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A Behavioral and ERP Study of the Role of Radical Position Distribution in Character Recognition: Evidence for Position-Specific Radical Representation

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A dissertation submitted in partial fulfilment of the requirements for the Bachelor of Science (Speech and Hearing Sciences), The University of Hong Kong, June 30, 2011.
Abstract

The present study investigated the role of radical position distribution in character recognition using a masked primed lexical decision task. Thirty-four normal adults (mean age: 22 years old) who were skilled readers of Chinese and native Cantonese speakers participated in the study. Radicals were used as the primes and complex characters were used as the targets. Participants were asked to judge whether the complex characters presented is a real character or not as quickly and accurately as possible. Response latencies, accuracy rates and ERP data were recorded. Behavioral data indicated that characters with position-biased related primes were recognized significantly faster than those with position-biased unrelated ones and the reverse was observed in position-neutral radical priming. ERP data only observed lexicality effect in N400 component. The findings have demonstrated the complex role of radical position distribution in character recognition and substantiated the argument for position-specific radical representation.
A Behavioral and ERP Study of the Role of Radical Position Distribution in Character Recognition: Evidence for Position-Specific Radical Representation

The Chinese writing system is a non-alphabetic script with words composed of characters. Each character occupies a squared-shaped space that is constructed by combination of stroke patterns. Particular grouping of strokes form radicals and they form constituent of complex characters (Hoosain, 1991). Radical can be defined as “contiguity of its strokes on the one hand and recurrence in different characters on the other.” (Taft & Zhu, 1997, p.761). Many complex characters contain radicals carrying phonetic (e.g. 椰, je21 contain phonetic radical 耶, je21) or semantic (e.g. 樹 “tree” contain semantic radical 木 “wood”) cues (Hoosain, 1991). Different spatial arrangement of radicals results in different complex character configurations. Horizontal (AB 說, ABC 辦), vertical (呆) and semi-enclosed (送) configuration (the reader may refer to Appendix A for phonetics and meanings of Chinese characters appeared in this paper) are some examples (Chen, 1996).

Studies investigating different aspects of radical feature using different tasks and paradigms had provided evidence supporting radical as an important level of representation in Chinese orthographic processing system. For example, considering radical form, Taft and Zhu (1997) found an effect of radical type frequency (number of characters containing that radical) and radical status (real or invented radical) in a lexical decision task. Considering radical function, Feldman and Siok (1997) found an effect of combinability (whether a radical can enter into few or many combinations in compound characters) for semantic and phonetic radicals in lexical decision. Zhou and Marslen-Wilson (1999) observed priming effects in a primed lexical decision task when the simple character target is semantically related to the phonetic radical in the complex character prime even though the prime and target were not semantically related.

While it is evident that the radical acts as a sublexical processing unit, a question
arises regarding its nature in orthographic processing. In Chinese script, radicals can be located in different positions of characters (Hoosain, 1991). For example, a radical (e.g. 田) can be located at the left (e.g. 略), the right (e.g. 細), the top (e.g. 胃) or the bottom (e.g. 雷) of characters. With respect to this feature, the issue of position specificity of radicals has been intensively investigated but with contradictory results.

On the one hand, Taft and Zhu (1997) found that character decision latency was influenced by radical position frequency (number of characters containing that radical in that position). Specifically, for two characters of equal character frequency, the one with high radical position frequency (e.g. 鴣 containing 鳥 which is located at the right of many characters) was easier to be recognized than the one with low radical position frequency (e.g. 門 containing 門 which is located at the right of few characters). Furthermore, Taft, Zhu, and Peng (1999) observed no interference in character recognition when transposable characters were presented in both lexical decision and naming tasks. Specifically, characters containing transposable radicals (e.g. 呆 and 杏) had response latencies and error rates comparable to those containing non-transposable radicals (e.g. 孕). This suggested that the same radical occurring in different positions were represented differently. In a priming study, Ding, Peng, and Taft (2004) further observed that the priming effect was significant when prime-target characters shared a radical in the same position (e.g. 軀-樞) but was not significant when they shared a radical in different positions (e.g. 歐-樞). In short, these results suggest that the radical is specified for position information which is sensitive to position frequency and could help distinguish the same radical unit occurring in different positions.

On the other hand, Tsang and Chen (2009) found that participants would mistakenly perceive the target character as being one of the two preceding source characters when target-source characters have shared radical(s). They found this effect to be comparable no
matter whether the shared radical is in the same (e.g. 拆 preceded by 結 and 桧) or different (e.g. 顔 preceded by 結 and 桧) positions across source-target. The authors argued this result to position-general radicals which would activate characters containing it in whatever position, therefore resulting in the same degree of illusory effect abovementioned. They also argued that the findings were consistent with Lai and Huang’s study (as cited in Tsang & Chen, 2009) which was not explicitly addressing radical position-specificity but nonetheless implied position-general over position-specific radical units.

The present study was therefore motivated by the inconsistent findings concerning position-specificity of radical representation, and would advance the discussion by exploring how radical position distribution influences character recognition. Previous literature studying radical position-specificity was based on the description of a specific position occupied by a radical. Another way of conceiving radical position is the relative distribution of a radical across all possible positions in characters containing it. As mentioned, radicals can occupy different positions in characters, it is worth noting that some radicals have a usual location. For example, some radicals (e.g. 冊) can occur in different positions but occur more frequently on the right (e.g. 瑚) than on the left (e.g. 刪) of a character (Biased radical distribution). However, some radicals (e.g. 公) occur equally frequently in different positions (e.g. 訟, 頌, 翁 etc) of a character (Neutral radical distribution). These two distribution patterns (biased and neutral) had probably been mixed up in the conceptualization of radical position in previous literature. For example, in Taft and Zhu’s (1997) second experiment, stimuli for each experimental condition were matched in terms of character frequency and position-sensitive radical frequency. However, according to the Hong Kong Corpus of Chinese Newspaper (Leung & Lau, 2011), for two characters matched on frequency (e.g. 珊: 87.97 per million, 松: 70.52 per million) and position-sensitive radical frequency (e.g. 冊 as
right radical: 100.45 per million, 公 as right radical: 112.19 per million), the critical radicals can be either with biased (冊) or neutral (公) distribution. Regarding this, radical position was manipulated in terms of relative position distribution which is a finer conceptualization to further investigate position-specificity of radical representation in the current study. If position information is specified at the radical level, such information should be sensitive to position distribution which is an inherent property of a radical. Specifically, if characters containing a radical with biased distribution are recognized differently to those containing neutrally distributed radicals, the argument for position-specific radicals will be substantiated.

