Family Effects of Semantic Radicals and Phonetic Components in the Recognition of Chinese Phono-semantic Compound Characters

Authors: Wang Juan, Ma Xuemei, Li Bingbing, Zhang Jijia, Zhang Jijia

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Abstract

Using a lexical decision task and ERP technique, we manipulated the family size of semantic and phonetic components to investigate the family size effects of semantic and phonetic components in the recognition of phonetic-semantic compound characters. The results showed: (1) When the semantic component was of large family size, characters with large-family phonetic components elicited smaller P200 amplitudes than those with small-family phonetic components; when the semantic component was of small family size, the difference in P200 amplitudes between characters with large-family and small-family phonetic components was not significant. (2) Characters with large-family phonetic components elicited larger N400 amplitudes than those with small-family phonetic components, but this difference between large-family and small-family phonetic component characters was more pronounced when the semantic component was of large family size than when it was of small family size. This indicates that the family sizes of semantic and phonetic components jointly influence the recognition of phonetic-semantic compound characters, and the family size effect of phonetic components is modulated by the family size of semantic components. The study demonstrates that at different stages of lexical recognition, the resource allocation to semantic and phonetic components is in a dynamic state, which depends on the difference in their frequency of occurrence. Overall, the study suggests that there exists an interplay between the roles of semantic and phonetic components in the recognition of phonetic-semantic compound characters, and the trade-off between their functions is related to processing stage and family size.

The Neighborhood Effect of Semantic and Phonetic Radicals in Phonogram Recognition

WANG Juan[1], MA Xuemei[1], LI Bingbing[1], ZHANG Jijia[2]
[1]School of Education Science, Jiangsu Normal University, Xuzhou 221116, China
[2]Department of Psychology, Renmin University of China; The State Ethnic Affairs Commission Key Research Center for National Language Cultural Psychology; Ethnic Education Development Research Center of Ministry of Education, Beijing 100872, China

Abstract

Using a lexical decision task and ERP technology, this study manipulated the neighborhood size of semantic and phonetic radicals to investigate their respective neighborhood effects in phonogram recognition. The results revealed: (1) When the semantic radical had a large neighborhood size, phonograms with large phonetic radical neighborhoods elicited smaller P200 amplitudes than those with small phonetic radical neighborhoods; when the semantic radical had a small neighborhood size, the difference in P200 amplitudes between large and small phonetic radical neighborhoods was not significant. (2) Phonograms with large phonetic radical neighborhoods elicited larger N400 amplitudes than those with small phonetic radical neighborhoods, but this difference was more pronounced when the semantic radical had a large neighborhood size compared to when it had a small neighborhood size. These findings demonstrate that the neighborhood sizes of semantic and phonetic radicals jointly influence phonogram recognition, with the phonetic radical’ s neighborhood effect being modulated by the semantic radical’ s neighborhood size. The study indicates that at different stages of lexical recognition, the resource allocation between semantic and phonetic radicals is dynamic, depending on differences in their frequency of occurrence.

Overall, the results suggest that in phonogram recognition, a dynamic interplay exists between semantic and phonetic radicals, with their relative contributions waxing and waning in relation to processing stage and neighborhood size.

Keywords: phonetic radical; semantic radical; neighborhood size; phonogram recognition

The Chinese writing system is predominantly composed of phonograms. Among 7,000 commonly used Chinese characters, phonograms account for over 80% (Li & Kang, 1993). Phonograms consist of semantic radicals and phonetic radicals. The phonetic radical provides a phonological cue for the character’ s pronunciation, while the semantic radical is a component that has semantic connections with the whole character, reducing the arbitrariness between the character’ s form and meaning. The mechanism underlying the roles of semantic and phonetic radicals in phonogram recognition has long been a central focus in Chinese character psychology research. Unfortunately, no consensus has yet emerged regarding this issue. Three representative viewpoints have developed concerning which radical plays a more important role in phonogram recognition: (1) the phonetic radical advantage hypothesis, which posits that phonetic radicals play a more critical role (Hung, Hung, Tzeng, & Wu, 2014; Wang, Xieshun, Wu, Zhao, Ni, & Zhang, 2016; Zhang, Wang, & Yin, 2014); (2) the semantic radical advantage hypothesis, which argues that semantic radicals are more important (Williams, 2012; Williams & Bever, 2010); and (3) the semantic radical neighborhood modulation hypothesis, which suggests that the contributions of semantic and phonetic radicals to whole-character processing are regulated by the semantic radical' s neighborhood size (Hsiao, Shillcock, & Lavidor, 2006, 2007).

