naming responses.

Yu et al. (1990) further supported their position, though, by demonstrating that conflict between the pronunciation of a character and the pronunciation of its phonetic radical had no impact on naming responses to the character (i.e., there was no regularity effect). This suggested that characteristics of the radical were not being taken into account when the character was being processed. Others, however, have observed significant regularity effects in Chinese (e.g., Fang,

[1] Because of the different ways in which the term *radical* has been used, it might seem preferable to use a different term when referring to a bùjiàn. The general term *component* might seem to be the best alternative but was not adopted here because not all components of a character form a bùjiàn. Sometimes they are simply strokes (e.g., 𡿨) or else they might only ever appear in the one combination (e.g., the [illegible] of 非).

Horng, & Tzeng, 1986; Hue, 1992; Seidenberg, 1985; Shu, 1986; Wu, Chou, & Liu, 1994; Zhu, 1988).

The fact that there is contradiction in the research findings both in relation to complexity (stroke number) and regularity can be explained by the fact that both effects appear to interact with character frequency. That is, the effects may not be observed when a character is of high frequency, and Chen and Yung (1989) and Yu et al. (1990) probably used sufficiently high-frequency characters for the effects to disappear. Zhu and Shen (1990) found such an interaction for the complexity effect, and Hue (1992), Seidenberg (1985), Shu (1986), and Zhu (1988) found it for the regularity effect. Such interactions have been explained in terms of race models (e.g., Huang & Wang, 1992; Yu & Cao, 1992a, 1992b), whereby the componential and holistic mechanisms compete with each other for a limited attentional capacity, the winner being governed by frequency. The holistic pathway beats the componential pathway when the character is of high frequency and vice versa when the character is of low frequency, and, therefore, no effects of subcharacter units are observed for high-frequency characters. Huang and Wang suggested that the race model is also able to explain how certain other phenomena observed in Chinese character recognition interact with character frequency, such as perceptual separability (Huang, 1984), the character inferiority effect (H. C. Chen, 1986), and illusory conjunctions (Fang & Wu, 1989).

Race models, however, suffer from a difficulty in justifying the existence of the different levels of processing that compete with each other. What would be the purpose, for example, of processing the name of a radical when a character is to be named? It is only going to provide the correct pronunciation for about one quarter of all characters (Fan et al., 1984) and even when it does, one cannot know this unless it is confirmed by checking with the character pronunciation, in which case there was no point in determining the pronunciation of the radical in the first place. Instead, it seems that the radical is processed as an integral stage of the processing of the character, and this is what happens within an interactive–activation framework (e.g., McClelland, 1987; McClelland & Rumelhart, 1981; Rumelhart & McClelland, 1982; Taft, 1994).

In this model, the lexicon is seen as being made up of different levels of units or nodes hierarchically corresponding to features, sublexical units, and lexical units (i.e., words). Between any particular two units there is an excitatory connection if they are at different levels or an inhibitory connection if they are at the same level. When a stimulus is presented, the units concerned at the feature level will be activated first, and then activation passes up from these feature units to word units via the sublexical units until the amount of activation in one word unit reaches some criterial level. Therefore, in the interactive–activation model, word-level processing is affected by the properties of the components of the word.

If we adopt such an interactive–activation framework, then, what are the potential levels of processing in Chinese? At the lowest level there might be features (e.g., horizontal line, right angle, or dot) and then strokes (e.g., ¯, ㇄, or ˋ), though features and strokes might be combined in the one level. At the next level, the units might be the radicals, either separated into independent modules depending on position (i.e., left–right, up–down, and so forth) or treated as a single set. Above the radicals in the hierarchy come the characters and then, finally, the multicharacter words. Such a hierarchical set-up is depicted in Figure 1 (see also Taft & Zhu, 1994).[2]

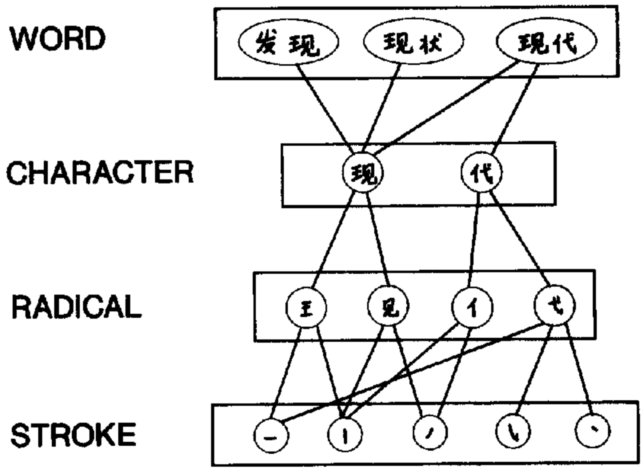

Figure 1. A multilevel interactive–activation framework for the processing of Chinese words.

The focus of the present article is whether the radical level exists as a psychological entity. As mentioned earlier, approximately 96% of Chinese characters are composed of two or more radicals, each of which can occur in more than one character, and, for this reason, it is reasonable to suppose that radicals are represented as sublexical units. There is some evidence to suggest that this is the case.

One set of findings that is consistent with the idea that radicals exist as units of processing comes from research into illusory conjunctions during Chinese character perception (Fang & Wu, 1989; Lai & Huang, 1988). Participants are asked to judge whether a particular probe character is included amongst a set of tachistoscopically presented test characters. An illusory conjunction occurs when the left radical of one test character and the right radical of another can be put together to create the probe character. The existence of such illusory conjunctions points to the importance of the radical as a unit of processing. However, it should also be said that Fang and Wu demonstrated the same likelihood of illusion when it was a stroke rather than a

[2] The interactive–activation model is also able to explain interactions between component-level effects and character frequency. Very little processing is required at the subcharacter levels for a high-frequency character to be recognized. That is, a frequently used character-level unit needs little activation to be passed up to it from the lower levels to reach recognition threshold. For this reason, characteristics of lower level units will have minimal effect on the recognition of high-frequency characters compared with that of low-frequency characters that require more detailed processing at the lower levels.

radical that migrated from one character to another. Although this suggests that strokes also form units of processing, it might be possible to explain the effect obtained with radicals purely in terms of a stroke level (or even feature level) of representation (where several strokes migrate at the same time).

The priming paradigm has also been used to garner evidence for the importance of the radical in lexical processing. In a series of studies reported by Flores d'Arcais (1992) and Flores d'Arcais, Saito, and Kawakami (1995) in which both Chinese and Japanese Kanji characters were used, naming responses to a character were faster when either its left or its right radical was briefly presented before the presentation of the whole character, depending on the preexposure period and the function of the radical within the character. The amount of priming was measured in relation to a baseline condition in which a nonradical fragment was preexposed. Because such nonradical fragments included incomplete strokes, though, it might have been possible again to explain the priming effect in terms of stroke-level processing only, where priming occurs with preexposure of intact strokes. However, the fact that the function of the radical (semantic or phonetic) influenced the amount of priming suggests otherwise. For example, in one of the studies reported by Flores d'Arcais which used Chinese characters, the consistency between the semantic function of the left radical and that of the whole character had an effect at longer preexposure periods of the left radical. Because facilitation was observed at short preexposure periods, even for characters in which semantic radicals gave no guide to the meaning of the character, there seems to be a purely graphemic effect at the early stages of processing (which could be happening at the stroke level rather than at the radical level), but the effect of semantic function at long preexposure periods shows that the radical level is at least involved at some point. Peng and Tan (1990) also observed what appeared to be a graphemic priming effect, though it could be taken to be a radical priming effect because the graphemically similar prime and target characters had at least one radical in common.

The above evidence indicates that information about radicals may be represented in the lexicon in some way and seems to play a role in character activation. However, it could be argued that the effects observed by using the illusory conjunction paradigm (Fang & Wu, 1989; Lai & Huang, 1988) and the priming paradigm (Flores d'Arcais, 1992; Flores d'Arcais et al., 1995; Peng & Tan, 1990) do not arise from the actual on-line processing of the character. Both paradigms could involve some sort of guessing strategy, either by using partial information extracted from the tachistoscopic display or by using information in the prime to anticipate the target. In the research reported in this article we made use of a different paradigm to examine this issue, one that has been used elsewhere in a somewhat different context.