To test this hypothesis, the present study employed a lexical decision task using a masked priming paradigm which can reveal how information in the prime influences target processing (Grainger & Jacob, 1999) with further processing of the prime being blocked by the mask (Holcomb & Grainger, 2006). Simple radicals with biased or neutral distribution were used as primes. Complex characters containing either type of prime were used as targets. According to Taft’s (2006) Chinese word processing model, words are processed hierarchically from feature, to radical, then to complex character and word level. Thus, higher-level character processing would be affected by lower-level radical processing. In other words, attributes of radical would influence character processing. If radicals with different position distributions are processed differently at lower-level radical processing, higher-level character processing will be affected. Therefore, by contrasting recognition of complex characters containing radical with different position distributions, the role of radical position distribution in character recognition can be revealed.

The role of radical position distribution was investigated in two prime durations, 48 ms and 96 ms. Theoretically, when the prime is presented for different durations, different amounts of information would be activated from the prime (Perfetti & Tan, 1998). The manipulation of prime duration would reveal how different amounts of pre-activated
information influence subsequent character recognition. Moreover, studies have shown that
orthographic facilitation occurred at short stimulus-onset asynchrony (SOA), 43 ms, while
phonological and semantic facilitation occurred at longer SOA, 85 ms (Perfetti & Liu, 2006).
The former suggested that early orthographic processing occurred at short SOA when the
prime character was not identified. The latter suggested that lexical processing occurred at
longer SOA when the prime character has been identified as having phonological and
semantic information. Therefore, manipulation of prime duration would also allow
comparison of radical position distribution effect in early pre-lexical and later lexical stages.

In addition to behavioral data, event-related potentials (ERPs) were also recorded.
While response time data can only reveal the final product of a sequence of cognitive events,
ERPs can reveal the temporal sequence of these events in character recognition (Lee, Tsai,
Huang, Hung & Tzeng, 2006). The time course of cognitive events revealed in different ERP
components would allow one to disentangle different stages and investigate the effect of
experiment manipulation at each stage or stages of processing (Luck, 2005). Among the ERP
components, N1, P2 and N400 components are relevant to the question of the present study.

In ERP studies of Chinese character processing, N1 and P2 component have been
found to be related to radical processing. Hsu, Tsai, Lee, and Tzeng (2009) observed an
interaction of phonetic combinability (combinability of phonetic radical) and phonological
consistency (degree of agreement in pronunciation among orthographic neighbours having
the same phonetic radical) at N170 (N1), and main effects of phonetic combinability and
phonological consistency at P200 (P2). Moreover, Hsiao, Shillcock, and Lee (2007) have
shown that both N1 and P2 components are sensitive to the difference between two types of
characters having opposite arrangement of semantic and phonetic radicals (one with semantic
radical on the left and phonetic radical on the right versus one with the opposite alignment).

On the other hand, N400 component has been identified to be linked to lexical level
processing as it is sensitive to semantic information associated with words (Holcomb, Grainger, & O'Rourke, 2002). In studies examining N400 in single word processing, pseudo words elicited larger N400 than real words (Holcomb & Neville, 1990, Holcomb et al., 2002).

Since early orthographic processing was the main interest of the present study, only lexicality effect was analyzed in this component to validate results obtained in the lexical decision task.

**Method**

**Participant**

Seventeen males and 17 females ranging in age from 18 to 25 (Mean: 22) years were recruited through e-mail/phone. All of them were skilled readers of traditional Chinese, native Cantonese speakers, right-handed, had normal/corrected to normal vision, normal hearing, received education in local mainstream schools, and had no history of head injury. They were randomly assigned to one of the prime duration conditions.

**Stimuli**

Character frequencies were obtained from the Hong Kong Corpus of Chinese Newspaper (Leung & Lau, 2011) and all stimuli were selected from it. For each radical, the percentage of occurrence in each possible position was calculated by dividing the sum of character frequencies of all the characters containing that radical in that position by the sum of character frequencies of all the characters containing that radical. Radicals that can be located in more than one possible position in characters and have over 64% occurrences in one position were classified as “Position-biased radical”. The rest were classified as “Position-neutral radical”. Only characters with horizontal (AB, ABC) and semi-enclosed configuration were used as targets. Prime-target relationships were divided into four conditions by manipulating radical position distribution (bias vs. neutral) and relatedness (related vs. unrelated), see Table 1 for illustration. In the related conditions, target characters were categorized as containing position-biased or -neutral radical. The former group included
characters containing the target radical in either a more frequently occurred or a less frequently occurred position. All targets were low frequency (< 100 in a million) characters, and matched in frequency and stroke number across conditions (all $F$’s < 1.27, $p$’s > .27).

Target characters were unrelated to the prime in terms of semantic and phonology as much as possible. The same number of pseudo characters having real radicals in their legal positions and sizes was created. They were constructed by combining the prime radicals with other radicals and were excluded from all the analyses except N400 analysis. All the prime-target pairs were pseudo-randomized for each participant to avoid successive exposure to the same prime. There were 37 primes and 222 targets (111 real characters and 111 pseudo characters).

