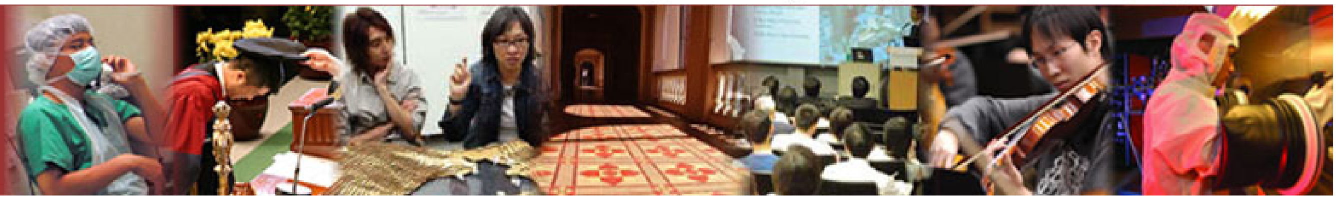

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A Study of the Role of Structural Configuration in Visual Recognition of Chinese Characters Using Primed Lexical Decision Task

Lee Ho Mei, Rosanna

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A Study of the Role of Structural Configuration in Visual Recognition of Chinese Characters Using Primed Lexical Decision Task

Lee Ho Mei, Rosanna

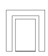
Abstract

The Lexicality Constituency Model (LCM) (Perfetti, Liu and Tan, 2006) postulated the role of structural configuration in Chinese character recognition, however, with no concluding evidence from past research. To investigate the role of configuration, a primed lexical decision task was used. The configuration and the radicals of the primes were manipulated. Behavioral data and electrophysiological data were collected from 34 Cantonese-speaking individuals. The behavioral results indicated an interdependent relationship of radicals and configuration, whereby the effect of radical similarity was only exhibited when the primes had the same configuration as the targets. Interestingly, the electrophysiological results suggested that the effect of radicals and configuration were independent of each other. A modified LCM was thus proposed to account for the present findings.

Keywords: configuration, radical, Lexical Constituency Model, character recognition

A Study of the Role of Structural Configuration in Visual Recognition of Chinese Characters Using Primed Lexical Decision Task

The logographic Chinese script has distinct orthographic properties from that of alphabetic scripts like English. First, Chinese characters can be hierarchically divided into different levels, with the two fundamental levels being strokes and radicals, while that of English are visual features and letters. The basic composite unit, consisting of lines and dots, of a Chinese character is called ‘stroke’. A particular combination of contiguous strokes, which appears recurrently as orthographic unit, is called radical (Taft & Zhu, 1997). Two radicals may combine together to form phonetic compounds, which made up of 90% of Chinese characters (Hoosain, 1991). In a phonetic compound, one radical provides information regarding the meaning of the character and is termed ‘semantic radical’, while the other radical, the ‘phonetic radical’, provides information regarding the pronunciation of the character (Hoosain, 1991). For example, for the phonetic compound ‘媽’ (/maa1/, mother), the semantic radical ‘女’ (/neoi5/, female) gives clue to the meaning, and the phonetic radical ‘馬’ (/maa5/, horse) gives clue to the pronunciation.

Second, as opposed to the linearly arranged alphabetic scripts with variable lengths, each Chinese character occupies a relatively constant square-shape size with different structural configurations. Structural configuration can be defined as the relative spatial relationship among the radicals of a character (Huang & Wang, 1992) and can be conceptualized as ‘spatial slots’ (Perfetti & Liu, 2006, p.231) in which the radicals occupy. According to Lui, Leung, Law and Fung (2010), the most common structural configurations have radicals arranged (1) horizontally with the left-right spatial slots  like 嫁 (/gaa3/, marry), (2) vertically with top-bottom spatial slots  such as 爸 (/baa1/, father) and (3) by enclosing a unit partially  as in 鬧 (/naau6/, scold) or completely inside another unit  like 困 (/kwan3/, trapped). These three types of configuration constituted 94% of all the Chinese characters acquired during primary school years, with the left-right configurations being the most common structural representation, making up of approximately 60% of those characters learnt (Lui et al., 2010).

There are two major schools of thought regarding the structural representation of characters. In the *Lexical Constituency Model* (LCM) as indicated in Figure 1, Perfetti and Liu (2006) proposed that word identification involves the specification of three mutually dependent constituents, which are orthography, phonology and semantics. They further proposed that visual word recognition begins with holistic analysis of the Chinese character in terms of its structural configurations. This spatial relationship specifies the order of arrangement of radicals, which are the basic input units channeled to the orthography constituent as shown in Figure 1.