Proponents of the phonetic radical advantage hypothesis argue that phonetic radicals are more prominent in phonogram recognition. Hung et al. (2014) used magnetoencephalography (MEG) to examine the roles of phonetic and semantic radicals separately in phonogram recognition. Using homophone judgment and synonym judgment tasks, participants determined whether prime-target character pairs shared the same pronunciation or meaning. Results showed facilitatory effects of phonetic radical sharing in both behavioral responses and MEG components, but no facilitatory effects of semantic radical sharing were found in the MEG data. The researchers concluded that in phonogram recognition, phonetic radicals are activated earlier and more strongly than semantic radicals. Zhang et al. (2014) employed eye-tracking technology to investigate attentional resource allocation to semantic and phonetic radicals during different processing tasks. They found that phonetic radicals enjoyed attentional resource advantages over semantic radicals during phonological and semantic access, with this advantage being more pronounced in phonological retrieval tasks: phonetic radicals could activate whole-character pronunciation relatively independently without relying on semantic radical information, whereas semantic extraction required cooperation from phonetic radicals. Wang et al. (2016) used a lexical decision task with phonograms whose radicals were both independent characters, manipulating the frequency of semantic and phonetic radicals to examine their roles. They found that phonetic radical frequency significantly affected phonogram recognition in terms of reaction time and error rate, whereas no effect of semantic radical frequency was observed. ERP studies revealed that phonetic radical frequency began to exert its influence earlier than semantic radical frequency, as evidenced by P200 modulation by phonetic radical frequency but not by semantic radical frequency. Therefore, phonetic radicals are activated earlier than semantic radicals. They argued that because phonetic radicals are more complex and variable than semantic radicals, readers first process the phonetic radical during phonogram recognition; once the phonetic radical is identified, character recognition becomes easier. In the N400 component, phonetic radical frequency produced more sustained effects and broader brain activation than semantic radical frequency. Moreover, high-frequency semantic radicals elicited smaller N400 amplitudes than low-frequency semantic radicals, whereas high-frequency phonetic radicals elicited larger N400 amplitudes than low-frequency phonetic radicals. They suggested that the manipulated radical frequency in their study essentially reflected familiarity with the radical as an independent character. During semantic extraction, phonetic radicals are semantically unrelated to the whole character, requiring participants to suppress phonetic radical semantics, which resulted in larger N400 amplitudes for high-frequency phonetic radicals. Semantic radicals, however, provide semantic cues for phonograms, leading to stronger semantic activation and facilitatory effects for high-frequency semantic radicals during semantic extraction. Thus, compared to semantic radicals, phonetic radical effects emerged earlier, beginning in the early stages of phonogram recognition, and were more sustained.

Advocates of the semantic radical advantage hypothesis argue that semantic radicals play a more important role in phonogram recognition. These researchers blurred either the semantic or phonetic radicals of phonograms and required participants to perform character judgment tasks. Results showed that phonograms with blurred semantic radicals were more difficult to recognize than those with blurred phonetic radicals, leading to the conclusion that phonogram recognition relies more on semantic information and that semantic radicals are therefore more important (Williams, 2012; Williams & Bever, 2010).

Hsiao and colleagues propose that the contributions of semantic and phonetic radicals to whole-character processing are regulated by the semantic radical’ s neighborhood size. Hsiao et al. (2006) used repetitive transcranial magnetic stimulation (rTMS) with left-right structured phonograms, requiring participants to judge semantic transparency. They found significant facilitatory effects of semantic radical neighborhood size and semantic transparency. Compared to rTMS applied to the right occipital cortex, stimulation of the left occipital cortex significantly slowed responses to characters with large semantic radical neighborhoods, thereby reducing the facilitatory effect of large semantic radical neighborhoods. That is, virtual lesions to the left hemisphere affected phonetic radical processing and consequently influenced semantic judgments for characters with large semantic radical neighborhoods, whereas virtual lesions to the right hemisphere affected semantic radical processing and thus influenced semantic judgments for characters with small semantic radical neighborhoods. The researchers argued that when semantic radicals have small neighborhoods, both left and right components equally influence whole-character semantic access, making semantic radicals more informative for character recognition. When semantic radicals have large neighborhoods, whole-character semantic access relies more heavily on phonetic radicals because many characters share the same semantic radical, making phonetic radicals more informative. When phonetic radicals receive more attention, they obtain more cognitive resources, become more highly activated, and are processed more thoroughly. Hsiao et al. (2007) used a lateralized foveal cueing paradigm to examine semantic transparency judgments for left-right structured phonograms. They found that compared to cues directing attention to the right component, cues directing attention to the left component facilitated semantic transparency judgments for characters with small semantic radical neighborhoods but inhibited such judgments for characters with large semantic radical neighborhoods. This occurs because unilateral cues guide attention to the corresponding component, leading to its prioritized processing. If the cued component is highly informative, it facilitates character recognition. For characters with small semantic radical neighborhoods, the semantic radical is highly informative because few characters share it, effectively cueing whole-character semantics and facilitating recognition. For characters with large semantic radical neighborhoods, the semantic radical is less informative for representing whole-character semantics and plays a limited role in determining meaning, making the right-side phonetic radical more informative for semantic access. Therefore, right-side cues are more advantageous for recognition.

In summary, previous research agrees that both semantic and phonetic radicals influence phonogram processing. However, most studies have examined semantic and phonetic radical effects separately through semantic or phonological tasks, determining each radical' s contribution by comparing effect sizes (Wang et al., 2016; Hung, 2014; Zhang et al., 2014; Williams, 2012; Williams & Bever, 2010). This approach overlooks an important factor: the mutual influence between semantic and phonetic radicals during processing. That is, when examining phonetic radical effects, characteristics of the semantic radical may influence the direction and magnitude of the effect, and vice versa. Therefore, examining semantic radical effects without considering phonetic radicals, or examining phonetic radical effects without considering semantic radicals, cannot fully resolve the mechanism of their roles in phonogram recognition. The process by which semantic and phonetic radicals influence phonogram recognition is likely a dynamic interplay, with different resource demands at different stages depending on radical characteristics such as neighborhood size (reflecting frequency of occurrence) and whether the radical forms an independent character. The relative advantages of semantic and phonetic radicals may vary across different processing stages of Chinese character recognition, representing a waxing and waning relationship. Thus, new evidence is needed to address this issue.