The same set of stimuli was used for each prime duration condition.

Table 1

| Examples of Stimuli with Mean Character Frequency and Stroke Number in Each Condition |
|---------------------------------------------|----------------------------------|----------------------------------|
| Radical position distribution | Bias distribution | Neutral distribution |
| Relatedness | Related | Unrelated | Related | Unrelated |
| Prime Meaning | 多 | 変 | 変 | 変 |
| Target Meaning | 死 | 待 | 死 | 死 |
| Phonetics in International Phonetic Alphabet symbols | /tsay22/ | /tsa425/ | /jæ55/ | /puk2/ |
| Mean frequency per million | 15.15 (11.08) | 13.85 (10.41) | 21.17 (19.43) | 20.16 (19.01) |
| Mean stroke number | 11.91 (3.17) | 11.82 (3.17) | 11.62 (3.08) | 11.18 (3.32) |
| Number of trials$^a$ | 40 | 20 | 34 | 17 |

Note. Standard Deviations are given in parenthesis.

$^a$In the original design, the position of dominant versus subordinate was intended to be an independent variable. However, subsequently it was decided that it would be more reasonable to contrast radicals with respect to biased versus neutral distribution as an initial question. As a result, the number of unrelated trials is half of the trial number of the related trials.

Procedure

Stimuli (size: 5cm x 4.8cm, font: MingLiu, colour: yellow) were presented on a LCD monitor (refresh rate of 16ms per sweep) with a black background. Each trial consisted of a sequential presentation of a fixation cross, a blank page, a forward mask, a prime, a backward
mask, a target, a blank page, an eye-blink cue, and a blank page (see Figure 1 for schematic). The participant sat approximately 100 cm from the monitor in a dimly lit acoustically and electrically shielded booth. They were asked to press one button on the response box labeled “Yes” with one thumb if the target was a real Chinese character and another button labeled “No” with another thumb if it was not. They were asked to do the task as quickly and accurately as possible, and to refrain from blinking or moving during the interval from fixation to button pressing. The Yes/No labels assigned to the two buttons were counterbalanced across participants. Each participant received five practice trials and 222 randomized experimental trials in one test session. Breaks were provided between each experimental block of 55 or 56 trials. The E-Prime program was used to present stimuli, and record reaction time and accuracy. ERP data were collected and recorded by Neuroscan SynAmps2 data acquisition unit and Scan 4.5 software.

**Figure 1.** Schematic of a typical trial sequence with presentation duration under each slide.

**ERP Recording**

EEG signals were recorded from 128 Ag/AgCl electrodes held in place of an elastic cap (128 channel Quick-Cap, Neuromedical Supplies, Sterling, USA) with a common vertex reference between electrodes 63 and 64 (see Appendix B for electrode location). The ground electrode was located on the forehead between electrodes 59 and 60 (see Appendix B for electrode location). Additional electrodes were placed on the super- and infraorbital ridges of the left eye, and lateral to the outer canthi of each eye to record vertical and horizontal eye movements respectively. Electrode impedance was maintained below 10 kΩ whenever possible. The EEG signals were continuously sampled and digitized at a rate of 1000 Hz. The signals were amplified by SynAmps2 (Neuroscan, Inc.) with a bandpass of 0.05-200 Hz for
off-line analysis.

**ERP Data Processing**

Off-line analyses included bandpass filtering (0.05-30 Hz, zero phase shift mode, 12 dB), eye-blink reduction, epoched segmentation (with 400 ms pre-stimulus and 1000 ms post-stimulus onset intervals), baseline correction (using the pre-stimulus interval, -400-0 ms), trials rejection (excluding those contaminated by ocular movement or with voltage exceeding the range of ±60 μV) and finally re-referencing using the whole head average.

**Behavioral Data Statistical Analysis**

Trials with incorrect responses, response that exceeded 3 s and ±3 standard deviations from the mean for each participant were excluded from final analysis (12%). Mixed between-within participant and between-item Analysis of Variance tests (ANOVA) were performed on response time and accuracy rate with radical position distribution, relatedness and prime duration as the independent measures. Sphericity was met as there were only 2 levels for each within-participant variable. Multiple post-hoc comparisons for 2 way interactions were corrected using Bonferroni adjustment (alpha level = .05 / 6 = .008).

**ERP Data Statistical Analysis**

Electrodes selected for analyzing each component of interest were those recording stable signals and positioned as closely as possible to those chosen by Hsu et al. (2009) for analyzing the corresponding components. Two electrodes, 41 and 96, in the occipito-temporal region were selected for N1 component analysis; two electrodes, 34 and 89, in the frontal region were selected for P2 component analysis; three electrodes, 51, 63 and 77 in the centro-parietal region were selected for N400 component analysis. Using the grand average waveform of real characters for each prime duration condition, the time window corresponding to each component (N1 component: ±30 ms of the N1 peak, 60-120 ms; P2 component: ±35 ms of the P2 peak, 230-300 ms; N400 component: ±100 ms of the N400
peak, 290-490 ms) was selected to compute the mean amplitude for each participant. For each prime duration condition, mean amplitudes of each component were analyzed by repeated within-participant ANOVA with radical position distribution, relatedness and hemisphere (left and right) as independent variables for N1 and P2 component. Electrode location (51, 63 and 77) and lexicality served as the independent variables for N400 component. Note that separate ANOVAs were carried out for each prime duration condition in order to simplify the analysis. Assumptions of sphericity were met for N1 and P2 components analyses. Greenhouse-Geisser correction was applied to the N400 component analysis when the assumption of sphericity was not met (see Appendix C). Post-hoc t-tests for multiple comparisons were corrected with Bonferroni adjustments.