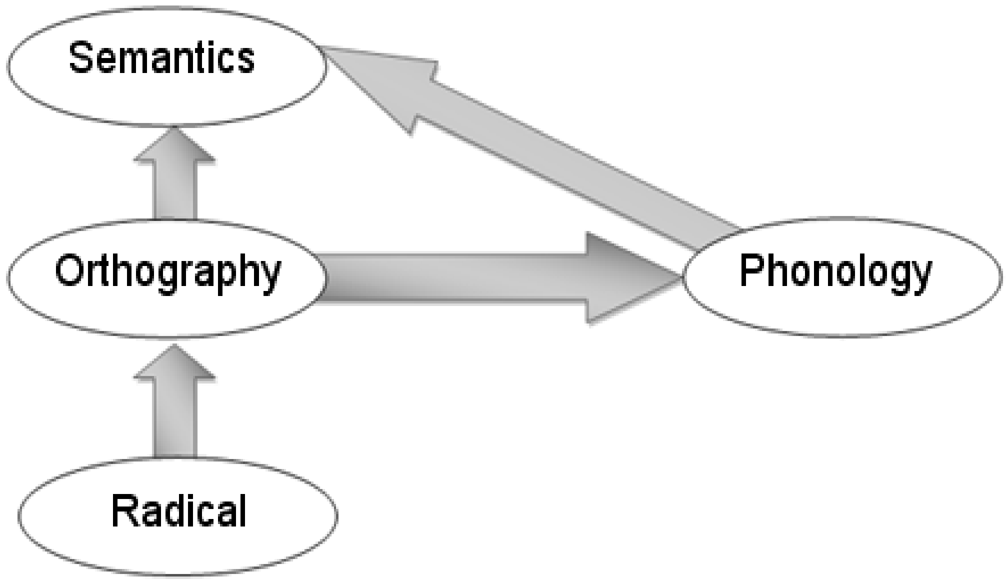


Figure 1. The Lexical Constituency Model (Perfetti & Liu, 2006)

The findings from Perfetti and Tan (1998) lent support to this model. In their study using a primed naming task, participants were required to name a target character after a brief exposure of the prime character. Perfetti and Tan (1998) found graphic primes, which were visually similar to the target character, provided the initial facilitation at 43ms Stimulation Onset Asynchrony (SOA, the time interval between the presentation of prime and target), followed by facilitation from phonological prime at 57ms SOA and semantic prime at 85ms SOA. They argued that these findings revealed the time course of the involvement of the three constituents, in which graphical information initiated the word identification process.

However, the results obtained from Perfetti and Tan (1998) should be interpreted with caution. First, in that study, the properties of the graphic primes used were not carefully manipulated, resulting in some primes being graphically similar to the targets, while 79% of the primes share one radical with the target. Therefore, the priming effect observed can be due to priming by the same radicals instead of the graphical structures. This view is supported by Ding, Peng, and Taft (2004) who only found radical priming effect but no priming when using primes which are graphically similar to the targets in a lexical decision task. Second, Perfetti and Tan (1998) did not control for the relative frequency between the primes and targets. This renders their results hard to interpret as Segui and Grainger (1990) found inhibition when orthographically-related prime was of a higher frequency than that of the target and vice versa. Furthermore, most of their results were not replicable. Contradictory results, in which inhibitory but not facilitative effects of graphically-similar primes, were found in Chen and Shu (2001) even when they used the same testing stimuli and experimental design as Perfetti and Tan (1998). Similarly, Wu and Chou (2000) also found graphical inhibition present with orthographically-related primes in a lexical decision task.

On the other hand, Yeh and Li (2002), using a visual search paradigm, have found that similar structural configurations and similar radicals between distracters and targets would greatly slow down the rate of identification, thus providing convergent evidence for LCM. Supporting evidence also came from a study by Shen and Forster (1999), who observed graphic priming effects at SOA 50ms for both simple and compound characters when the relative frequency of primes and targets were carefully controlled. These conflicting findings complicated the interpretation of the role that structural configurations may play in visual word recognition.