To make a decision as to whether a stimulus belongs to category *X*, a reader must process that stimulus at the *X* level of analysis. If this *X*/non-*X* judgment is affected by characteristics of the stimulus at a level lower than *X*, then one can assume that that lower level was passed through to reach the *X* level. For example, the judgment of whether a stimulus is a word appears to be affected by manipulations of morpheme frequency (e.g., Bradley, 1979; Burani, Salmaso, & Caramazza, 1984; Colé, Beauvillain, & Segui, 1989; Taft, 1979; Taft, Huang, & Zhu, 1994; Zhang & Peng, 1992). This suggests that the word level of lexical representation is attained via processing at the lower morpheme level. In terms of the interactive–activation model, one can say that activation in units at the morpheme level is passed up to appropriate units at the word level.

To look at the influence of radicals in character recognition, the same logic can be followed. In particular, one can use a task that requires a character/noncharacter decision to be made, manipulating the frequency of the radicals contained within the characters. Such a character decision task was adopted in our experiments.

Experiment 1

If radicals form units of representation that are activated when a character is to be recognized, then the frequency of those radicals in the language should have an impact on character recognition times. For example, if the radicals 月 and 土 are activated more rapidly than the radicals 冫 and 水 because they are more common in the language (i.e., of higher frequency), then the character 肚 should be activated more rapidly than the character 冰, even though these two characters are of equal frequency in the language.

Alternatively, it may be only one of the radicals that plays a role in the recognition of the character. For example, it is quite possible that the internal units of a character are analyzed from left to right (i.e., in the same order that they are produced when written) and that the left radical is therefore encountered before the right. It might therefore be the case that the left radical is used to activate a set of candidate characters, with the right radical only being used to make a top-down selection from amongst this set. If so, it will only be the frequency of the left radical that influences character decision times and not the frequency of the right.

In Experiment 1 we examined this issue. Horizontally structured characters were presented in a character decision task for discrimination from horizontally structured noncharacters, and the frequency of their left and right radicals was factorially manipulated while character frequency was held constant.

As has been pointed out earlier, the position of a radical in a Chinese character tends to be confounded with its function: The left radical tends to provide semantic information, whereas the right radical tends to provide phonetic information. In the manipulations of radical frequency that follow, the description is given in terms of positional information rather than in terms of functional information (i.e., left versus right rather than semantic versus phonetic) in that this is the more neutral approach: A left radical is always on the left but does not always provide a semantic cue, whereas the right radical is always on the right but does not always provide a phonetic cue. Thus, we can be certain about the position of a radical but not about its function. Whether any effects of position that are observed in the experiments can alternatively be described as being effects of function is something that is considered later.

Experiment 1 also included a manipulation of the internal structure of the noncharacters. Here, however, we were not looking at radical frequency but, rather, at the radical status of the right part or left part; each part is either a real radical or an invented radical. By using logic similar to that used by Taft and Forster (1976) in relation to English compound nonwords, the failure of a nonexistent radical to activate any representation in lexical memory will allow participants to classify the stimulus rapidly as a noncharacter, but only if an attempt is made to recognize the stimulus via its individual parts. By comparing noncharacters that have nonexistent radicals on their left side with those that have nonexistent radicals on their right side, one can see which side of the character is more important in the classification process.

Method

Participants. Participants in the experiment were 20 postgraduate students at the University of New South Wales and were native Chinese (Mandarin) speakers from the People's Republic of China.

Materials. Only horizontally structured characters consisting of two radicals were used in the experiment. There were 52 characters that made up four groups of 13 items. The groups were differentiated according to the frequencies of their left and right radicals according to the *Chinese Radical Position Frequency Dictionary* (1984), creating four conditions: high-frequency left and right radicals (high–high), high-frequency left radical and low-frequency right radical (high–low), low-frequency left radical and high-frequency right radical (low–high), and low-frequency left and right radicals (low–low). Radical frequency is given in the *Dictionary* in terms of the number of characters containing that radical (i.e., type frequency). For example, the radicals 月, 土, 木, and 王 are all of high frequency, whereas the radicals 斤, 犭, 冫, and 水 are all of low frequency, therefore, 肚 is a high–high character, 析 is high–low, 狂 is low–high, and 冰 is low–low. The average number of characters in which the radicals appear was 296 for the left side of the high–high items and 293 for their right side, 351 for the left side of the high–low items and 21 for their right, 69 and 280 for the low–high items, and 51 and 34 for the low–low items. In all characters, the left-hand radical was the bùshǒu.

The four conditions were matched in quadruplets on character frequency according to the *Modern Chinese Frequency Dictionary* (1985), in which character frequency is based on the total number of times the character occurs in the language, regardless of whether it occurs on its own or in combination with another character (i.e., token frequency). The mean frequency was calculated as 98.8 per million. In addition, the complexity of each radical, as measured by the number of strokes, was matched on average across the four groups, with the complexity of the left and right radical also being matched. All characters were presented in the simplified script adopted in the People's Republic of China.

In addition to the above characters, four conditions of noncharacters were generated by manipulating whether the left or right radical was real or not. For example, 扌 is an existing radical, whereas  never occurs. Nonexistent radicals were constructed by adding, subtracting, or moving a stroke within a real radical. There were 13 noncharacters in each condition comprising two real radicals that do not co-occur (the real–real condition, for example, 扌刂), a real radical followed by a nonexistent one (the real–nonsense condition, for example, ), a nonexistent radical followed by a real one (the nonsense–real condition, for example, ), or two nonexistent radicals (the nonsense–nonsense condition, for example, ).

The items were set up in Kǎi Shū (楷书) font within a matrix of 45 × 45 pixels. The real radicals of the noncharacters were extracted from real characters, whereas the nonsense radicals were constructed from real radicals by removing pixels, adding pixels, or both.

Procedure. Each participant received all of the items, which were presented in random order on a computer screen. Computer presentation elongated the characters such that each was approximately 2.5 cm in height and 2.0 cm in width. The visual angle was approximately 2.05° vertically and 1.64° horizonatally. Each item was presented for 900 ms after which there was a blank display for 600 ms. The next item was then presented. Participants were requested to press the yes key as quickly as possible if the presented item was a real character and the no key if it was not, the dependent variable being the latency from onset of the screen display to initiation of the button press. Ten practice items preceded the testing of each participant. No feedback in terms of accuracy or speed was given to participants at any stage during the experiment.

Results

The character decision times for each participant were normalized by setting cutoffs two standard deviations away from the participant mean averaged across conditions and adjusting any outlying scores to that value. All responses scored as errors were excluded from the analysis of response times (RTs).

Table 1 presents the RTs and error rates for both the characters and the noncharacters. The data were analyzed using planned contrasts testing the manipulation of the left radical, the manipulation of right radical, and the interaction between them. For the item analyses, the real character conditions were treated as four within-item conditions because they were matched in quadruplets on character frequency. With 13 items in each condition, this meant that there were 12 degrees of freedom for the denominator. For the noncharacters, the four conditions of 13 items each were treated as four between-item conditions because items containing noncharacters cannot be matched on character

Table 1
Character Decision Latencies (Response Times [RTs]; in Milliseconds) and Error Rates (in Percentages) for Experiment 1

Condition	Example	RT	Errors (%)
Characters			
High–high	肚	708	2.31
High–low	析	762	4.24
Low–high	狂	705	4.62
Low–low	冰	758	8.09
Noncharacters			
Real–real	扌刂	1025	16.94
Real–nonsense		894	7.32
Nonsense–real		890	4.62
Nonsense–nonsense		755	1.16

frequency. This meant there were 48 degrees of freedom for the denominator.