Results

Behavioral Analysis

Three participants, two in short and one in long prime duration; and three targets were excluded from analysis because of low accuracy (< 75% and < 25%, respectively). The assumption of equal variance was met for all participant and item analyses (all Levene’s test, \( p > .05 \)). Table 2 reports all the effects in response time.

Table 2

<table>
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<th>Effects</th>
<th>By Participant</th>
<th>By item</th>
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<tbody>
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<td>( F_1 )</td>
<td>( d.f. )</td>
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<td>Main effects</td>
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<td></td>
<td>( \text{Re} )</td>
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<tr>
<td></td>
<td>( \text{P}_\text{du} )</td>
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<tr>
<td>2 way interaction</td>
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<tr>
<td></td>
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<tr>
<td></td>
<td>( \text{Re} \times \text{P}_\text{du} )</td>
<td>0.45</td>
</tr>
<tr>
<td>3 way interaction</td>
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</tr>
<tr>
<td>Interaction at SS</td>
<td>( \text{Pos}_D \times \text{Re} ) at SS</td>
<td>10.21</td>
</tr>
<tr>
<td>Interaction at SL</td>
<td>( \text{Pos}_D \times \text{Re} ) at SL</td>
<td>18.31</td>
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Note: \( \text{Pos}_D \) = Radical position distribution effect, \( \text{Re} \) = Relatedness effect, \( \text{P}_\text{du} \) = Prime duration effect, SS = Short prime duration, SL = Long prime duration. \(* p < .05, ** p = .01, *** p < .001\).
No main effect of radical position distribution or relatedness was observed. Mean reaction times for position-biased radical primes ($M_1$: 708.32 ms, $SE_1$: 23.31; $M_2$: 721.58 ms, $SE_2$: 8.13) and position-neutral radical primes ($M_1$: 696.50 ms, $SE_1$: 21.51; $M_2$: 704.20 ms, $SE_2$: 8.60); for related ($M_1$: 700.96 ms, $SE_1$: 23.61; $M_2$: 711.89 ms, $SE_2$: 6.83) and unrelated ($M_1$: 703.86 ms, $SE_1$: 21.03; $M_2$: 713.90 ms, $SE_2$: 9.66) primes were comparable. Main effect of prime duration was only observed in the item but not participant analysis (Short: $M_1$: 679.14 ms, $SE_1$: 31.94; $M_2$: 690.79 ms, $SE_2$: 8.37, Long: $M_1$: 725.68 ms, $SE_1$: 30.93; $M_2$: 735.00 ms, $SE_2$: 8.37), indicating that primes presented longer would lengthen responses to target characters.

In addition, a significant two-way interaction between radical position distribution and relatedness was observed both by-participant and by-item. As seen in Figure 2 (left graph), responses to characters with position-biased related radical primes ($M_1$: 695.60 ms, $SE_1$: 24.07; $M_2$: 707.30 ms, $SE_2$: 9.88) were significantly faster than those with position-biased unrelated ones ($M_1$: 722.67 ms, $SE_1$: 23.06; $M_2$: 735.86 ms, $SE_2$: 13.82) by-participant but not by-item ($t_1$ (30) = 4.38, $p = .000$, $t_2$ (112) = 1.68, $p = .097$). However, a reversed pattern was observed in neutral radical distribution, whereby responses to characters with position-neutral related radical primes ($M_1$: 707.91 ms, $SE_1$: 23.72; $M_2$: 716.47 ms, $SE_2$: 10.53) were significantly slower than those with position-neutral unrelated ones ($M_1$: 686.45 ms, $SE_1$: 19.73; $M_2$: 691.93 ms, $SE_2$: 12.89) by-participant but not by-item ($t_1$ (30) = 2.86, $p = .008$, $t_2$ (100) = 1.41, $p = .163$). Responses to characters with position-neutral unrelated radical primes were also significantly faster than those with position-biased unrelated ones by-participant but not by-item ($t_1$ (30) = 4.30, $p = .000$, $t_2$ (70) = 2.31, $p = .024$). All other two-way interactions were not significant (all $F$’s < .46, $p$’s > .50).
Figure 2. Mean latency and standard error of two-way interaction between radical position distribution and relatedness with prime duration conditions collapsed (Left), in the short prime duration (Middle) and in the long prime duration (Right) across participants.

Note. * p = .008, ** p < .008, *** p < .001.

Furthermore, a significant three-way interaction between prime duration, radical position distribution and relatedness was found by-participant but not by-item, suggesting that the two-way radical position distribution by relatedness interaction observed was not uniform across prime durations. Post-hoc analyses separated by prime duration revealed that the interaction between radical position distribution and relatedness were significant by-participant but not by-item in the short prime duration; both by-participant and by-item in the long prime duration. Detailed analyses revealed that the interaction pattern was the same in both prime durations but stronger in the long prime duration. In the short prime duration (Figure 2, middle graph), responses to characters with position-biased related radical primes ($M_1$: 673.82 ms, $SE_1$: 22.86; $M_2$: 725.43 ms, $SE_2$: 14.90) were significantly faster than those with position-biased unrelated ones ($M_1$: 692.25 ms, $SE_1$: 21.64; $M_2$: 766.69 ms, $SE_2$: 22.44), by-participant but not by-item ($t_1$ (14) = 3.13, $p = .007$, $t_2$ (55) = 0.79, $p = .432$). All other differences were not significant (all $t's < 1.96, p's > .07$). In the long prime duration (Figure 2, right graph), responses to characters with position-biased related radical primes ($M_1$: 716.01 ms, $SE_1$: 41.60; $M_2$: 725.43 ms, $SE_2$: 14.90) were significantly faster than those with position-biased unrelated ones ($M_1$: 751.19 ms, $SE_1$: 39.22; $M_2$: 766.69 ms, $SE_2$: 22.44), by-participant but not by-item ($t_1$ (15) = 3.37, $p = .004$, $t_2$ (55) = 1.56, $p = .123$). On the other hand, responses to characters with position-neutral related radical primes ($M_1$: 735.60 ms, $SE_1$: 41.36; $M_2$: 745.69 ms, $SE_2$: 14.99) were marginally slower (after correction) than those with position-neutral unrelated ones ($M_1$: 699.92 ms, $SE_1$: 32.18; $M_2$: 702.17 ms, $SE_2$: 16.74),
by-participant but not by-item ($t_1 (15) = 2.87, p = .012, t_2 (49) = 1.79, p = .080$). Moreover, characters with position-neutral unrelated radical primes were responded significantly faster than those with position-biased unrelated ones by-participant but not by-item ($t_1 (15) = 4.16, p = .001, t_2 (34) = 2.26, p = .030$). All other differences were not significant (all $t$’s < 2.00, $p$’s > .06).