Another group of researchers (Taft & Zhu, 1997; Taft, Zhu & Peng, 1999; Ding, Peng, & Taft, 2004) used the *Multi-Level Interactive-Activation Model* to explain the processing of Chinese words. In this model, sub-character information is represented in three hierarchical levels including graphic features, radicals and whole character. In a study by Taft and Zhu (1997) using characters with the left-right configuration as targets in a lexical decision task, they found that response latencies were sensitive to the frequency of the radicals on the right but not on the left. Based on this finding, Taft and Zhu (1997) argued that Chinese characters were not being viewed holistically, but instead, processing of a character started from left to right. However, Feldman and Siok (1997) criticized this view as ignoring the unique structural representations of Chinese and questioned how this notion can be applied to characters with different configurations.

Apart from that, Taft, Zhu and Peng (1999) also proposed that radicals are position-sensitive and carry position-specific information. For example, the left, right, top and bottom positions in which the same radical may appear in a character would have four position-specific representations. They based this argument on the findings that characters with transposable radicals like '呆' (/ngoi4/, dull) and '杏' (/hang6/, apricot) were not confused with each other. Tsang and Chen (2009) challenged this claim by using a false matching task. They found that false matching resulted whenever there was one common radical, irrespective to its position, in the source character, hence, supporting position-general radicals.

In short, neither model has examined Chinese characters with different configurations. The relative role played by positional-specific information of radicals and the holistic structural configuration is still not resolved. Moreover, manipulation of both radical position and the structural configuration will almost always be confounded with each other. Hence, in this study, the role of structural configuration in visual recognition of words was focused on and thoroughly studied using a primed lexical decision task with electrophysiological recordings.

The present study used the masked priming paradigm, which is a technique referring to the brief presentation of a prime stimulus sandwiched between the forward and backward mask, prior to the presentation of the target stimulus (Forster, 1998). The forward and backward masks serve to minimize the prime visibility so as to rule out the possibility that any priming effect observed be attributed to predictive strategies (Forster, 1998). It should be highlighted that information extracted from the prime was not processed as an independent perceptual entity. Instead, it was integrated with the information provided by the target. Thus, this masked priming technique was especially useful in the current study for investigating the information that was relevant in Chinese characters recognition by manipulating the properties of the primes. The extent of information extracted from the prime could be controlled by manipulating the priming duration. Past studies have observed Chinese orthographic priming effect with priming duration from 43 to 50 ms (Shen & Forster, 1999; Feldman & Siok, 1999a; Perfetti & Tan, 1998). As the monitor available in this experiment has a refresh rate of 60Hz, a priming duration of 48 ms (equivalent to 3 sweeps) was chosen

In addition to collecting behavioural data of response time (RT) and accuracy, which only provide us with the overt response of the participants after they have undergone a series of mental operation, the present investigation was aided by the use of event-related potential (ERP). The electrophysiological data time-locked to specific stimulus events, may reflect the rapid underlying perceptual and cognitive processes because of its high temporal resolution and real-time imaging (Bentin, Mouchetant-Rostaing, Giard, Echallier & Pernier, 1999; Fonaryova Key, Dove & Maguire, 2005). In this study which aimed to investigate early orthographic processes, these covert cognitive processes might have been overlooked without the use of ERP.

In our experiment, the three ERP components chosen were N1, P2 and N400 measured in the occipital region, frontal region, and central-parietal region respectively. While the N400 component would only be analyzed for its lexicality effect, both the visual N1 and P2 involved in the early orthographic processing would be analyzed in depth. N1 is functionally associated with spatial properties of stimuli (Heinze, Luck, Mangun & Hillyard, 1990). Also, according to Grainger and Holcomb (2009), N150 (or N1) reflects visual features processing, and with increased feature similarity between the prime and target, more negativity in amplitude is observed. In literature of Chinese character processing, N1 was found to be related to radical processing. Hsiao, Shillcock and Lavidor (2007) reported that when semantic radicals were located on the left hand side, a more negativity of the ERP component N1 was observed at the left hemisphere as compared to the right. On the other hand, P2 was associated with graphical processing as Liu, Perfetti and Hart (2003) found that the amplitude of P2 was attenuated when graphically-similar prime was presented prior to the target. Furthermore, in a study by Kong, Zhang, Kang, Du, Zhang and Wang (2010) using a semantic judgment task, a greater positivity of P2 was observed when the prime was phonologically similar to the target. Thus, P2 is sensitive to both orthographic and phonologic processing in Chinese. The ERP component N400 reveals long term semantic memory use during semantic processing and integration (Kutas & Federmeier, 2000). The easier it is to access the semantic information in the long term memory, the less negative the amplitude of N400 (Holcomb & Grainger, 2009).