Based on Hsiao et al.' s (2006, 2007) research, radical neighborhood size modulates the roles of semantic and phonetic radicals in phonogram processing. Therefore, examining the contributions of semantic and phonetic radicals to whole-character processing requires considering radical neighborhood size. The present study investigates the role of radicals in Chinese character processing from the perspective of neighborhood effects. Orthographic neighborhood size is a crucial characteristic of sublexical components. Characters with the same structure that share a semantic or phonetic radical with the target character are called orthographic neighbors. Among these neighbors, those sharing a semantic radical constitute the semantic radical neighborhood, while those sharing a phonetic radical constitute the phonetic radical neighborhood. The ability of semantic and phonetic radicals to form characters differs substantially: semantic radicals can form between 1 and 99 characters, with an average of 40.9; phonetic radicals can form between 1 and 23 characters, with an average of 12.5 (Li &

Kang, 1993). Differences in character recognition caused by radicals' ability to form characters are known as orthographic neighborhood effects. A primary goal of this study is to examine the roles of semantic and phonetic radicals in phonogram recognition by manipulating radical neighborhood size.

According to the modulation model of semantic radical influence on phonogram semantic processing, a modulation mechanism exists at the radical level that allocates resources to different processing pathways, with the upward activation pathways of semantic and phonetic radicals competing for resources (Wang & Zhang, 2016). Based on this hypothesis, when semantic radicals have large neighborhoods, whole-character recognition relies more heavily on phonetic radicals for early orthographic access, manifesting as a phonetic radical neighborhood effect and greater phonetic radical contribution. When semantic radicals have small neighborhoods, recognition relies more easily on semantic radicals for orthographic access, and the phonetic radical neighborhood effect is suppressed. During semantic access, regardless of semantic radical neighborhood size, phonetic radicals demonstrate greater advantages. Thus, if semantic and phonetic radicals have different mechanisms at various processing stages and compete with each other, their neighborhood effects should show different patterns in P200 and N400 components. Therefore, this study manipulated both semantic and phonetic radical neighborhood sizes, using four types of characters: large semantic/large phonetic neighborhoods (HH), large semantic/small phonetic neighborhoods (HL), small semantic/large phonetic neighborhoods (LH), and small semantic/small phonetic neighborhoods (LL), to examine the mechanism of semantic and phonetic radical processing. A lexical decision task was employed, focusing on P200 and N400 components. Previous investigations of orthographic neighborhood effects have found significant effects in both components (Barber, Vergara, & Carreiras, 2004; Wang et al., 2016). The P200 component reflects early orthographic information activation in lexical processing (Liu, Perfetti, & Hart, 2003; Chen, Liu, Wang, Peng, & Perfetti, 2007) and has been identified as an ERP component related to lexical neighborhood size effects (Lee, Tsai, Chan, Hsu, Hung, & Tzeng, 2007; Hsu, Tsai, Lee, & Tzeng, 2009; Carrasco-Ortiz, Midgley, Grainger, & Holcomb, 2017). The N400 component is associated with semantic processing (Hsu et al., 2009; Lee et al., 2007; Taler & Phillips, 2007). By analyzing mean amplitudes in these two time windows for phonograms with different neighborhood sizes, we can probe the competition for cognitive resources during lexical recognition and provide further evidence for sublexical information representation and processing mechanisms.

In summary, while previous research has yielded some conclusions about radical roles in phonogram recognition, most studies have focused on only "half" of the character in a single experiment, examining either phonetic radical effects or semantic radical effects separately (Zhang, Zhang, & Kong, 2009; Zhou & Marslen-Wilson, 1999; Zhang & Zhang, 2016; Zhang & Zhang, 2017; Wang & Zhang, 2016), without reaching unified conclusions or a comprehensive explanation of how semantic and phonetic radicals influence phonogram processing. This study breaks through the current limitation of focusing on only "half" of a character by simultaneously manipulating both semantic and phonetic radical neighborhood sizes within the same characters. By examining the neighborhood effects of these radicals, we aim to explore their roles in phonogram recognition, explain resource competition and interrelationships between them at different processing stages, and provide a theoretical basis for sublexical information representation and processing mechanisms.

2.1 Participants

Twenty-two undergraduate students were recruited (9 male, 13 female), aged 19-24 years (M = 21.55). All participants were right-handed with normal or corrected-to-normal vision. Their native language was Mandarin Chinese. A sample size of 22 participants was appropriate for each condition, as previous studies on Chinese character component processing (Wang et al., 2016) successfully detected expected effects with similar sample sizes. Additionally, power analysis using G*Power software indicated that this experiment had adequate power (0.99) to detect expected effects.

2.2 Design

A 2 (semantic radical neighborhood size: large/small) × 2 (phonetic radical neighborhood size: large/small) within-subjects design was employed.

2.3 Materials

Materials included target stimuli and filler stimuli. Target stimuli consisted of 240 left-right structured phonograms divided into four types: large semantic/large phonetic neighborhoods (HH), large semantic/small phonetic neighborhoods (HL), small semantic/large phonetic neighborhoods (LH), and small semantic/small phonetic neighborhoods (LL), with 60 characters in each type.