Error analysis revealed significant main effects of radical position distribution ($F_1 (1,29) = 7.50, p = .01, \eta^2 = .21$) and relatedness ($F_1 (1,29) = 9.08, p = .01, \eta^2 = .24$), by-participant but not by-item (all $F_2$’s < 3.00, $p$’s > .09). Participants were more accurate when characters were preceded by position-neutral radicals ($M_1$: 87.38%, $SE_1$: 1.03; $M_2$: 87.38%, $SE_2$: 1.65) than by position-biased ones ($M_1$: 83.65%, $SE_1$: 1.42; $M_2$: 83.65%, $SE_2$: 1.56) and to characters preceded by unrelated primes ($M_1$: 87.49%, $SE_1$: 1.25; $M_2$: 87.49%, $SE_2$: 1.86) than by related ones ($M_1$: 83.55%, $SE_1$: 1.20; $M_2$: 83.55%, $SE_2$: 1.31). A main effect of prime duration was also found by-participant and marginally significant by-item ($F_1 (1,29) = 4.47, p = .04, \eta^2 = .13; F_2 (1,208) = 3.67, p = .06, \eta^2 = .02$), where characters preceded by primes with a longer duration ($M_1$: 87.70%, $SE_1$: 1.44; $M_2$: 87.69%, $SE_2$: 1.61) were more accurate than primes presented for a short duration ($M_1$: 83.34%, $SE_1$: 1.48; $M_2$: 83.34%, $SE_2$: 1.61). Significant two-way interaction between radical position distribution and relatedness was also found in the participant but not item analysis ($F_1 (1,29) = 4.31, p = .05, \eta^2 = .13; F_2 (1,208) = 1.33, p = .25, \eta^2 = .01$). No speed-accuracy trade-off was evident for characters with position-neutral radical primes and for characters with unrelated primes as participants were more accurate at judging characters preceded by position-neutral unrelated radicals ($M_1$: 90.70%, $SE_1$: 1.30; $M_2$: 90.66%, $SE_2$: 2.08) than by position-neutral related ones ($M_1$: 84.16%, $SE_1$: 1.35; $M_2$: 84.10%, $SE_2$: 1.84) by-participant but not by-item ($t_1 (30) = 4.02, p = .000, t_2 (100) = 2.19, p = .031$) and to characters preceded by position-neutral unrelated radicals than by position-biased unrelated radicals ($M_1$: 84.38%, $SE_1$: 1.94; $M_2$: 84.31%, $SE_2$: 1.94).
2.62) by-participant but not by-item ($t_1 (30) = 2.96, p = .006$, $t_2 (70) = 1.87, p = .066$). Other interaction effects were not significant (all $F$’s < 1.00, $p$’s > .33).

**ERP Analysis**

Participants removed in behavioral analysis were also excluded from the ERP analysis. Figure 3 shows the topographic maps and Figure 4 shows the grand average ERPs waveforms for N1, P2 and N400 components.

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**Figure 3.** Topographic maps of ERP activities across conditions for N1, P2 and N400 component at time window of interest.  

**N1 component.** In both prime durations, there was no main effect of hemisphere (Short: $F(1,14) = 0.01, p = .91, \eta^2 = .00$; Long: $F(1,15) = 1.54, p = .23, \eta^2 = .10$), indicating that the mean amplitude at the left (Short: $M: 0.30 \mu V, SE: 0.79$; Long: $M: -0.96 \mu V, SE: 0.82$) and right (Short: $M: 0.22 \mu V, SE: 0.81$; Long: $M: -0.16 \mu V, SE: 0.53$) occipito-temporal sites were equally negative in N1. There was also no significant effect of radical position distribution (Short: $F(1,14) = 2.19, p = .16, \eta^2 = .14$; Long: $F(1,15) = 0.00, p = .97, \eta^2 = .00$) or relatedness (Short: $F(1,14) = 1.83, p = .20, \eta^2 = .12$; Long: $F(1,15) = 0.07, p = .80, \eta^2$
A Behavioral and ERP Study of Radical Feature

= .00), revealing that characters preceded by position-biased radicals (Short: $M$: 0.04 μV, $SE$: 0.76; Long: $M$: -0.57 μV, $SE$: 0.63), or by position-neutral radicals (Short: $M$: 0.47 μV, $SE$: 0.75; Long: $M$: -0.56 μV, $SE$: 0.61), and with related (Short: $M$: 0.02 μV, $SE$: 0.81; Long: $M$: -0.52 μV, $SE$: 0.68) or unrelated (Short: $M$: 0.50 μV, $SE$: 0.72; Long: $M$: -0.60 μV, $SE$: 0.58) primes elicited a negative N1 component of comparable amplitude. All interaction effects were not significant in both prime durations (see Figure 4 and refer to Appendix C for statistical results).