In the present study, a primed lexical decision task was carried out. The participants had to decide whether the target was a real character or not after a brief presentation of the prime. The configurations and ‘radicals’ of the primes were manipulated in order to investigate the role played by configuration in word recognition. Manipulation of ‘radicals’, apart from referring to the manipulation of the orthographic units, also included manipulation of symbols made up by blocks. The term ‘radical’ was chosen over ‘component’ so as to avoid confusion with ERP components. Conditions involving blocks were included to investigate whether non-linguistic stimulus which only specified the spatial relationship would be able to produce a priming effect.

In the lexical constituency model, with its consideration given to the radicals and spatial relationships among radicals, one would expect the participants to respond fastest to targets if the target has the same configuration and radicals as that of the prime; but to respond slowest to targets if the target and prime have different configurations and radicals. Also, if configuration has a role to play during character recognition, conditions with primes having the same configuration as the targets would have a larger negativity at N1 or less positive amplitude at P2 than conditions with different configuration. If there is an effect of radical similarity, then conditions with prime having the same radicals as the targets would exhibit a P2 with reduced positivity when compared to priming conditions with different radicals. Lexicality effect would be observed at N400 in which pseudo characters showed a more negative N400 than real characters.

Method

Participants

Thirty-four right-handed native Cantonese-speaking volunteers within the age of 18 to 25 years old (M = 21.52, SD = 1.60, male: 17, female: 17) were recruited. They all had completed their secondary education in local mainstream schools and had not lived outside of Hong Kong for more than 2 years. All of them had corrected-to/normal vision, normal hearing, without any neurological disorder and indicated no prior history of reading difficulties. Edinburgh Handedness questionnaire (Oldfield, 1971) was used to measure handedness.

Materials

All the stimuli were of size 5 cm x 4.8 cm and they were presented in yellow, MingLiu font on a black background (See Appendix A for the full list of targets and primes). The targets included thirty real characters and thirty pseudo characters. The real character targets used were less than 80 per million in printed frequency according to Hong Kong Corpus of Chinese NewsPaper (HKCCNP) (Leung & Lau, 2011) and the number of strokes of these characters ranges from 7 to 16 (M = 10.77, SD = 2.60). All real character targets used were not regular phonetic compound and each of them consisted of two radicals. The pseudo character targets were generated by re-arranging the radicals of the thirty real characters. For example, the pseudo character target ‘’ was formed by combining the radical of ‘女’ (/neoi5/, girl) and ‘立’ (/laap6/, stand) from the real character target ‘姚’ (/jiu4/, handsome) and ‘粒’ (/lap1/, granule) respectively. It should be noted that all the pseudo character targets were treated as fillers in this experiment and they were stroke-matched to the real-character targets. The primes were created by manipulating the two independent variables: (1) the configuration (2 levels: same or different configuration), and (2) the radicals (3 levels: symbol, same or different radicals) respective to the real character targets. As a results, each target character (e.g. 峴, /jin6/, a steep hill) was paired with six types of primes. They were: (1) same configuration-same radical (SCSR) (e.g.); (2) different configuration-same radical (DCSR) (e.g. ); (3) same configuration-different radical (SCDR) (e.g.); (4) different configuration-different radical (DCDR) (e.g.); (5) same configuration-symbol (SCSY) (e.g. ); (6) different configuration-symbol (DCSY) (e.g. ). Four of the priming conditions (i.e. SCSR, DCSR, SCDR, DCDR) were pseudo characters with total number of instances in which components appearing in legitimate positions in real characters matched across the conditions. These four types of primes were stroke-matched to their corresponding targets. The symbol conditions were made up of two blocks which resembled the definition of structural configuration proposed by Perfetti and Liu (2006).