Semantic radical neighborhood size was determined based on statistics from the *Modern Chinese Commonly Used Characters List* (7,500 characters): large semantic radical neighborhoods were defined as those forming 101 characters, including radicals such as 氵 (water), 口 (mouth), 木 (wood), 扌 (hand), 钅 (metal), 亻 (person), 月 (moon/flesh), 土 (earth), 虫 (insect), 讠 (speech), 纟 (silk), 忄 (heart), 女 (woman), 石 (stone), 王 (king/jade), and 日 (sun). Small semantic radical neighborhoods were defined as those forming 72 characters, including radicals such as 又 (again), 田 (field), 戈 (spear), 彳 (step), 礻 (spirit), 巾 (cloth), 米 (rice), 页 (page), 饣 (food), 马 (horse), 车 (vehicle), 贝 (shell), 衤 (clothing), 阝 (left) (mound), 禾 (grain), 刂 (knife), 阝 (right) (city), 犭 (dog), 冫 (ice), 耳 (ear), 舟 (boat), 子 (child), 立 (stand), 殳 (weapon), and 欠 (owe).

Phonetic radical neighborhood size was determined based on *A Convenient Lookup of Phonetic Radical Pronunciations* (Zhou, 1980): large phonetic radical neighborhoods were defined as those forming >10 characters, such as 各 (ge), 古 (gu), 交 (jiao), 乍 (zha), 包 (bao), 卑 (bei), 干 (gan), 戈 (ge), 可 (ke), 台 (tai), 羊 (yang), 斤 (jin), 曷 (he), 方 (fang), 由 (you), 它 (ta), 皮 (pi), 圭 (gui), and 丁

(ding). Small phonetic radical neighborhoods were defined as those forming <5 characters, such as 另 (ling), 肯 (ken), 觉 (jue), 朵 (duo), 库 (ku), 户 (hu), 史 (shi), 君 (jun), 岁 (sui), 冒 (mao), 兄 (xiong), 节 (jie), 曲 (qu), 乎 (hu), 匀 (yun), 勾 (gou), 兰 (lan), and 巾 (jin).

Character frequency was based on the *Comprehensive Frequency Table of Chinese Characters in Social and Natural Sciences*. Mid-frequency characters were selected, with a mean frequency of 0.002845. The four character groups did not differ significantly in character frequency, $F(3, 177) = 1.47$, $p > 0.05$, or stroke number, $F(3, 177) = 2.21$, $p > 0.05$. Material information is presented in Table 1 .

Table 1 Example stimuli and characteristic information for real characters

Character Type	Examples	Mean Frequency (SD)	Mean Stroke Number (SD)
HH	扛, 吵, 泡	0.002443 (0.0026)	9.72 (1.79)
HL	捏, 吼, 泻	0.001551 (0.0011)	9.60 (2.00)
LH	衬, 陪, 狗	0.004279 (0.0099)	9.47 (2.39)
LL	裤, 随, 猿	0.003109 (0.0055)	9.57 (2.27)

Note: Values in parentheses are standard deviations. Character frequency is expressed as occurrences per million characters.

Filler stimuli consisted of 240 pseudo-characters created using the Private Character Editor program in Windows 2007. These pseudo-characters were formed by recombining components from real phonograms and met the requirements for semantic and phonetic radical neighborhood combinations (HH, HL, LH, LL). These pseudo-characters conformed to Chinese orthographic rules, with 60 items in each of the four groups. Stroke numbers ranged from 6 to 14, and phonetic radicals were pronounceable. Example pseudo-character stimuli are presented in Table 2 .

2.4 Apparatus and Procedure

The experiment was programmed using E-Prime. Stimuli were presented in 48-point Song font as black characters on a gray background on a desktop computer. The procedure was as follows: A fixation cross "+" appeared at the center of the screen for 500 ms, followed by the target stimulus for 800 ms, then a blank screen for 300 ms, and finally "???" for 4 s during which participants made their response. If no response was made within 4 s, the screen automatically advanced. A random blank interval of 300–1500 ms followed, allowing participants to blink and prepare for the next trial. Participants performed a lexical decision task, pressing the "J" key for real characters and the "F" key for pseudo-characters. Response mapping was counterbalanced across participants. The experimental flow is illustrated in Figure 1 [Figure 1: see original paper].

The formal experiment consisted of six blocks with rest periods between blocks. Each block contained 80 trials, with equal numbers of real and pseudo-characters. Block order and trial order within blocks were randomized. The program automatically recorded response times and accuracy, with timing precision of ±1 ms. A practice session preceded the formal experiment to familiarize participants with the procedure.

2.5 EEG Recording

EEG was recorded using a 32-channel BrainAmp MR plus amplifier and 32-channel actiCAP electrode caps (Brain Products, Germany) according to the international 10–20 system. The left mastoid served as the reference electrode, with horizontal and vertical electrooculograms (EOG) recorded simultaneously. Horizontal EOG electrodes were placed at the outer canthi of both eyes, and vertical EOG electrodes were placed above and below the left eye. Impedance at each electrode site was maintained below 5 kΩ (below 10 kΩ for EOG electrodes). The bandpass filter was 0.01–100 Hz, and the sampling rate was 1000 Hz per channel. During offline analysis, the reference was converted to averaged mastoids, and a 0.01–30 Hz bandpass filter was applied. Eye movement, muscle activity, and other artifacts were removed semi-automatically. The analysis epoch spanned from 200 ms pre-stimulus to 600 ms post-stimulus, with the 200 ms pre-stimulus interval serving as the baseline. Only trials with correct responses and amplitudes within ±100 µV were included in the final averaging.