Looking first at the real characters, it can be seen from the table that the responses to those in which the right radical was of high frequency were faster than those in which the right radical was of low frequency (707 ms vs. 760 ms), and this was significant, $F_s(1, 19) = 10.90, p < .01, MSE = 5{,}355$; $F_i(1, 12) = 6.59, p < .05, MSE = 4{,}880$ (where F_s is the result of the analysis across subject means, and F_i is the result of the across item means). There was no such frequency effect for the left radical (735 ms vs. 732 ms), $F_s(1, 19) = 0.08, p > .10, MSE = 3{,}129$; $F_i(1, 12) = 0.09, p > .10, MSE = 4{,}305$. A similar outcome was observed for the error responses, though the effect of right radical frequency (3% vs. 6%) reached significance on the item analysis only, $F_s(1, 19) = 4.21, p > .05, MSE = 35$; $F_i(1, 12) = 4.75, p < .05, MSE = 23$. There was an apparent tendency toward a left-radical frequency effect on error rates as well (3% vs. 6%), but it turns out that this arose from the responses to only two items (one with an error rate of 35% and the other of 55%) as confirmed by the item analysis that was far from significant, $F_s(1, 19) = 4.25, p > .05, MSE = 45$; $F_i(1, 12) = 0.81, p > .10, MSE = 172$. Finally, there was no significant interaction between the left radical and right radical for either RTs or error rates (all $Fs < 1$).

Turning to the noncharacter responses, a significant RT effect was found for the radical status of both the right part (958 ms vs. 825 ms), $F_s(1, 19) = 90.54, p < .001, MSE = 3{,}905$; $F_i(1, 48) = 14.15, p < .001, MSE = 18{,}191$, and the left part (960 ms vs. 823 ms), $F_s(1, 19) = 81.90, p < .001, MSE = 4{,}569$; $F_i(1, 48) = 16.22, p < .001, MSE = 18{,}191$, with no significant interaction (both $Fs < 1$). Similarly, there was an error rate effect for the radical status of the right part (11% vs. 4%), $F_s(1, 19) = 32.11, p < .001, MSE = 27$; $F_i(1, 48) = 4.21, p < .05, MSE = 132$, and also of the left part (12% vs. 3%), $F_s(1, 19) = 44.85, p < .001, MSE = 38$; $F_i(1, 48) = 8.39, p < .01, MSE = 132$. Although the interaction was significant on the subject analysis, $F_s(1, 19) = 8.94, p < .01, MSE = 21$, it failed to approach significance in the item analysis, $F_s(1, 48) = 0.93, p > .10, MSE = 132$.

Discussion

The results obtained for the noncharacters are exactly what would be expected if an attempt was made to recognize characters via activation of a representation of both the left and the right radical. When either the left or the right part of a noncharacter is not a real radical, and hence does not possess any mental representation, it is easier to classify the stimulus as a noncharacter than if it is an existing radical. The fact that there is no interaction between the radical status of the left and right parts suggests that neither side has priority in activation.

The results for the real characters, however, tell a very different story. If the mental representation for a character is accessed via activation of the representations of its radicals, then the degree to which each of the radicals is activated (as determined by their frequency) should have had an impact on the character decision responses. Thus, the frequency of both the left and the right radicals should have been relevant. However, it was found that only the frequency of the right radical had an impact.

Such a result is also incompatible with the possibility that the left radical is used to activate a set of candidates that is then narrowed down on the basis of the right radical. Because the right radical would not directly participate in the access process, there would be no reason for its frequency to have an impact on character recognition, whereas the use of the left radical in accessing lexical information could well be sensitive to the frequency of that radical. Clearly, the present results do not support such an access procedure.

How then can we explain the pattern of data obtained with the characters and noncharacters? Adopting the interactive–activation framework illustrated in Figure 1, we might propose that the left side and the right side of a character are simultaneously fed into the system in an attempt to activate two radical-level units in which activation will converge upon a single character-level unit. This would account for the noncharacter data because the less activation there is at the radical level, the less strongly any character-level units will be activated, and, consequently, the faster the noncharacter RT will be. It would not matter whether a nonexistent radical occurred on the left side or the right side because in neither case would there be activation at the radical level.

Explaining the real character data in this way is problematical, however. The strength of activation within a character-level unit will be influenced by the strength of activation being fed up from the appropriate radical-level units. If one of these radical-level units is weak and one is strong (corresponding to a low-frequency and a high-frequency radical, respectively, as in the high–low and low–high conditions), activation at the character level will be weaker than if both were strong (as in the high–high condition), though stronger than if both were weak (as in the low–low condition). Therefore, one should find a frequency effect for both the left- and the right-side radicals with no difference between the low–high and high–low conditions, but this is not what we found.

Alternatively then, it might be the case that one radical is given priority over the other in some way. One possibility is that only the right-hand radical is used to activate a set of candidates at the character level, and a selection is then made from these on the basis of the left-hand radical. If we make the assumption that only the activation stage is influenced by radical frequency, we can then explain our finding that only right-hand radical frequency plays a role in recognizing a character. The problem with this explanation, however, is that it cannot account for the noncharacter data. That is, if the right-hand radical did not activate any characters at all because it is a nonexistent radical, then there would be no selection stage, and, therefore, the reality of the left-hand radical would be irrelevant. Yet we did observe a difference between the real–nonsense and nonsense–nonsense conditions.

It seems then that we need an explanation whereby both radicals are involved in the activation stage, in which one has priority over the other, however. The following is such

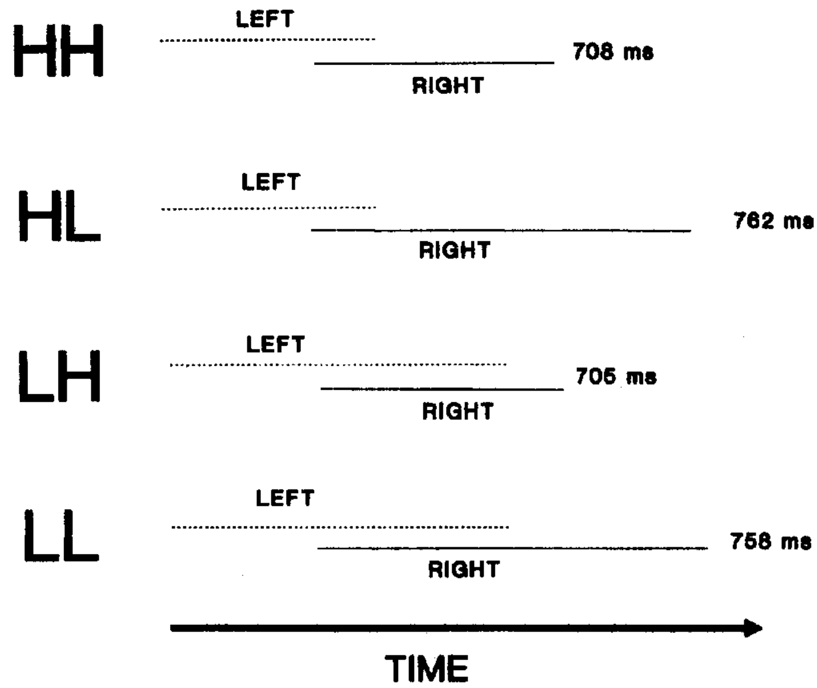

Figure 2. A graphical depiction of the time course of activation for characters in each of the four conditions of Experiment 1. HH = high-frequency left and right radicals; HL = high-frequency left radical and low-frequency right radical; LH = low-frequency left radical and high-frequency right radical; LL = low-frequency left and right radicals.

an explanation. If processing of a character proceeds from left to right (just as the writing of a character does), activation of the unit representing the left-hand radical will commence before activation of that representing the right-hand radical. As activation builds up in the two radical-level units, so activation develops in the character-level unit that corresponds to the combination of those two radicals. The point at which this character-level unit is activated sufficiently to be recognized will therefore be constrained by whichever of the two radical-level units is the slower to be sufficiently activated.[3] As a result of the delay in processing the right-hand radical relative to the left-hand radical, the unit corresponding to the former might typically be the slower one, even when it is a common radical. The situation is depicted in Figure 2.

The lines in this figure indicate the source of the activation that is occurring within a character, that is, the left- and right-hand radicals. Short lines indicate that the activation comes from a high-frequency radical, taking little time to provide its activation, whereas longer lines represent a low-frequency radical. The character can be recognized once activation from both radicals is completed. It can be seen from the figure how it would only be the frequency of the right-hand radical that has an impact on character recognition times. The frequency of the left-hand radical affects the speed with which the appropriate radical unit is activated but is not reflected in character decision times because this activation process reaches completion while the unit representing the right-hand radical is still being activated.