Procedure

A primed lexical decision task was carried out. The participants were seated in front of a LCD monitor (16ms per sweep), which was at a distance of approximately 100 cm, in an electrically and acoustically shielded room. Each participant underwent 15 practice trials before the experiment and was given 360 experimental trials evenly divided into six blocks. The sequence of presentation of blocks was randomized across participants and the items within each block were pseudo-randomized to avoid consecutive presentation of target characters. Excluding electrode placement procedures, the entire test session lasted about 1.5 hour for each participant. Participants were allowed to take breaks in between blocks for as long as they needed. Before the experiment began, the participants were instructed to keep their movements and eye blinks minimal, and the effects of eye and body movements to the electroencephalography (EEG) signals were also shown to them. The experimental trial began with a fixation cross lasting 500 ms, followed by a blank page which remained for 500 to 700 ms to reduce the anticipation effect of the subjects. The exact duration of the blank page was varied randomly with an average of 600.07 ms. A forward mask lasting for 100 ms was then followed sequentially by the presentation of the prime for 48 ms, backward mask of 16 ms and the target, which remained on the screen until the participant made a response using keypress. Participants were instructed to indicate whether the target was a real Chinese character as quickly and accurately as possible. After a response, a blank screen lasting 500 ms was shown, followed sequentially by a 500 ms 'eye blink' cue and another blank screen for a random duration within 800 ms to 1000 ms with an average of 896.78 ms. The eye blink cue served to signal the participant to blink before the next trial began. A trial sequence is shown in Figure 2. The E-prime program was used to present the stimuli and to measure RT and the accuracy of the response. Across all the participants, the response hand for lexical decision was counter-balanced.

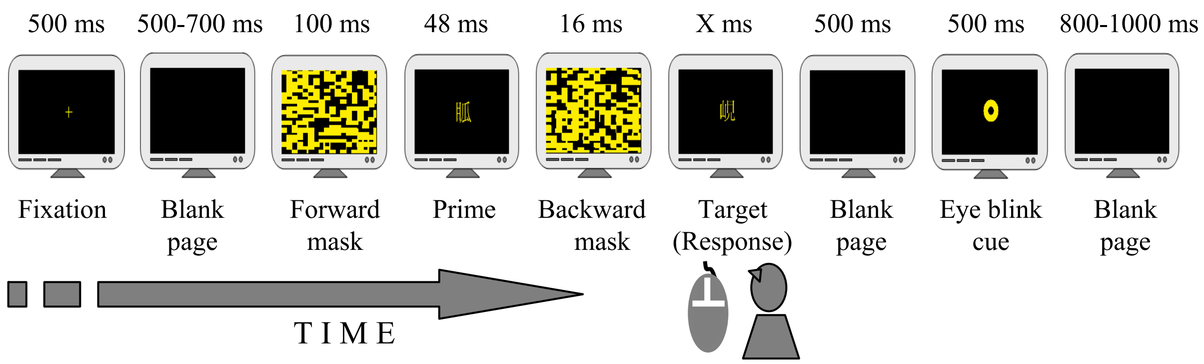


Figure 2. Experimental trial sequence of the primed lexical decision task

EEG recording and pre-processing

The EEG signals were recorded from 128 Ag/AgCl electrodes (QuikCap, Neuromedical Supplies, Sterling, USA) with a common vertex reference electrode located between electrodes 63 (Cz) and 64 (CPz), and the ground electrode positioned anterior to electrode 60 (Fz) on the forehead. Two electrodes placed on the supra- and infraorbital ridges of the left eye was to measure vertical eye movements (VEOG) while the horizontal eye movements (HEOG) were measured by another pair of electrodes placed lateral to the outer canthus of both eyes (see Appendix B for the electrode montage). Electrode impedance was maintained below 10 KΩ as much as possible. Continuous recording and digitization of the EEG signals at a rate of 1000Hz were then followed by the use of SynAmps2 ® (Neuroscan, Inc.) amplifiers at a band-pass filter of 0.05-200 Hz to amplify the signals for off-line analysis.

For the off-line analysis, first, bad channels for each participant were deleted. Then, the continuous wave was filtered using a band-pass filter, specifying the low-pass filtered below 30 Hz and high-pass filtered above 0.05 Hz (zero phase shift mode, 12 dB). Channels that were affected by eye blinks were then corrected for each participant. After that, the EEG wave was epoched with 400-ms pre-stimulus intervals and 1000-ms post-stimulus onset intervals. Following baseline correction which used the pre-stimulus interval (-400 ms - 0 ms), trials with voltage variations outside the range of ±60 μV or with contamination by eye movements were rejected. Finally, data was re-referenced to the average activity across the whole head for further analysis.