2.6 Data Analysis and Statistics

To avoid contamination of ERP signals by behavioral responses, the experiment employed a delayed response paradigm; therefore, only accuracy rates were analyzed (response times were not statistically examined). Based on previous research (Carrasco-Ortiz, Midgley, Grainger, & Holcomb, 2017) and inspection of grand-averaged waveforms, two time windows were examined: 180–300 ms (P200) and 300–500 ms (N400). Mean amplitudes were calculated for each time window. Two factors were examined: hemisphere (left, midline, right) and anterior-posterior region (anterior, central, posterior), with nine electrode sites representing nine brain regions analyzed. Left hemisphere sites included F3, C3, and P3 (left anterior, left central, left posterior); midline sites included FZ, CZ, and PZ (midline anterior, midline central, midline posterior); and right hemisphere sites included F4, C4, and P4 (right anterior, right central, right posterior). Among these, F3, FZ, and F4 were classified as anterior regions, while P3, PZ, and P4 were classified as posterior regions.

Repeated measures ANOVAs were conducted on raw grand-averaged data for both time windows with the following factors: 2 (semantic radical neighborhood size: large/small) × 2 (phonetic radical neighborhood size: large/small) × 3 (hemisphere: left/midline/right) × 3 (anterior-posterior region: anterior/central/posterior).

3.1 Response Accuracy

Mean accuracy rates for HH, HL, LH, and LL characters were 94.86%, 95.46%, 93.82%, and 95.35%, respectively. ANOVA revealed no significant differences in accuracy among the four character types, $F(3, 87) = 0.49$, $p > 0.05$.

3.2 ERP Results

Grand-averaged waveforms for the four character types are shown in Figure 2 [Figure 2: see original paper].

3.2.1 180-300 ms Time Window (P200)

Repeated measures ANOVA revealed a significant main effect of phonetic radical neighborhood size, $F(1, 21) = 8.71$, $p = 0.008$, ^{2}p = 0.29. Characters with large phonetic radical neighborhoods elicited smaller P200 amplitudes than those with small phonetic radical neighborhoods. The interaction between semantic and phonetic radical neighborhood sizes was marginally significant, $F(1, 21) = 3.50$, $p = 0.075$, ^{2}p = 0.14, 95% CI = [-1.27, -0.22].

The three-way interaction among semantic radical neighborhood size, phonetic radical neighborhood size, and hemisphere was significant, $F(2, 42) = 4.25$, $p = 0.021$, ^{2}p = 0.17. Simple simple effects analysis revealed that at the large semantic radical neighborhood level, the main effect of phonetic radical neighborhood size was significant in the left hemisphere ($p = 0.003$, 95% CI = [-1.81, -0.44]), midline ($p < 0.001$, 95% CI = [-1.98, -0.66]), and right hemisphere ($p = 0.025$, 95% CI = [-1.54, -0.12]), with large phonetic radical neighborhoods eliciting smaller P200 amplitudes than small phonetic radical neighborhoods across all three regions. At the small semantic radical neighborhood level, no significant differences were found between large and small phonetic radical neighborhoods in any hemisphere, ps > 0.05.

The three-way interaction among semantic radical neighborhood size, phonetic radical neighborhood size, and anterior-posterior region was also significant, $F(2, 42) = 3.95$, $p = 0.027$, ^{2}p = 0.16. Simple simple effects analysis showed that at the large semantic radical neighborhood level, the main effect of phonetic radical neighborhood size was significant in anterior ($p < 0.001$, 95% CI = [-2.50, -1.01]) and central ($p = 0.001$, 95% CI = [-1.93, -0.61]) regions, with large phonetic radical neighborhoods eliciting smaller P200 amplitudes than small phonetic radical neighborhoods in these regions. At the small semantic radical neighborhood level, no significant differences were found between the two phonetic radical neighborhood sizes across anterior-posterior regions, ps > 0.05.

The interaction among semantic radical neighborhood size, hemisphere, and anterior-posterior region was significant, $F(4, 84) = 4.51$, $p = 0.002$, ^{2}p = 0.18. Simple simple effects analysis revealed that the main effect of semantic radical neighborhood size was only marginally significant in the right anterior region,

$F(1, 21) = 3.05$, $p = 0.095$, 95% CI = [-0.775, 0.068], and non-significant in all other regions. The interaction among phonetic radical neighborhood size, hemisphere, and anterior-posterior region was significant, $F(4, 84) = 3.54$, $p = 0.01$, ^{2}p = 0.14. Simple simple effects analysis showed that the main effect of phonetic radical neighborhood size was significant at electrodes F3 ($p = 0.002$, 95% CI = [-1.681, -0.446]), C3 ($p = 0.004$, 95% CI = [-1.264, -0.266]), P3 ($p = 0.077$, 95% CI = [-0.923, 0.052]), FZ ($p < 0.001$, 95% CI = [-1.83, -0.654]), CZ ($p = 0.014$, 95% CI = [-1.515, -0.189]), F4 ($p = 0.001$, 95% CI = [-1.862, -0.610]), and C4 ($p = 0.005$, 95% CI = [-1.526, -0.305]), indicating that large phonetic radical neighborhoods elicited smaller P200 amplitudes than small phonetic radical neighborhoods at all sites except P3 and P4. All other main effects and interactions were non-significant, ps > 0.05.

Mean amplitudes for the P200 component at different electrode sites are illustrated in Figure 3 [Figure 3: see original paper].

3.2.2 300-500 ms Time Window (N400)

Repeated measures ANOVA revealed a significant main effect of phonetic radical neighborhood size, $F(1, 21) = 23.63$, $p < 0.001$, ^{2}p = 0.53, 95% CI = [-1.977, -0.792]. Characters with large phonetic radical neighborhoods elicited larger N400 amplitudes than those with small phonetic radical neighborhoods. The interaction between semantic radical neighborhood size and anterior-posterior region was significant, $F(2, 42) = 4.85$, $p < 0.05$, ^{2}p = 0.19. Simple effects analysis showed that the main effect of semantic radical neighborhood size was marginally significant only in the posterior region, $p = 0.09$, 95% CI = [-0.081, 0.957], and non-significant in other regions.