Figure 4. Grand average ERP waveforms in both prime durations at 7 representative electrodes for N1, P2 and N400 components. Note. FM = Forward mask, P = Prime, BM = Backward mask, Bias_Re = Position-biased related radical prime, Bias_UnRe = Position-biased unrelated radical prime, Neu_Re = Position-neutral related radical prime, Neu_UnRe = Position-neutral unrelated radical prime. Electrode location was indicated aside each graph. *$p$ ≈ .05, **$p$ < .05.
P2 component. In both prime durations, results revealed no main effects of hemisphere (Short: $F(1,14) = 0.17, p = .69, \eta^2 = .01$; Long: $F(1,15) = 1.17, p = .30, \eta^2 = .07$), suggesting that like the N1, the mean amplitude at the left (Short: $M$: 1.30 μV, $SE$: 0.53; Long: $M$: 3.93 μV, $SE$: 0.41) and right (Short: $M$: 1.19 μV, $SE$: 0.51; Long: $M$: 3.62 μV, $SE$: 0.50) frontal sites were equally positive in amplitude for the P2 component. There was also no main effect of radical position distribution (Short: $F(1,14) = 2.25, p = .16, \eta^2 = .14$; Long: $F(1,15) = 0.59, p = .46, \eta^2 = .04$) or relatedness (Short: $F(1,14) = 0.16, p = .70, \eta^2 = .01$; Long: $F(1,15) = 1.76, p = .20, \eta^2 = .11$), indicating that characters primed by position-biased radicals (Short: $M$: 0.88 μV, $SE$: 0.59; Long: $M$: 3.68 μV, $SE$: 0.42) or by position-neutral radicals (Short: $M$: 1.61 μV, $SE$: 0.53; Long: $M$: 3.87 μV, $SE$: 0.49), and by related (Short: $M$: 1.16 μV, $SE$: 0.59; Long: $M$: 3.65 μV, $SE$: 0.41) or unrelated (Short: $M$: 1.32 μV, $SE$: 0.50; Long: $M$: 3.90 μV, $SE$: 0.48) primes elicited similar positive amplitudes at P2. All interaction effects were not significant in both prime durations (see Figure 4 and refer to Appendix C for statistical results).

N400 component. In the short prime duration, a significant main effect of electrode location was observed ($F(2,13) = 4.45, p = .03, \eta^2 = .41$). Post-hoc comparisons indicated that target characters elicited a more negative-going N400 component at the middle ($M$: 1.09 μV, $SE$: 0.67) than at the right electrode ($M$: 1.66 μV, $SE$: 0.62) with marginal significance ($p$ = .06). Activities at the left electrode ($M$: 1.56 μV, $SE$: 0.61), however, were comparable in amplitude to middle and right electrodes. Moreover, a main effect of lexicality ($F(1,14) = 3.38, p = .09, \eta^2 = .19$) was marginally significant. Pseudo characters ($M$: 1.21 μV, $SE$: 0.68) elicited more negative-going N400 component than real characters ($M$: 1.67 μV, $SE$: 0.58).

In the long prime duration, significant main effect of lexicality was observed ($F(1,15) = 5.06, p = .04, \eta^2 = .25$), whereby pseudo characters ($M$: 1.74 μV, $SE$: 0.55) elicited a larger negative-going N400 component than real characters ($M$: 2.05 μV, $SE$: 0.56). No main effect
of electrode location was found \(F(2,14) = 1.91, p = .19, \eta^2 = .21\), indicating that ERP activities at left \((M: 1.97 \, \mu V, SE: 0.56)\), middle \((M: 1.68 \, \mu V, SE: 0.64)\) and right electrodes \((M: 2.03 \, \mu V, SE: 0.52)\) were equally negative-going in N400 epoch.

There was no significant electrode location by lexicality interaction in both prime duration conditions (see Figure 4 and refer to Appendix C for statistical results).

To summarize, the behavioral results showed that participant responded faster but less accurate when primes were presented for a shorter duration. In position-biased radical priming, facilitatory priming effect was observed in both short and long prime duration. In position-neutral radical priming, null priming effect was observed in short prime duration and inhibitory priming effect was observed in long prime duration. However, the ERP results only showed a main effect of lexicality, whereby pseudo characters had a larger N400 than real characters.

**Discussion**

This study has demonstrated the role of radical position distribution in character recognition, which consequently substantiated the argument for position-specific radical representation.

**The Role of Radical Position Distribution as Revealed From Behavioral Results**

As revealed from behavioral results of response latency, both short and long pre-exposure of position-biased radical facilitated complex character recognition whereas a short pre-exposure of position-neutral radical did not assist character recognition and a long pre-exposure of the same radical even inhibited the recognition. The dissimilar patterns of priming effects between radical position distributions and prime durations suggest that radical position distribution plays a complex role in character recognition.

In general, participants responded slower to targets with primes presented for a longer duration. This may suggest that longer prime exposure leads to stronger competition in
lexical decision. It is important to note that although targets were manipulated in terms of radical features, representations at the lexical level will also be activated in lexical decision. Therefore, the stronger confusion observed is likely due to competition between the target and prime-related characters which are pre-activated in the long but minimally so in short prime duration.

Addressing the specific role of radical position distribution, a two-way radical position distribution by relatedness interaction was observed. Specifically, position-biased radical priming effect was facilitatory whereas position-neutral radical priming effect was inhibitory. This may be accounted for with reference to the interactive-activation model for the Chinese orthographic system (Taft, 2006). Taft’s (2006) model suggested interaction between units within and across levels, and inhibitory links at radical level. Inhibitory links at lexical level were also suggested in Ding et al. (2004). In the model, activation of complex characters is mediated by simple character or radical unit through the activation of position-sensitive radical units (Taft, 2006). Incorporating the radical position distribution feature into the model (see Figure 5), when there is a more preferred radical position as in biased radical distribution, it is likely that fewer position-sensitive units of the same radical exists (交: <交, 交>) compared to that in neutral radical distribution (木: 木, 木, 木) with no preferred radical position.