The noncharacter data are explained in terms of the amount of activation happening at the character level. How a no decision is reached within an activation framework is discussed by Taft (1991). To classify an item as a noncharacter, a reader must decide that no character-level unit is going to reach recognition threshold. The less activation there is at the character level, the more sure the reader can be about this decision. Nonexistent radicals will generate less activation than will real radicals and therefore will be associated with shorter RTs. As long as the decision is delayed until processing of the right-hand radical is well under way, it will make little difference whether the nonexistent radical is on the left- or right-hand side; the same amount of activation will be happening at the character level for both the real–nonsense and nonsense–real conditions, and this will be more than for the nonsense–nonsense condition and less than for the real–real condition.

Furthermore, when no character-level unit reaches threshold, as in the case of a nonword, it may be the case that a further attempt is made to activate a character-level unit via the radicals to confirm this outcome. This extra processing might now be carried out on both radicals at the same time, rather than serially, and therefore produce a radical status effect for both positions.

Radical frequency was determined in Experiment 1 simply on the basis of the number of characters containing

[3] Although speed of activation is referred to here, it could equally be thought of as strength of activation. We are assuming that the stronger the activation, the faster the unit will reach its threshold.

the particular radical. The position in which that radical appeared in the character was ignored when determining frequency. As was pointed out earlier, most radicals are position specific (either always on the left or always on the right in a horizontally structured character), but a large number can also be found in either position with varying relative frequencies. Although many of these occur relatively frequently in either position, some radicals are common on the left-hand side but rare on the right, and vice versa. Given this fact, it is possible to examine whether the radical frequency that is important in character recognition is sensitive to positional information. That is, does a common radical facilitate character recognition relative to a rare radical, even when the former is in a position in which it rarely occurs? This was tested in Experiment 2.

Experiment 2

To evaluate the effect of position sensitivity of radical frequencies on character recognition, we set up two contrasts manipulating the right-hand radical of a horizontally structured character (or the bottom radical of a vertically structured character). In the first contrast, characters were matched on character frequency as well as on the overall frequency of the relevant radical, but they were varied on the position-sensitive frequency of that radical. For example, the characters 鸪 and 扪 are of equal character frequency, and the radical 鸟 can be found in 67 characters, which is approximately the same number as the 66 characters that contain the radical 门. However, the radical 鸟 occurs on the right-hand side of 59 of the 67 characters in which it occurs, whereas 门 occurs on the right-hand side of only 2 of the 66 characters in which it occurs. Therefore, if the effect of radical frequency depends on where the radical occurs in the character, 鸪 should be easier to recognize than 扪 because the right-hand radical of the latter is relatively rare in that position.

The second contrast that was set up used characters matched on position-sensitive radical frequency while varying overall radical frequency. For example, 佃 and 颈 are of equal character frequency, but the radical 田 occurs in 144 different characters, whereas the radical 页 occurs in only 59. However, in terms of occurring on the right-hand side of a character, 田 occurs in only 58 characters, whereas 页 occurs in approximately the same number, namely, 56. Therefore, if overall radical frequency is relevant to character recognition regardless of where it occurs in the character, 佃 should be easier to recognize than 颈.

Method

Participants. Twenty more graduate students from the People's Republic of China, based at the University of New South Wales, were used as participants.

Materials and procedure. Fifteen pairs of characters were designed so that they were matched on character frequency (average of 7.5 per million) according to the *Modern Chinese Frequency Dictionary* (1985). It was not possible to find sufficient horizontally structured items to fit the frequency requirements of the experiment, and, therefore, vertically structured characters were also included. The top radical of a vertically structured character is usually taken to be positionally equivalent to the left radical of a horizontally structured character (*Chinese Radical Position Frequency Dictionary,* 1984) inasmuch as horizontally structured characters are written from left to right, whereas vertically structured characters are written from top to bottom. Eight of the pairs had a horizontal structure (e.g., 鸪), whereas 7 had a vertical structure (e.g., 贡). The pairs were also matched on the frequency of their right-hand radical if horizontally structured and on their bottom radical if vertically structured (with an average of 92 occurrences). This frequency value was taken from the *Chinese Radical Position Frequency Dictionary* and constituted the number of characters in which that radical appeared regardless of position. Where the pairs of characters varied was on the position-sensitive frequency of their right-hand or bottom radical, which was also determined from the *Chinese Radical Position Frequency Dictionary.* In one condition (high position frequency) this radical was of relatively high frequency (appearing on average in 69 characters), whereas in the other (low position frequency) it was relatively low (an average of 14 characters). The frequency of the left-hand or top radical was not considered because the first experiment had failed to demonstrate any impact of it on character recognition times.

Another 15 pairs of characters were designed whereby each pair was matched on character frequency (an average of 2.9 per million) and position-sensitive radical frequency (an average of 37 characters) but varied on total radical frequency (i.e., regardless of position). Again, 8 pairs were horizontal characters, whereas 7 were vertical. In one condition (high total frequency), the right-hand or bottom radical was relatively common (appearing on average in 131 characters), whereas in the other (low total frequency), that radical was relatively uncommon (an average of 44 characters). Again, the frequency of the left-hand or top radical was ignored.

Unlike Experiment 1, the right-hand (or bottom) radical was sometimes the bùshǒu of the character. This was true for six of the high position frequency items, four of the low position frequency, three of the high total frequency, and three of the low total frequency items.

In addition to the real characters, a set of 60 noncharacters was generated. All noncharacters were composed of genuine radicals and had either a horizontal or a vertical structure.

Procedure. The procedure was the same as in Experiment 1.

Results

Table 2 shows the mean RTs and error rates.

The latency advantage of the high position frequency condition over the low position frequency condition proved to be significant by subjects only, $F_s(1, 19) = 6.61, p < .05$, $MSE = 871$; $F_i(1, 14) = 2.73, p > .05, MSE = 2{,}340$, but the error difference was significant both by subjects and by

Table 2
Character Decision Latencies (Response Times [RTs]; in Milliseconds) and Error Rates (in Percentages) for Experiment 2

Condition	Example	RT	Errors (%)
High position frequency	鸪	592	7.35
Low position frequency	扪	616	22.67
High total frequency	佃	624	16.68
Low total frequency	颈	607	13.68

items, $F_s(1, 19) = 47.58$, $p < .001$, $MSE = 50$; $F_i(1, 14) = 13.08$, $p < .01$, $MSE = 135$. There was a tendency for the high total frequency condition to be harder than the low total frequency condition according to the subject analysis of both RT and errors, but the item analyses fell far short of significance, $F_s(1, 19) = 4.14$, $p > .05$, $MSE = 731$; $F_i(1, 14) = 1.06$, $p > .05$, $MSE = 3{,}477$ for RTs, and $F_s(1, 19) = 4.53$, $p < .05$, $MSE = 19.86$; $F_i(1, 21) = 0.39$, $p > .05$, $MSE = 171$ for errors, suggesting no effect.

The mean RT for the nonwords was 687 ms with an error rate of 18%.

Discussion

It is apparent from the results that the frequency measure that is relevant in determining the effect of radicals on character recognition is the position-sensitive one. The comparison of equally frequent characters with high- or low-frequency radicals revealed a significant difference only when the radical frequency took positional information into account.

In terms of the interactive–activation approach, one cannot simply say that there are radical-level representations that are activated whenever the appropriate radical appears in a character. It seems that the radical level is somehow sensitive to the position in which the radical occurs. One possible way to handle this is to suggest that the different forms that the same radical takes in different positions (e.g., 牜 when on the left, 牛 when on the right) have their own independent representations at the radical level. However, many radicals do not change their form in different positions, and, in fact, those that do were avoided in the present experiment as much as was feasible.

Another possibility is that positional information is built into each radical representation. To take an English example, one could differentiate the *L*s of *LULL* by representing them as #*L*–, –*L*–, and –*L*#, respectively, where # symbolizes a word boundary, and – symbolizes the rest of the word. Similarly, the radical 鸟 could be represented as # #鸟–for the purposes of activating the character 鸵 and as –鸟# for the purposes of activating the character 鸪.

The final possibility is that there is a separate set of radical units for each position in a character. Thus the radical level of units is split into a right-hand radical set and a left-hand radical set (as well as a top and bottom set).