Data analysis

The behavioral data of response latencies and percentage of error were submitted to within-participant and between-item two-way Analysis of Variance (ANOVAs). The two independent variables were configurations (2 levels: same and different configuration) and radicals (3 levels: symbols, same and different radicals). In both analysis, post-hoc multiple comparisons were adjusted using the Bonferroni correction. The Greenhouse-Geisser (ε) correction was applied when the assumption of sphericity of variance was violated.

For the analysis of ERPs, the mean amplitudes of the chosen electrodes for each participant were computed for investigating the experimental effects. Within-participant three-way ANOVA was conducted for each ERP component, with the inclusion of electrode location (left, central, and right) as the additional independent variable. When the assumption of sphericity of variance was violated, the Greenhouse-Geisser (ε) correction was reported. The significance threshold of post-hoc ANOVAs was corrected for multiple comparisons using the Bonferroni adjustment.

Results

Behavioral results

Thirty-three participants provided data for behavioral analysis as one participant was eliminated due to technical errors in the E-prime recording. Before the analysis, four trials (out of 11880 trials, < 0.01%) were eliminated as the response latency either exceeded 3 s or less than 200 ms. Both participant and item analysis excluded incorrect trials and three items (2 real-character targets and 1 pseudo character target) whose error rates were more than 30% across all six conditions. This accounted for 8.42% of the trials eliminated. Trials with pseudo character targets were treated as fillers, and trials that exceeded ±3standard deviations (0.02%) from the mean of each participant were also excluded from the final analysis. Mean response latencies of correct trials for each condition are shown in Table 1.

Table 1.
Mean response latencies (in ms) in participant analysis and item analysis

Conditions	Example		Participant Analysis		Item analysis	
	Prime	Target	M_1	SE	M_2	SE
SCSR		峴	566.34	12.72	567.20	5.51
DCSR		峴	578.18	13.56	578.49	5.66
SCDR		峴	597.92	13.08	600.97	7.79
DCDR		峴	587.04	13.63	586.52	4.81
SCSY		峴	565.22	12.65	567.21	6.01
DCSY		峴	572.65	15.01	574.45	8.64

The results showed a main effect of radical similarity, F_1 (2, 64) = 29.18, $p < .05$, $\eta_p^2 = .48$; F_2 (2, 162) = 2.24, $p < .05$, $\eta_p 2 = .09$, thus suggesting that response latencies were affected by the units presented in the prime. Bonferroni post hoc tests revealed that targets were responded to significantly faster ($p < .05$) when primes shared the same radicals (M_1 = 572.26, SE = 12.82; M_2 = 572.84, SE = 3.99) than ones that had different radicals (M_1 = 592.48, SE = 13.13; M_2 = 593.74, SE = 4.64). Similarly, targets were also responded to significantly faster ($p < .05$) when the primes were symbols (M_1 = 568.93, SE = 13.67; M_2 = 570.83, SE = 5.24) than when they had different radicals. The comparison between primes with symbols and primes with same radicals as the target was not significant (p = 1.00). The main effect of configuration was non-significant, F_1 (1, 32) = .76, p = .39, $\eta_p^2 = .02$; F_2 (1, 162) = 0.65, p = .80, $\eta_p^2 = .00$, thus indicating that response latencies were not affected by the similarity or difference of the configurations between the primes and targets.

The interaction effect of configuration and radical was found to be significant in the participant analysis, F_1 (1.63, 52.05) = 5.72, $p < .05$, $\eta_p^2 = .15$, ε = .81, but not in the item analysis F_2 (2, 162) = 2.24, $p < .11$, $\eta_p^2 = .03$. Further one-way ANOVAs with the alpha (α) level adjusted to 0.02 were carried out to compare the effects of configuration among same radicals, different radicals and symbols. Even though none of the three comparisons was significant, the results showed that the effect of configuration was approaching significance when linguistic units were used in the primes. Targets in the same configuration as the primes were faster to respond to than in different configuration when targets and primes shared the same radicals (F_1 (1, 32) = 4.10, p = .05, $\eta_p^2 = .11$; F_2 (1, 54) = 2.04, p = .16, $\eta_p^2 = .04$), and when they shared different radicals F_1 (1, 32) = 4.91, p = .03, $\eta_p^2 = .13$; F_2 (1, 54) = 2.49, p = .12, $\eta_p^2 = .04$. However, the effect of configuration was far from being significant when symbols were used as primes, F_1 (1, 32) = 2.37, p = .13, $\eta_p^2 = .07$; F_2 (1, 54) = 0.47, p = .50, $\eta_p^2 = .01$, suggesting that nonlinguistic stimuli were processed differently from linguistic materials. Therefore, the symbol conditions (i.e. SCSY, DCSY) were removed from further participant and item analysis.