The interaction between phonetic radical neighborhood size and anterior-posterior region was significant, $F(2, 42) = 34.54$, $p < 0.001$, ^{2}p = 0.62. Simple effects analysis revealed that the main effect of phonetic radical neighborhood size was significant in anterior ($p < 0.001$, 95% CI = [-2.521, -1.250]), central ($p < 0.001$, 95% CI = [-2.069, -0.838]), and posterior ($p < 0.01$, 95% CI = [-1.40, -0.229]) regions, with large phonetic radical neighborhoods eliciting larger N400 amplitudes than small phonetic radical neighborhoods across all regions. Moreover, the N400 amplitude differences between large and small phonetic radical neighborhoods decreased from anterior to posterior regions.

The three-way interaction among semantic radical neighborhood size, phonetic radical neighborhood size, and hemisphere was significant, $F(2, 42) = 4.27$, $p = 0.02$, ^{2}p = 0.17. Simple simple effects analysis showed that at the large semantic radical neighborhood level, the main effect of phonetic radical neighborhood size was significant in the left hemisphere ($p < 0.001$, 95% CI = [-2.454, -1.091]), midline ($p < 0.001$, 95% CI = [-2.568, -1.385]), and right hemisphere ($p < 0.001$, 95% CI = [-2.048, -0.673]), with large phonetic radical neighborhoods eliciting larger N400 amplitudes than small phonetic radical neighborhoods across all hemispheres. At the small semantic radical neighborhood level, the main effect of phonetic radical neighborhood size was also significant in the left hemisphere ($p = 0.032$, 95% CI = [-1.704, -0.085]), midline ($p = 0.023$, 95% CI = [-2.019, -0.165]), and right hemisphere ($p = 0.009$, 95% CI = [-2.082, -0.338]), with large phonetic radical neighborhoods eliciting larger N400 amplitudes. However, the amplitude difference between large and small phonetic radical neighborhoods was more pronounced at the large semantic radical neighborhood level than at the small semantic radical neighborhood level.

The interaction among semantic radical neighborhood size, hemisphere, and anterior-posterior region was significant, $F(4, 84) = 3.00$, $p = 0.023$, ^{2}p = 0.13. Simple simple effects analysis revealed that the main effect of semantic radical neighborhood size was significant only at electrode P4 ($p = 0.053$, 95% CI = [-0.008, 1.094]), indicating that characters with large semantic radical neighborhoods elicited larger N400 components than those with small semantic radical neighborhoods in the right posterior region. All other main effects and interactions were non-significant, ps > 0.05. Mean amplitudes for the N400 component at different electrode sites are shown in Figure 4 [Figure 4: see original paper].

3.3 ERP Differences Between Large and Small Phonetic Radical Neighborhoods at Different Semantic Radical Neighborhood Levels

Figure 5 [Figure 5: see original paper] shows the grand-averaged waveforms for characters with large and small phonetic radical neighborhoods at the large semantic radical neighborhood level, visually illustrating the processing differences between these conditions when semantic radicals have large neighborhoods.

Figure 6 [Figure 6: see original paper] shows the grand-averaged waveforms for characters with large and small phonetic radical neighborhoods at the small semantic radical neighborhood level, visually illustrating the processing differences between these conditions when semantic radicals have small neighborhoods.

Figure 7 [Figure 7: see original paper] displays topographic maps of difference waves (large phonetic radical neighborhood minus small phonetic radical neighborhood) for both semantic radical neighborhood levels across the 180–300 ms and 300–500 ms time windows, allowing direct comparison of the magnitude of differences between large and small phonetic radical neighborhoods at different semantic radical neighborhood levels. As shown in Figure 7, the scalp distribution of P200 was concentrated primarily in anterior regions, consistent with previous research (Lee et al., 2007; Hsu et al., 2009). The N400 scalp distribution was also primarily anterior, which may be related to the specific materials used in this study. Although the typical N400 scalp distribution is concentrated in central-posterior regions, its location can be influenced by materials and task demands. Research has found that while abstract words elicit N400 in central-posterior regions, concrete words and pictures elicit more anterior N400 distributions (Ganis, Kutas, & Sereno, 1996; Kounios & Holcomb, 1994). Other studies suggest that anterior N400 distributions are often associated with material familiarity, whereas posterior distributions are associated with semantic priming (Voss & Federmeier, 2010). The relatively anterior N400 distribution in this study may be related to radical frequency of occurrence (i.e., neighborhood size), though this speculation requires verification in future research.

This study investigated the roles of semantic and phonetic radical neighborhood sizes in phonogram recognition. Results showed that at the large semantic radical neighborhood level, characters with large phonetic radical neighborhoods elicited smaller P200 amplitudes than those with small phonetic radical neighborhoods; at the small semantic radical neighborhood level, no significant P200 amplitude differences were found between large and small phonetic radical neighborhoods. This indicates that in the early stage of phonogram processing, the phonetic radical neighborhood effect is modulated by semantic radical neighborhood size. The study also found that characters with large phonetic radical neighborhoods elicited larger N400 amplitudes than those with small phonetic radical neighborhoods, with this difference being more pronounced at the large semantic radical neighborhood level than at the small semantic radical neighborhood level. This suggests that in later processing stages, larger phonetic radical neighborhoods produce stronger semantic activation. Overall, phonetic radical neighborhood size consistently influences lexical access in phonogram recognition, but this effect is modulated by semantic radical neighborhood size.