It would be very difficult to find a way to differentiate these last two accounts. One idea that might be considered would be to see if the presentation of a character that contains radical *X* on its left-hand side facilitates the recognition of a subsequently presented character that contains radical *X* on its right-hand side. Facilitation might be expected according to the boundary-representation account because the representations of #*X*– and –*X*# would be activated by the same stroke-level units. On the other hand, if the left-hand *X* were represented in a completely independent set of radical units from the right-hand *X*, one might not expect to find any priming between them. However, this separate set account could also explain facilitation if it were assumed that both sets are activated by the same set of stroke-level units. Therefore, it is probably the case that the boundary and separate set accounts cannot empirically be distinguished.

The trend toward the high total frequency condition being harder than the low total frequency condition should perhaps not be ignored. The high total frequency characters and low total frequency characters had their radicals matched on position-sensitive frequency while varying on total frequency. To achieve this, it was necessarily the case that the position-sensitive radical frequency of a low total frequency character (37 on average) was approximately the same as its total radical frequency (44 on average), whereas the position-sensitive radical frequency of a high total frequency character (also 37) was considerably less than its total radical frequency (131). This meant that the right-hand radical of a high total frequency character was in a relatively unusual position for that radical. It may have been for this reason that there was a tendency for the high total frequency condition to be harder than the low total frequency condition. In fact, an analysis of the contrast between unusual and usual radical position (i.e., low position frequency plus high total frequency vs. high position frequency plus low total frequency) was significant for error rate (1% vs. 20%), $F_i(1, 29) = 7.27$, $p < .02$, $MSE = 6.90$, though not quite for RT (632 ms vs. 604 ms), $F_i(1, 29) = 3.99$, $p > .05$, $MSE = 2{,}835$. If this is the right way to interpret the effects of position sensitivity (i.e., they arise from the radical being in an atypical position), then the model must incorporate competition from typically positioned radicals. For example, if –鸟# is a more commonly activated unit than is #鸟–, then the greater bias toward the former could inhibit activation of the latter.

Whatever the best way to capture it is, the outcome of this experiment is important not only in that it places constraints on one's model of lexical processing but also because it provides guidance for the design of experiments that manipulate radical frequency. When calculating the frequency of a radical, it is clearly necessary to take into account the position in which the radical occurs in the character.

Finally, a word needs to be said about the fact that horizontal and vertical characters were combined in the one experiment. In determining the radical to be manipulated, we drew on the usual equation of the right radical of a horizontal character with the bottom radical of a vertical one, on the basis of the standardized order in which the strokes are drawn. It is quite possible, though, that lexical processing in reading ignores this ordering of strokes and that our assumption does not hold. Given that approximately half of the items used were horizontal and the rest were vertical, it is possible to ascertain if there is any indication that the two types of character were treated differently. The mean RTs suggested that the pattern of data was much the same for the two, though this was based on few items. For horizontal characters, the RTs for the high and low position frequency conditions were 606 and 628 ms, respectively, and for the high and low total frequency conditions they were 656 and 619 ms, respectively. For vertical characters, the RTs for the high and low position frequency conditions were 593 and 627 ms, respectively, and for the high and low total frequency conditions they were 611 and 599 ms, respectively.

So far, then, we have established that the recognition of characters that are composed of two radicals is affected by the frequency of their right-hand radical and that positional information has an impact on this effect. We can now ask about what happens in the common situation in which the characters have more than two radicals. In particular, what if the right-hand side of a character were a compound radical composed of two component radicals? For example, is the recognition of the character 浇 influenced by the separate frequencies of the two right-hand components 戈 and 兀, or by the frequency of the compound radical 尧, or by both? In Experiment 3 we examined this question by looking at the effect on character decision times of the frequency of compound radicals and of their components.

Experiment 3

Method

Participants. Fifteen more participants were recruited from the same pool of participants as was used in the previous two experiments. Most of them had not participated in either of the other studies.

Materials. A 2 × 2 factorial design was set up by using characters in which the right radical was a compound composed of two vertically positioned radicals (e.g., 浇). The frequency of the compound radical and the frequency of its components were independently manipulated. Items were designed in quadruplets matched on character frequency (average of 14.7 per million) according to the *Modern Chinese Frequency Dictionary* (1985) and on stroke number. Given the results of Experiment 1, the frequency of the left radical (which was always the bùshǒu) was not controlled. There were 20 characters with high-frequency compound radicals (high compound frequency) and 20 with low (low compound frequency). Half of each of these types of compound radical were themselves composed of high-frequency radicals (high radical frequency), and half were composed of low-frequency radicals (low radical frequency). Thus there were 10 items in each condition: high compound–high radical, high compound–low radical, low compound–high radical, and low compound–low radical.

Frequency of compound radical was determined by adding up the frequency (according to the *Modern Chinese Frequency Dictionary,* 1985) of every character containing that compound radical on its right side. The average frequency for the high compound frequency items was 256 per million, whereas for the low compound frequency items it was 19.2 per million. For example, the 尧 of 浇 (high compound frequency) is much more common than the 孛 of 脖 (low compound frequency), even though the frequency of these two characters is matched. It should also be noted that although compound radical frequency was determined on the basis of the number of times that compound appears in the language (i.e., token frequency), the high compound frequency and low compound frequency conditions also differed on the number of characters containing that compound (i.e., type frequency). Because the *Chinese Radical Position Frequency Dictionary* (1984) does not list compound radicals, type frequency was calculated by hand, only including those characters that are sufficiently well-known to be included in the *Modern Chinese Frequency Dictionary.* The high compound frequency compound radicals appeared on average in 9.1 characters, whereas the low compound frequency compound radicals appeared in 2.9.

To estimate the frequency of the component radicals of a compound, we determined the number of characters containing each radical from the *Chinese Radical Position Frequency Dictionary* (1984), taking into account the position in which the radical occurred in the character (i.e., top-right or bottom-right position). The average of the two radicals was then used to determine whether the radicals were of high frequency (appearing in an average of 136 characters) or of low frequency (an average of 22.5 characters). For example, although the compound radicals 尧 and 分 are equally common, the component radicals 戈 and 兀 occur less often than the component radicals 八 and 刀; therefore, 浇 is a low radical frequency item, whereas 扮 is a high radical frequency item.

The noncharacters in this experiment were of the same structure as the real characters. That is, their right-hand sides were made up of two vertically positioned radicals. The left-hand radicals were randomly selected and overlapped partially with the left-hand radicals that occurred in the real characters. The right-hand sides of the noncharacters were of two types. In half of the items, the two radicals formed an existing compound radical (the real-compound condition, for example, [illegible], where [illegible] is a real compound radical), whereas in the other half they did not (the nonsense-compound condition, for example, [illegible] where [illegible] does not exist as a compound radical).

Procedure. The procedure was the same as in the previous two experiments.

Results

Table 3 shows the mean RTs and error rates for both the characters and noncharacters.

Turning first to the real characters, the frequency of the compound radical had no significant impact on either RTs (594 ms for high compound frequency, 606 ms for low compound frequency) or errors (10% for both high compound frequency and low compound frequency; all $Fs < 1.2$). The frequency of its component radicals, on the other hand, did significantly affect RTs (581 ms for high radical frequency, 620 ms for low radical frequency), $F_s(1, 14) = 8.75$, $p < .02$, $MSE = 2{,}634$; $F_i(1, 18) = 7.26$, $p < .02$, $MSE = 3{,}477$, but not error rates (9% for high radical frequency, 11% for low radical frequency; both $Fs < 1$). The interaction between compound frequency and component radical frequency was neither significant on RT (both $Fs < 1$) nor on error rates, $F_s(1, 14) = 3.68$, $p > .05$, $MSE = 116$; $F_i(1, 18) = 2.09$, $p > .05$, $MSE = 136$.