![Figure 5](image.png)

**Figure 5.** Interactive-activation model with feature of radical position distribution integrated. *Note.* Arrows indicate activation pathways; dashed loops indicate inhibitory links. Thicker lines indicate stronger activation in priming. Appropriate units activated in target recognition are inside grey polygons.
When a radical is pre-activated in priming, it will send activation to each position-sensitive unit linked to it. With fewer position-sensitive units linked to a position-biased radical, each unit will receive more activation from the radical presumably due to less diverging resources allocation. Consequently, each position-sensitive unit linked to a position-biased radical will have a lower threshold level compared with that linked to a position-neutral radical.

When a complex character (狡) containing a position-biased radical (交) is presented, both appropriate (交>) and inappropriate (<交) position-sensitive units are activated as they are connected to the same position-general radical unit. Yet, the appropriate one will be more strongly activated due to the position information encoded in the complex character. This activation is expected to exceed the threshold for recognition and consequently suppresses other non-target units through the inhibitory links. In other words, with the facilitation of priming, competition between appropriate position-sensitive unit and inappropriate ones of a position-biased radical can be settled easily. This accounts for the facilitatory effect observed in position-biased radical priming. On the other hand, when a complex character (枚) containing a position-neutral radical (木) is presented, both appropriate (<木) and inappropriate (木>, 木, 木) position-sensitive units are similarly activated with the appropriate one being more strongly activated. However, this activation may not be enough for the recognition of the appropriate position-sensitive unit above threshold to suppress other competing units. In other words, pre-exposure of the prime is not enough to settle competition between appropriate position-sensitive unit and inappropriate ones of a position-neutral radical. This accounts for the inhibitory effect observed in position-neutral radical priming.

Nonetheless, this two-way radical position distribution by relatedness interaction was only evident in the long prime duration. In the short prime duration, position-biased radical
priming effect was still facilitatory but position-neutral radical priming was neither facilitatory nor inhibitory. The interaction pattern across prime duration may be attributed to the influence of lexical competition which only manifests in the long prime duration.

In the short prime duration, the orthographic system is expected to be pre-activated up to the radical level. Competition among position-sensitive units of a position-biased radical can be settled with facilitation of priming as discussed earlier. A facilitatory effect was therefore evident in position-biased radical priming. Yet, priming results in mild elevation of activation level perhaps just enough to offset the competition among position-sensitive units of a position-neutral radical. Therefore, null priming effect was seen in position-neutral radical priming.

In the long prime duration, one more level of competition, that between the actual target character and other pre-activated-characters containing the radical prime has to be settled. As discussed earlier, when a complex character containing a position-biased radical (狡) is presented after priming, the recognition level of the appropriate position-sensitive unit (交>) can be raised well above threshold to suppress inappropriate units (<交). Activation from the radical level can then be sent to characters linked to that appropriate unit (e.g. 狡, 皎), thus inhibiting pre-activated-characters linked to the inappropriate units (e.g. 效, 効). In other words, priming facilitates settling of both competitions at the radical level and character level, thus overall facilitatory priming effect was evident in position-biased radical priming. On the other hand, as mentioned above, when a complex character containing a position-neutral radical is presented (枚) after priming, the recognition level of appropriate position-sensitive unit (<木) can just reach the threshold for suppressing competing units (木>, 杓, 杖). As a consequence, characters linked to that appropriate unit (e.g. 枚) may not be activated to a level to suppress pre-activated-characters linked to the inappropriate units.
(e.g. 休, 杏). In other words, priming is just enough to facilitate settling of competition at radical level but not enough for that at character level. Hence, an overall inhibitory priming effect was detected in position-neutral radical priming.

Behavioral results of accuracy rate can also be accommodated by the above accounts. Target characters containing position-biased radical were more error-prone than those containing position-neutral ones. In the above account, inappropriate position-sensitive units linked to position-biased radical are more strongly activated, which may lead to stronger confusion in lexical decision. However, this should be interpreted cautiously as the effect was mainly driven by unrelated conditions (position-biased-unrelated controls were more error-prone than position-neutral-unrelated ones). In the unrelated conditions, all the pre-activated units (e.g. 交, 亻 when the prime 亻 is presented) are unrelated to the target units (e.g. 回 when the unrelated target 回 is presented). Therefore, the unrelated but more strongly activated position-sensitive units linked to position-biased radical may lead to stronger confusion. This was also reflected in the response latency as position-biased-unrelated controls were also responded slower than position-neutral-unrelated ones. In addition, related targets (e.g. 狡/枚) were more error-prone than unrelated targets (e.g. 回/抄). In the above account, inappropriate position-sensitive units of the related targets (e.g. 交/木) are pre-activated while those of unrelated targets (e.g. 回/少) are not, the former one may therefore bring about stronger confusion. Nonetheless, this should be interpreted with caution as the effect was mainly driven by position-neutral radical priming condition (position-neutral related targets were more error-prone than position-neutral unrelated ones). This may be attributed to the stronger confusion arisen from the pre-activation of multiple inappropriate position-sensitive units (木, 亻, 丂) linked to the position-neutral radical (木) in related priming (target: 枚). Finally, participants were less
accurate in judging characters with primes presented for a shorter duration. However, as a participant also responded more quickly in the short prime duration condition, it may be viewed as a speed-accuracy trade-off.

It is important to note that results obtained in this study were not confounded with radical function or specific position occupied by the prime radical, as both semantic and phonetic radicals were chosen as primes, and they occupied the left position in half of the targets and the right position in the rest.