4.1 On the Neighborhood Effects of Semantic and Phonetic Radicals in Phonogram Recognition

This study found that both semantic and phonetic radical neighborhood effects emerged during phonogram recognition, with distinct patterns across processing stages. In the P200 component, HH characters elicited smaller amplitudes than HL characters, whereas no P200 differences were observed between LH and LL characters. In the N400 component, characters with large phonetic radical neighborhoods elicited larger amplitudes, but the difference between HH and HL characters was greater than that between LH and LL characters. Radical neighborhood size reflects radical frequency of occurrence, which determines resource allocation in early processing stages. This study demonstrates that neither semantic nor phonetic radical neighborhood size independently influences phonogram processing; rather, their effects interact. When semantic radical frequency is high, its automatic activation is stronger, and to recognize characters quickly and efficiently, more cognitive resources are allocated to phonetic radicals, making recognition more dependent on phonetic radicals. Consequently, HH characters receive more activation than HL characters. When semantic radical frequency is low, recognition depends more on semantic radicals, and phonetic radical neighborhood size becomes less determinative. The N400 results indicate that in later stages of lexical access, phonetic radical neighborhood size consistently influences lexical access, suggesting that phonetic radicals play a more important role. Regardless of semantic radical frequency, larger phonetic radical neighborhoods produce stronger semantic activation, making later selection more difficult and resulting in inhibitory effects of phonetic radical neighborhood size (i.e., larger neighborhoods elicit more negative N400 amplitudes). Nevertheless, semantic radical neighborhood size also influences the manifestation of phonetic radical neighborhood effects. Therefore, determining whether semantic or phonetic radicals play a larger role in phonogram recognition requires analysis that considers both radical neighborhood size and processing stage.

These findings differ from those of Zhang et al. (2014), who found that phonetic radicals had attentional resource advantages over semantic radicals during phonological and semantic access, particularly in phonological retrieval tasks, but did not manipulate radical neighborhood sizes. The present study reveals that attentional resource advantage also depends on processing stage and semantic radical neighborhood size: in early processing, when semantic radicals have large neighborhoods, focusing on them does not facilitate rapid whole-character recognition, making it the most appropriate and economical strategy to shift attentional resources to phonetic radicals, thereby producing processing differences based on phonetic radical neighborhood size. When semantic radicals have small neighborhoods, attentional resources focus on semantic radical processing, and phonetic radical neighborhood size has no effect. In later processing stages, phonetic radicals receive more attention and their neighborhood size consistently influences lexical access, though semantic radical neighborhood size continues to exert some modulatory influence.

4.2 The Interplay Between Semantic and Phonetic Radical Neighborhood Effects in Lexical Access

This study found that both semantic and phonetic radical neighborhood attributes were activated during phonogram recognition, with a competitive relationship between them. From a cognitive resource perspective, resource allocation between semantic and phonetic radicals in phonogram recognition demonstrates a waxing-and-waning pattern: when orthographic activation of the semantic radical requires fewer resources, more resources are allocated to the phonetic radical. For phonetic radicals, recognition of small neighborhood phonetic radicals consumes more resources than large neighborhood phonetic radicals. When orthographic activation of the semantic radical requires more resources, the phonetic radical receives relatively fewer resources, and its contribution to phonogram recognition is reduced regardless of its neighborhood size. In semantic processing stages, the same waxing-and-waning pattern of resource allocation between semantic and phonetic radicals is observed. However, due to the precision required for semantic access, the role of phonetic radicals in whole-character semantic identification becomes prominent, and the cognitive resources they occupy become absolutely dominant. When semantic radicals have large neighborhoods, they occupy relatively fewer resources, making phonetic radical neighborhood effects more pronounced.

Overall, phonetic radical neighborhood size consistently influences lexical access in phonogram recognition. However, at both early and late processing stages, the effect of phonetic radical neighborhood size is modulated by semantic radical neighborhood size, though the degree of modulation differs. In early lexical recognition, when semantic radicals have large neighborhoods, phonetic radicals are dominant and receive more activation; when semantic radicals have small neighborhoods, they receive more attention and phonetic radical neighborhood effects are suppressed. In later lexical recognition stages, phonetic radicals again demonstrate processing advantages. In short, regardless of whether semantic radicals have large or small neighborhoods, phonetic radicals are crucial for phonogram recognition. These results are consistent with Hsiao’ s (2006, 2007) findings: for characters with large semantic radical neighborhoods, the semantic radical is less informative for character identification because many characters share it, making whole-character recognition more dependent on phonetic radicals. For characters with small semantic radical neighborhoods, the semantic radical can be processed quickly because few characters share it. Nevertheless, whole-character semantic access always requires phonetic radical information. Thus, phonetic radicals are more informative for whole-character access at both early and late processing stages.

Therefore, this study supports previous research affirming the role of phonetic radicals in phonogram processing (Hung et al., 2014; Wang et al., 2016; Zhang et al., 2014). However, it also reveals competition between semantic and phonetic radical processing: when semantic radicals have large neighborhoods, phonetic radicals receive more attention at both early and late processing stages, and phonetic radical neighborhood size consistently influences phonogram recognition. When semantic radicals have small neighborhoods, they receive more attention in early processing, but phonetic radical neighborhood attributes become more dominant in later processing, making phonetic radical neighborhood effects more salient.