The difference between real-compound noncharacters and nonsense-compound noncharacters was highly significant on both RTs, $F_s(1, 14) = 26.98$, $p < .001$, $MSE = 1{,}561$; $F_i(1, 18) = 13.26$, $p < .01$, $MSE = 2{,}978$, and errors, $F_s(1,$

Table 3
Character Decision Latencies (Response Times [RTs]; in Milliseconds) and Error Rates (in Percentages) for Experiment 3

Condition	Example	RT	Errors (%)
Characters			
High compound–high radical	扮	572	12.00
High compound–low radical	浇	616	8.00
Low compound–high radical	饰	589	6.67
Low compound–low radical	脖	624	13.33
Noncharacters			
Real compound	[illegible]	732	27.67
Nonsense compound	[illegible]	657	2.00

14) = 30.45, $p < .001$, $MSE = 162$; $F_i(1, 18) = 41.87$, $p < .001$, $MSE = 157$.

Discussion

The question being addressed in this experiment was whether compound radicals play a role in character recognition or whether only their component radicals play such a role. The pattern of frequency effects observed with the real characters suggests that the compound radical is not accessed as a unit in the recognition process. Although the frequency of the component radicals had a significant impact on character recognition, the frequency of the compound did not.[4] This suggests that the compound unit has no independent representation to be activated in the process of recognizing the character in which it occurs.

Such a conclusion has important implications for one's conceptualization of the lexical processing system. Although a compound radical may be a unit that recurs within many different Chinese characters, it seems that it does not develop into a unit of analysis in character recognition. Yet Seidenberg (1987, 1989) proposed that sublexical units, like morphemes or syllables, only appear to play a role in word recognition by virtue of their status as recurring units in the language and not by virtue of their status as linguistically definable units. Compound radicals, therefore, provide a counterexample to Seidenberg's statistical redundancy argument inasmuch as they form recurring units but do not appear to participate in the recognition process.

The results for the noncharacters, on the other hand, might be taken as support for the existence of compound radical units in the lexical processing system. It was harder to classify an item as a noncharacter when its right-hand side formed a real compound than when it did not. This might be taken to suggest that a unit representing the compound radical was activated, thus delaying the noncharacter response. However, we would also expect such a result even if there were no units representing compound radicals. If a character-level unit is directly activated by its associated radical units (without any mediating compound radical unit), then the real-compound noncharacters would activate character-level units to a greater degree than would the nonsense-compound noncharacters and hence inhibit the response. This is because two of the radicals of a real-compound noncharacter will activate the same character-level unit (e.g., the 𠂉 and 力 of ⿰王⿱𠂉力 will both activate 伤), whereas no character-level unit will be activated by two radicals when a nonsense-compound noncharacter is presented (e.g., the 厶 and 日 will activate different real characters). Therefore, the noncharacter results say nothing about whether a compound radical level exists or not.

For this reason the conclusion about the existence of a compound radical level must be based on the results of the real characters only, and from these it is concluded that units representing compound radicals do not exist. Such a conclusion, however, is perhaps surprising given that many compound radicals are actually characters in their right. For example, the 分 of 扮 is a character meaning *cent* and therefore should at least be represented at the character level. In the present experiment, 8 of the 10 high compound–high radical items had compound radicals that were real characters, as did 5 of each of the other three conditions. Perhaps these items did indeed generate a frequency effect, but this was washed out by the other items. Inspection of the item data suggested no obvious effect of compound radical frequency when the compound radical was a real character, though it was hard to tell because of variations in the frequency of the characters in which they occurred. Looking at the six frequency matched pairs in which the compound radical was a real character, the high compound frequency items took an average of 595 ms to respond to, and the low compound frequency items 602 ms, a difference of only 7 ms.

If it is the case that character decision responses are unaffected by the character status of the compound radical, it suggests that activation of the character-level representation of a three-radical character does not pass through the character representation of its compound right radical. The only representations that are passed through to reach the character-level representation of the three-radical character are those standing for the component radicals. This then raises the issue of the character status of these radicals. That is, because most radicals are also characters in their own right (e.g., 力 and 日), are they represented both as radicals and as characters? This issue is addressed in the General Discussion section as it is relevant to all three experiments.

General Discussion

The results of the three experiments reported in this article can be summarized in the following way. Although the frequency of the left-hand radical of a character does not affect the time taken to recognize that character (Experiment 1), the frequency of the right-hand radical(s) does (Experiments 1 and 3), but only when frequency takes radical position into account (Experiment 2). When there are two right-hand radicals, the frequency with which these two radicals combine does not affect recognition times (Experiment 3). Finally, the time taken to recognize an item as a noncharacter is affected by the reality of its component radicals regardless of the position of the radical (Experiment 1).

Our explanation for this pattern of data has been that all simple radicals participate in the activation of the character whether they make up the left-hand side of the character, the right-hand side of the character, or merely part of the right-hand side. The frequency with which such a radical occurs has an impact on the recognition of the character, but only when it takes radical position into account. Furthermore, processing of the left-hand radical commences before

[4] There was in fact a 12.5-ms trend toward a compound frequency effect, and it might be argued that there was simply not enough power in the experiment to pick up what was actually a real effect. Although this is conceivable, it must be said that the F_s value was far from significant (1.18, $p < .30$) and the F_i value was only .08 ($p < .78$). Furthermore, the experiment did at least have enough power to detect the effect of component radical frequency.

processing of the right-hand radical such that frequency manipulations of the left-hand radical are obscured.

The framework we have adopted for thinking about character processing is the multilevel interactive–activation model whereby activation is passed up to character-level representations via radical-level representations (see Figure 1). Such a model provides an explanation for the findings that the frequency characteristics of the component radicals of a character influence character recognition responses. However, one unsatisfactory aspect of this framework is the potential redundancy that might be thought to exist in the system. As mentioned earlier, most radicals are also characters in their own right and therefore would be represented twice in the hierarchy, that is, at both the radical and character levels. Is this really a problem?

From Experiment 2 it was suggested that positional information is built into the representation of a radical such that a radical can have different frequency characteristics depending on its position in the character. If we say that a radical appearing on the left is represented differently from a radical appearing on the right (i.e., #鸟 – and –鸟#, respectively), then a radical that is standing on its own will be represented differently again (i.e., #鸟#). In this sense the representations are not redundant. Whether the character representation #鸟# is activated via both the radical representations #鸟– and –鸟# is an open question. It may be the case that all three representations are activated directly from the stroke level and that #鸟 – and –鸟# continue to feed their activation only to the relevant two radical characters (e.g., 鸵, 鹕, and 鹤).

A further point that needs to be considered is the potential competition that might exist between characters sharing a radical. When a character-level representation is activated by its radicals, there will also be some activation taking place in the other character-level representations that share one of those radicals. It might then be expected that the more such competing representations there are, the greater the inhibitory effect on recognition times. Although a high-frequency radical may provide stronger activation to the character level than a low-frequency radical, this advantage could be counterbalanced by the greater competition at the character level. The fact that a frequency effect was observed in all of the experiments here suggests that the effects of this competition were minimal.

In fact, the interactive–activation model could account for any result that is found, that is, high-frequency items being faster than low-frequency items because of the greater shared activation, high-frequency items being slower than low-frequency items because of greater competition, or no difference between high- and low-frequency items because of a counterbalancing of shared activation and competition. This could be seen as being either a strength of the model because of its flexibility or a weakness of the model because of its unfalsifiability. What is really required then is a clear account of the circumstances under which each of the three outcomes is observed. Similar concerns have been addressed in relation to previous research using alphabetic scripts on the effects of word similarity, as measured by the number of words that are one letter different to the target (e.g., Andrews, 1989; Grainger, 1992). All that can be said here is that the conditions under which the characters were presented in the present set of experiments led to a facilitatory effect of high frequency. It remains to be seen whether there are other circumstances in which an inhibitory effect of high frequency can be found.

An important issue in relation to the potential existence of facilitative and inhibitory effects is the relationship between the type and token frequency of the radical. Type frequency refers to the number of different characters that contain the radical, whereas token frequency refers to the number of times the radical is seen regardless of the specific character it occurs in. The more often a radical is encountered (high token frequency) the faster the radical unit might be processed, but the more characters it appears in (high type frequency) the more opportunity for competition and thus inhibition. Because it will usually be the case that token frequency covaries with type frequency, the possibility of counteracting effects of facilitation and inhibition exists. In the present experiments, the calculation of token radical frequency was impracticable owing to the very large number of characters in which the radicals occurred: The *Chinese Radical Position Frequency Dictionary* (1984) only provides the number of characters that include a particular radical (i.e., type frequency), and to calculate the token frequency one must generate all of these characters and add up their frequency of occurrence as listed in the *Modern Chinese Frequency Dictionary* (1985). This was indeed undertaken for the compound radicals of Experiment 3, but there were only a small number of these, whereas the number of characters that included a particular simple radical could be over 500 (Experiment 1). It is very likely, however, that a radical of high type frequency in these experiments was also a radical of high token frequency, given their natural covariation in the language. To examine the independent effects of type and token frequency, clearly one will need to specifically examine those relatively unusual cases in which a radical occurs in very few characters, but these are characters that are common (i.e., low type frequency and high token frequency) and also where a radical occurs in many characters, but these characters are all relatively uncommon (i.e., high type and low token). Such a study remains to be carried out.