**The Role of Radical Position Distribution as Revealed From ERP Results**

While behavioral data suggest that radical position distribution plays a role in orthographic processing, its effect was not reflected in ERPs, namely in the N1 and P2 components. ERP data only observed lexicality effect, with pseudo characters elicited larger N400 than real characters, which is compatible with previous findings (Holcomb & Neville, 1990, Holcomb et al., 2002).

N1 and P2 components have been associated with radical processing. The absence of radical position distribution effect observed in N1 component may be accounted for by the model illustrated in Figure 5. As shown in the model, position-sensitive units are activated via a position-general radical unit. Since N1 is an early component (Fonaryova Key, Dove, & Maguire, 2005), it is possible that at that time window (approx. 90ms), position-general radical is activated while position-sensitive units linked to it are not. In other words, position information of a radical is presumably not yet processed at this time window, thus processing of position-biased and position-neutral radical cannot be differentiated in N1 component. Along this line, radical position distribution effect is expected to be observed at later time window, such as that corresponding to P2 component (approx. 265ms). However, the waveforms of P2 component were generally noisy due to poor recording quality of the representative electrodes for P2 component and data cannot be collected from more
participants due to time constraint. As a result, whether or not radical position distribution effect can be observed in P2 component is yet to be certain. This can be further investigated in the next study when data from more participants are collected and the recording quality for P2 component is monitored more carefully.

Moreover, it may be reasonable to analyze radical position distribution effect in N400 component. As suggested by the behavioral results discussed earlier, characters containing position-biased radical and those containing position-neutral one are processed differently at the lexical level. This implies that radical position distribution effect may manifest in the N400 component. In fact, there has been evidence suggesting that lexical processing as revealed in N400 is sensitive to information from subunits. For example, Lee et al. (2006) found significantly greater N400 when the phonetic radical of a complex character prime was semantically related to the target even though the prime and target were not semantically related. Furthermore, behavioral data in long prime duration were interpreted as indicating that lexical competition can be settled more efficiently in position-biased radical priming but not in position-neutral radical priming. This can be verified by studying N400 component as Holcomb et al. (2002), Lee et al. (2007) and Hsu et al. (2009) have observed that N400 is sensitive to lexical competition. Unfortunately, due to time constraint, the radical position distribution effect was not further analyzed in N400 component. This can be one of the directions for the next study. Note that the present account of the behavioral results is independent of character neighborhood size, but it is preferably controlled for if N400 component is to be further analyzed.

**Additional Future Research Direction**

Besides exploring the effect of radical position distribution in P2 and N400, the processing of position-biased radicals in more preferred contrary to less preferred positions is also worth investigating. With the present account, it may be possible that the preferred
position-sensitive unit is more strongly represented than the less preferred one.

**Limitation**

It is also worth pointing out an apparent limitation in the current design, i.e. the unequal numbers of trials between related and unrelated conditions.

**Conclusion**

Behavioral results in the present study have contributed to our understanding of the role of radical position distribution in character recognition. The findings support the claims that there are position-specific radical representations, perhaps in addition to position-general ones. Moreover, our manipulation of radical position is different from previous work in which radical position is conceived as the specific position occupied within characters. By conceptualizing radical position in a finer way in the current study, i.e. relative distribution across characters, the argument for position-specific radical representation is further supported.
References


Acknowledgement

I would like to extend my sincere thanks to my supervisor, Dr. Sam Po Law and co-supervisor, Dr. I-Fan Su, for their advice, guidance, support and encouragement throughout the entire process of the study. Under their guidance, I had developed a critical mind and learnt a lot about being a thoughtful researcher. Throughout the development of the study, I had encountered moment of exhaustion, frustration and disappointment. However, the enormous support from my supervisors and classmates had helped me to overcome all these moments. I enjoyed working in this team and especially valued the time we worked together for data collection. Also, I would like to express my sincere gratitude to all the participants for their precious time spent and patience. Lastly, I would like to thank my friends and family for their enduring support, especially to my friends for participating in the pilot study and my brother for being our last participant.
Appendix A – Phonetics and meaning of Chinese characters used throughout the paper

<table>
<thead>
<tr>
<th>Character</th>
<th>Phonetics</th>
<th>Meaning</th>
</tr>
</thead>
<tbody>
<tr>
<td>椰(p.3)</td>
<td>/je21/</td>
<td>“coconut tree”</td>
</tr>
<tr>
<td>耶(p.3)</td>
<td>/je21/</td>
<td>“transliteration of English names”</td>
</tr>
<tr>
<td>樹(p.3)</td>
<td>/syu33/</td>
<td>“tree”</td>
</tr>
<tr>
<td>木(p.3)</td>
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<td>“wood”</td>
</tr>
<tr>
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<td>/syut3/</td>
<td>“say”</td>
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*Note: Pages on which the character appeared were given in parenthesis*
Appendix B: Electrode location
Appendix C: Statistical results of interaction effect for N1, P2 and N400 component.

## Interaction effects for N1, P2 and N400 component

<table>
<thead>
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<th>Effects</th>
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<th>Long Prime duration</th>
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<td>Hemi x Rad_Po</td>
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<td>Rad_Po x Re</td>
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<td>Hemi x Rad_Po</td>
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<td>Electrode x Lexicality</td>
<td>(F(1.18, 16.50) = 0.13), (p = .77), (\eta^2 = .01)</td>
<td>(F(1.23, 18.38) = 0.99), (p = .35), (\eta^2 = .06)</td>
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*Note.* Greenhouse-Geisser correction was applied to effects violated assumption of sphericity. Compo = ERP component, Hemi = Hemispheric effect, Rad_Po = Radical position effect, Re = Relatedness effect, Electrode = Electrode location effect.
Appendix D: Stimuli list of target character

Target characters for each condition

<table>
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