4.3 Dynamic Interactions Between Semantic and Phonetic Radical Neighborhood Sizes in Phonogram Processing

This study demonstrates that semantic and phonetic radical neighborhood sizes jointly influence phonogram recognition. The neighborhood attributes of both radical types have definite effects on recognition, and phonetic radical neighborhood effects are modulated by semantic radical neighborhood size. Integrating the model of semantic radical function in phonogram lexical access (Chen & Zhang, 2012) and the modulation model of semantic radical influence on phonogram semantic processing (Wang & Zhang, 2016), semantic and phonetic radical neighborhood sizes exhibit dynamic interactions during phonogram processing. According to these models, lexical access involves three hierarchical levels: strokes, radicals, and compound characters. The joint action of semantic and phonetic radicals achieves phonogram lexical access. At the radical level, a modulation mechanism allocates cognitive resources to different processing pathways: (1) resources for semantic radicals to activate compound characters upward; (2) resources for phonetic radicals to activate compound characters upward; and (3) resources for semantic radicals to directly access the conceptual level. Within the lexical network, the upward activation resources from semantic and phonetic radicals jointly achieve whole-character access, which then activates conceptual nodes and ultimately accesses whole-character semantics. Readers' long-term language experience shapes this modulation mechanism, with radical frequency of occurrence (i.e., neighborhood size) being a crucial factor. Semantic and phonetic radical neighborhood sizes influence resource allocation within this modulation mechanism.

According to cognitive resource theory, phonogram processing requires cognitive resources, which are limited. The more resources required to process one radical, the fewer resources remain for processing other radicals. For Chinese character components, higher frequency of occurrence produces stronger automatic activation and consumes fewer cognitive resources, leaving more resources for processing other information. Semantic and phonetic radical neighborhood sizes affect resource allocation in the radical-level modulation mechanism, manifesting as competition for resources between semantic and phonetic radicals during phonogram processing. Semantic radical neighborhood size reflects the frequency with which semantic radicals form characters and modulates the activation level of phonetic radical neighborhood attributes. When semantic radicals have large neighborhoods and high frequency of occurrence, they are less informative for phonogram lexical access. To achieve rapid and accurate whole-character recognition, the modulation mechanism tends to allocate resources to phonetic radicals at both early and late processing stages, utilizing the distinctive function of phonetic radicals to achieve lexical access. Phonetic radicals also vary in frequency. In early processing stages, large phonetic radical neighborhoods have higher frequency, produce stronger automatic activation, and thus show facilitatory effects. In later processing stages, however, readers must select the target character from many activated neighborhood members, so larger neighborhoods produce more intense competition and inhibition, making target selection more difficult. This manifests as an inhibitory effect of phonetic radical neighborhood size. When semantic radicals have small neighborhoods, the semantic correspondence between the radical and its family members is more precise. In early processing, resource allocation favors small semantic radical neighborhoods, and readers attempt to achieve lexical access quickly by focusing on semantic radicals, leaving fewer resources for phonetic radicals. In later processing stages, the modulation mechanism increases resource allocation to phonetic radicals to facilitate rapid phonogram recognition. When phonetic radicals have large neighborhoods, more family members are activated, competition is stronger, and responses are slower, producing inhibitory effects of phonetic radical neighborhood size. Conversely, as phonetic radical neighborhoods become smaller, competition among family members decreases, and inhibitory effects are reduced.

In summary, semantic and phonetic radical neighborhood sizes jointly influence phonogram recognition. At different stages of lexical recognition, the resources obtained by semantic and phonetic radicals change depending on differences in their frequency of occurrence. This study has some limitations. For instance, whether radical character-forming ability and radical frequency influence the roles of semantic and phonetic radicals in phonogram recognition, and how these factors interact with radical neighborhood size to affect phonogram processing, remain unresolved questions for future research. Additionally, although this study' s interpretation of radical representation and processing in phonogram lexical access, based on previous models and reflecting dynamic changes in resource competition, is innovative, it requires further verification.

The findings have implications for Chinese character instruction. Future teaching might consider concentrated instruction based on radicals. According to this study' s results, concentrated radical instruction could be further differentiated into instruction focused on semantic radicals versus phonetic radicals. The former would help develop students' awareness of semantic radical neighborhoods, while the latter would foster awareness of phonetic radical neighborhoods. Moreover, these two approaches should be combined in character learning with different emphases for different character types: for characters with large semantic radical neighborhoods, instruction should emphasize phonetic radical differentiation, whereas for characters with small semantic radical neighborhoods, instruction should highlight the role of semantic radicals.

Conclusions

1. When semantic radicals have large neighborhoods, characters with large phonetic radical neighborhoods elicit smaller P200 amplitudes than those with small phonetic radical neighborhoods; when semantic radicals have small neighborhoods, no significant P200 amplitude differences emerge between large and small phonetic radical neighborhoods.
2. Characters with large phonetic radical neighborhoods elicit larger N400 amplitudes than those with small phonetic radical neighborhoods, with this difference being more pronounced when semantic radicals have large neighborhoods.
3. In phonogram recognition, a dynamic interplay exists between semantic and phonetic radicals, with their relative contributions waxing and waning in relation to processing stage and neighborhood size.

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Corresponding author: ZHANG Jijia, E-mail: zhangjj1955@163.com

Author Contributions:

WANG Juan: Conceptualized the research, designed the study protocol
MA Xuemei: Conducted the experiment
LI Bingbing: Collected, cleaned, and analyzed the data
WANG Juan, MA Xuemei: Drafted the manuscript
ZHANG Jijia: Revised the final version of the manuscript

Note: Figure translations are in progress. See original paper for figures.