The final issue to be considered concerns the functional characteristics of a radical. The manipulation of radicals in the three experiments reported in this article has been described in terms of their position within the target character, that is, left, right, up, or down. However, as mentioned earlier, radicals often also serve a semantic or phonetic cuing function. In horizontally structured characters, it is typically the left side that provides a rough guide to the meaning of the character, and the right side provides a rough guide to the pronunciation of the character. Given this fact, we can ask whether the differential effect of frequency of the left and right radicals observed in Experiment 1 can be attributed in some way to function rather than to position. It may be that semantic radicals are represented independently of phonetic radicals and that the latter are sensitive to frequency, whereas the former are not.

Apart from there being no independent reason for proposing that phonetic radicals are frequency sensitive while semantic ones are not, the results of Experiment 3 are not consistent with this conclusion. In a character that has a right side composed of two radicals, it is the compound radical that provides the phonetic cuing function (e.g., both the character 惯 and its right side 贯 are pronounced guàn). The results of Experiment 3, however, suggest that the frequency of the compound radical has no impact on RTs despite its potential phonetic function. On the other hand, the frequency of the component radicals (e.g., 毌 and 贝) does influence responses, yet these radicals provide no guidelines to the pronunciation of the character at all (贝 is pronounced "bèi," whereas 毌 has no pronunciation). Thus it appears that phonetic function is not specifically associated with frequency sensitivity.

However, to tease apart the effects of position and function in a direct manner, what is really needed is an experiment that examines those 10% of two-radical characters (Wang, 1981) in which the semantic radical is on the right-hand side with the phonetic radical on the left-hand side. If, under these circumstances, it is only the left-hand radical that reveals an effect of frequency, an explanation in terms of function rather than in terms of position would seem warranted. Unfortunately, the small number of such characters makes such an experiment difficult to mount.

Although there is recent evidence to suggest that phonology may automatically be activated in the course of character recognition (see, for example, Perfetti & Zhang, 1995; Tan, Hoosain, & Peng, 1995), it is debatable whether the phonetic radical plays a role in this process. We cannot even be sure that the phonological characteristics of radical units are represented in the lexical processing system at all. Orthographic–phonological links at the character level alone are all that is logically required for naming Chinese characters. Nevertheless, there is research that demonstrates that the relationship between the pronunciation of a character and that of its phonetic radical affects naming responses (e.g., Fang et al., 1986; Hue, 1992; Seidenberg, 1985; Wu et al., 1994) and this could be taken to suggest that the phonological characteristics of the radical are activated when pronouncing the character that contains it. However, it need not be the case that the influence of the radical arises at the radical level; it could arise from the character level. For example, the regularity effect, in which a character takes longer to name when its pronunciation clashes with that of its radical, can be explained in terms of there being competition between the range of pronunciations generated at the character level as a result of all the characters containing that radical being activated.

In conclusion, in the research reported in this article we examined the use of submorphemic information in the recognition of Chinese characters. It is suggested that characters are indeed recognized via the activation of information about their component radicals, and this is described within the framework of a multilevel interactive–activation model that incorporates a radical level of representation that takes positional details into account.

References

Andrews, S. (1989). Frequency and neighborhood effects on lexical access: Activation or search? *Journal of Experimental Psychology: Learning, Memory, and Cognition, 15,* 802–814.

Bowey, J. A. (1990). Orthographic onsets and rimes as functional units of reading. *Memory & Cognition, 18,* 419–427.

Bradley, D. C. (1979). Lexical representation of derivational relation. In M. Aronoff & M. L. Kean (Eds.), *Juncture* (pp. 37–77). Cambridge, MA: MIT Press.

Burani, C., Salmaso, D., & Caramazza, A. (1984). Morphological structure and lexical access. *Visible Language, 18,* 342–352.

Cao, C. Y., & Shen, Y. (1963). Preliminary research about the tachistoscopic identification of Chinese characters of children [In Chinese]. *Acta Psychologica Sinica, 7,* 271–279.

Chao, Y. R. (1968). *A grammar of spoken Chinese.* Berkeley: University of California Press.

Chen, H.-C. (1986). Component detection in reading Chinese characters. In H. S. R. Kao & R. Hoosain (Eds.), *Linguistics, psychology, and the Chinese language* (pp. 1–10). Hong Kong: Centre of Asian Studies, University of Hong Kong.

Chen, H.-C. (1992). Reading comprehension in Chinese: Implications from character reading times. In H.-C. Chen & O. J. L. Tzeng (Eds.), *Language processing in Chinese* (pp. 175–205). Amsterdam: North-Holland.

Chen, M. J., & Yung, Y. F. (1989). Reading Chinese: A holistic or piecemeal process? In A. F. Bennett & K. M. McConkey (Eds.), *Cognition in individual and social contexts* (pp. 91–100). Amsterdam: Elsevier.

Cheng, C.-M. (1981). Perception of Chinese characters [In Chinese]. *Acta Psychologica Taiwanica, 23,* 137–153.

Cheng, C.-M., & Fu, G.-L. (1986). The recognition of Chinese characters and words under divided visual field presentation. In H. S. R. Kao & R. Hoosain (Eds.), *Linguistics, psychology, and the Chinese language* (pp. 23–37). Hong Kong: Centre of Asian Studies, University of Hong Kong.

Chinese radical position frequency dictionary. (1984). Hunan, China: Hunan Institute of Computer Science.

Colé, P., Beauvillain, C., & Segui, J. (1989). On the representation and processing of prefixed and suffixed derived words: A differential frequency effect. *Journal of Memory and Language, 28,* 1–13.

Dictionary of Chinese character information. (1988). Shanghai: Science Press.

Fan, K. Y., Gao, J. L., & Ao, X. P. (1984). Pronunciation principles of Chinese characters and alphabetic script [In Chinese]. *Chinese Character Reform, 3,* 23–27.

Fang, S. P., Horng, R. Y., & Tzeng, O. J. L. (1986). Consistency effects in the Chinese character and pseudo-character naming tasks. In H. S. R. Kao & R. Hoosain (Eds.), *Linguistics, psychology, and the Chinese language* (pp. 11–21). Hong Kong: Centre of Asian Studies, University of Hong Kong.

Fang, S. P., & Wu, P. (1989). Illusory conjunctions in the perception of Chinese characters. *Journal of Experimental Psychology: Human Perception and Performance, 15,* 434–447.

Flores d'Arcais, G. B. (1992). Graphemic, phonological, and semantic activation processes during the recognition of Chinese characters. In H.-C. Chen & O. J. L. Tzeng (Eds.), *Language processing in Chinese* (pp. 37–66). Amsterdam: North-Holland.

Flores d'Arcais, G. B., Saito, H., & Kawakami, M. (1995).

Phonological and semantic activation in reading Kanji characters. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 21*, 34–42.

Grainger, J. (1992). Orthographic neighborhoods and visual word recognition. In R. Frost & L. Katz (Eds.), *Orthography, phonology, morphology, and meaning* (pp. 131–146). Amsterdam: North-Holland.

Guo, D. J., Peng, D. L., & Zhang, S. L. (1985). The influences of morphological features and frequency on Chinese character recognition [In Chinese]. In *Advances in general and experimental psychology* (pp. 85–90). Chengdu, China: Chengdu Science and Technology Press.

Henderson, L. (1985). Towards a psychology of morphemes. In A. W. Ellis (Ed.), *Progress in the psychology of language* (Vol. 1, pp. 15–71). Hillsdale, NJ: Erlbaum.

Hoosain, R. (1992). Psychological reality of the word in Chinese. In H.-C. Chen & O. J. L. Tzeng (Eds.), *Language processing in Chinese* (pp. 111–130). Amsterdam: North-Holland.

Huang, J.-T. (1984). Perceptual separability and cohesive processes in reading Chinese words. In H. S. R. Kao & R. Hoosain (Eds.), *Linguistics, psychological studies of the Chinese language* (pp. 45–54). Hong Kong: Chinese Language Society of Hong Kong.

Huang, J.-T., & Wang, M. Y. (1992). From unit to gestalt: Perceptual dynamics in recognizing Chinese characters. In H.-C. Chen & O. J. L. Tzeng (Eds.), *Language processing in Chinese* (pp. 3–35). Amsterdam: North-Holland.

Hue, C.-W. (1992). Recognition processing in character naming. In H.-C. Chen & O. J. L. Tzeng (Eds.), *Language processing in Chinese* (pp. 93–107). Amsterdam: North-Holland.

Just, M. A., & Carpenter, P. A. (1987). *The psychology of reading and language comprehension.* Boston: Allyn & Bacon.

Kay, J., & Bishop, D. (1987). Anatomical differences between nose, palm, and foot, or, the body in question: Further dissection of the processes of sub-lexical spelling–sound translation. In M. Coltheart (Ed.), *Attention and performance XII* (pp. 449–469). Hillsdale, NJ: Erlbaum.

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 the Chinese language* (Vol. 1, pp. 57–67). Hong Kong: Asian Research Service.

Leong, C. K., Cheng, P. W., & Mulcahy, R. (1987). Automatic processing of morphemic orthography by mature readers. *Language and Speech, 30*, 181–196.

McClelland, J. L. (1987). The case for interactionism in language processing. In M. Coltheart (Ed.), *Attention and performance XII* (pp. 3–36). Hillsdale, NJ: Erlbaum.

McClelland, J. L., & Rumelhart, D. E. (1981). An interactive activation model of context effects in letter perception: Part 1. An account of basic findings. *Psychological Review, 88*, 375–407.

Modern Chinese frequency dictionary [Xianda huayu pinlu zidian]. (1985). Beijing, China: Beijing Language Institute Press.

Peng, D.-L., & Tan, L. H. (1990, August). *The functions of orthographical and phonological information during visual processing of Chinese characters* [In Chinese]. Paper presented at the 5th International Symposium on Cognitive Aspects of the Chinese Language, Beidaihe, China.

Perfetti, C. A., & Zhang, S. (1995). Very early phonological activation in Chinese reading. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 21*, 24–33.

Rumelhart, D. E., & McClelland, J. L. (1982). An interactive activation model of context effects in letter perception: Part 2. *Psychological Review, 89*, 60–94.

Seidenberg, M. S. (1985). The time course of phonological code activation in two writing systems. *Cognition, 19*, 1–30.

Seidenberg, M. S. (1987). Sublexical structures in visual word recognition: Access units or orthographic redundancy? In M. Coltheart (Ed.), *Attention and performance XII* (pp. 245–263). Hillsdale, NJ: Erlbaum.

Seidenberg, M. S. (1989). Reading complex words. In G. N. Carlson & M. K. Tanenhaus (Eds.), *Linguistic structure in language processing* (pp. 53–105). Amsterdam: Reidel.

Shu, H. (1986). *The process of naming Chinese characters of adult skilled readers* [In Chinese]. Unpublished master's thesis, Beijing Normal University, Beijing, China.

Taft, M. (1979). Recognition of affixed words and the word frequency effect. *Memory & Cognition, 7*, 263–272.

Taft, M. (1985). The decoding of words in lexical access: A review of the morphographic approach. In D. Besner, T. G. Waller, & G. E. MacKinnon (Eds.), *Reading research: Advances in theory and practice* (Vol. 5, pp. 83–123). New York: Academic Press.

Taft, M. (1991). *Reading and the mental lexicon.* Hove, UK: Erlbaum.

Taft, M. (1992). The body of the BOSS: Subsyllabic units in the lexical processing of polysyllabic words. *Journal of Experimental Psychology: Human Perception and Performance, 18*, 1004–1014.

Taft, M. (1994). Interactive–activation as a framework for understanding morphological processing. *Language and Cognitive Processes, 9*, 271–294.

Taft, M., & Forster, K. I. (1976). Lexical storage and retrieval of polymorphemic and polysyllabic words. *Journal of Verbal Learning and Verbal Behavior, 15*, 607–620.

Taft, M., Huang, J., & Zhu, X. (1994). The influence of character frequency on word recognition responses in Chinese. In H.-W. Chang, J.-T. Huang, C.-W. Hue, & O. Tzeng (Eds.), *Advances in the study of Chinese language processing* (Vol. 1, pp. 59–73). Taipei: National Taiwan University.

Taft, M., & Zhu, X. (1994). The representation of bound morphemes in the lexicon: A Chinese study. In L. Feldman (Ed.), *Morphological aspects of language processing* (pp. 293–316). Hillsdale, NJ: Erlbaum.

Tan, L. H., Hoosain, R., & Peng, D.-L. (1995). Role of early presemantic phonological code in Chinese character identification. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 21*, 43–54.

Tan, L. H., & Peng, D.-L. (1989). Processing Chinese words: Exploration of effects of context and frequency [In Chinese]. *Psychological Science, 2*, 5–10.

Tan, L. H., & Peng, D.-L. (1990). Empirical research on the relationship between semantic context and orthographic features of Chinese characters [In Chinese]. *Psychological Trends, 2*, 5–10.

Treiman, R., & Chafetz, J. (1987). Are there onset- and rime-like units in printed words? In M. Coltheart (Ed.), *Attention and performance XII* (pp. 281–298). Hillsdale, NJ: Erlbaum.

Wang, W. S. Y. (1981). Language structure and optimal orthography. In O. J. L. Tzeng & H. Singer (Eds.), *Perception of print: Reading research in experimental psychology* (pp. 223–236). Hillsdale, NJ: Erlbaum.

Wen, S. S. (1990, August). *Chinese character simplification: An information processing analysis.* Paper presented at the 5th International Symposium on Cognitive Aspects of the Chinese Language. Beidaihe, China.

Wu, J. T., Chou, T. L., & Liu, I. M. (1994). The frequency effects in processing Chinese characters and words [In Chinese]. In H. W. Chang, J. T. Huang, C. W. Hue, & O. J. L. Tzeng (Eds.), *Advances in the study of Chinese language processing* (pp. 31–58). Taipei: National Taiwan University.

Yeh, J. S., & Liu, I. M. (1972). Factors affecting recognition thresholds of Chinese characters [In Chinese]. *Acta Psychologica Taiwanica, 14,* 113–117.

Yu, B. L., & Cao, H. Q. (1992a). The effect of the stroke number disposition on Chinese character recognition [In Chinese]. *Psychological Science, 4,* 5–10.

Yu, B. L., & Cao, H. Q. (1992b). A new exploration on the effect of stroke number in the identification of Chinese characters. *Acta Psychologica Sinica, 24,* 120–126.

Yu, B. L., Feng, L., Cao, H. Q., & Li, W. L. (1990). Visual perception of Chinese characters—Effect of perceptual task and Chinese character attributes [In Chinese]. *Acta Psychologica Sinica, 22,* 141–147.

Zhang, B. Y., & Peng, D. L. (1992). Decomposed storage in the Chinese lexicon. In H.-C. Chen & O. J. L. Tzeng (Eds.), *Language processing in Chinese* (pp. 131–149). Amsterdam: North-Holland.

Zhu, X. (1988). Analysis of the cueing function of the phonetic in modern Chinese. *Proceedings of the Symposium on Chinese Language and Character* (pp. 260–288). Beijing, China: Guang Ming Daily Press.

Zhu, X. (1991). The effect of Chinese sentence context on word recognition [In Chinese]. *Acta Psychologica Sinica, 23,* 145–152.

Zhu, X., & Shen, L. M. (1990). *The effects of stroke number and character frequency during Chinese character recognition* [In Chinese]. Unpublished manuscript.

Received January 27, 1995
Revision received March 13, 1996
Accepted March 25, 1996 ■