A two-way ANOVA with radical similarity (same or different) and configurations (same or different) as independent variables were then carried out. The results again showed the main effect of radical similarity, F_1 (1, 32) = 41.06, $p < .05$, $\eta_p^2 = .56$; F_2 (1, 108) = 11.95, $p < .05$, $\eta_p^2 = .10$. Participants were significantly faster to recognize the character when the prime and target shared the same radicals ($M_1 = 572.26$, $SE_1 = 12.82$; $M_2 = 572.84$, $SE = 3.99$) then when the prime and target shared different radicals ($M_1 = 592.48$, $SE = 13.13$; $M_2 = 593.74$, $SE = 4.64$). No main effect of configuration was observed, F_1 (1, 32) = .02, $p = .89$, $\eta_p^2 = .00$; F_2 (1, 108) = 0.07, $p = .79$, $\eta_p^2 = .00$, suggesting that manipulating the configuration between primes and targets did not affect character recognition.

An interaction effect of radical similarity and configuration was revealed, F_1 (1, 32) = 7.67, $p < .05$, $\eta_p^2 = .19$; F_2 (1, 108) = 4.53, $p < .05$, $\eta_p^2 = .04$. Post-hoc multiple comparisons with alpha (α) level adjusted to .008 showed that the effect of the radical similarity was only manifested when the prime and target was in the same configuration ($p_1 < .008$; $p_2 < .008$). This is evidenced by targets of the SCSR priming condition were responded to significantly faster than targets in the SCDR priming condition. Other than that, the targets in the SCSR priming condition were significantly faster ($p_1 < .008$; $p_2 = .01$) responded to than in the DCDR priming condition; also, participants were significantly faster ($p_1 < .008$; $p_2 = .02$) to recognize the targets in the DCSR condition than in the SCDR condition. No other significant comparisons were observed (all *p*'s > .008) (see Appendix C for a summary of all the planned comparisons).

The error rate was subjected to participant and item analysis (see Appendix D for a table of the mean error rates). Both analyses showed that the error rate was not significantly affected by radical similarity, configuration or the interaction of radical and configuration of the prime (all *p*'s > .05).

In sum, the behavioral results indicated a main effect of radical similarity and interaction of configuration and radical. Characters that shared similar radicals to their primes were faster to respond to than target characters with different radicals to their primes. This radical similarity effect was only manifested when the primes and targets were of the same configuration.

Event-related Potential Results

Visual inspection of ERP waveforms and peaks

All ERP responses to the real character targets presented after different priming conditions were averaged and used to observe the general morphology of the ERP waveform. Figure 3 and 5 illustrated the grand average ERP's waveforms in micro Volts (μ V) across the time course of prime and target from the chosen electrodes (34, 42, 51, 61, 63, 68, 77, 89, and 97) to represent the N1, P2 and N400 components respectively. It should be noted that the grand average waveforms were plotted with the positive voltages in the downward direction. As shown in Figure 4 (bottom), the N1 component peaked in the occipital regions at approximately 110 ms, thus a time window of 80 ms to 140 ms was selected in the left (42), middle (68) and right (97) electrode sites to calculate the mean amplitude across conditions for each participant. The positive-going P2 component found at the centrofrontal region, see Figure 4 (middle), which peaked at approximately 255 ms and thus, a time window of 225 to 285 ms was chosen for electrodes 34, 61, and 89. After these early components, a smaller negative-going potential at the central region reflecting the N400 component, peaked at 320 ms. A time window of 290 to 490 ms was selected at electrodes 51, 63, and 77 for analysis. Visual examination of the whole head topographical plots illustrated in Figure 4 and 6 confirmed the regions of brain activation during those specified time windows for the ERP components N1, P2 and N400 respectively.

The priming conditions involving symbols (SCSY, DCSY) were not analyzed because the behavioral analysis indicated that there was no significant priming effect by symbols, and it was suspected that the processing of nonlinguistic stimuli (i.e. blocks as primes) was inherently different from the processing of linguistic stimuli (i.e. pseudo or real-characters). Indeed, this was confirmed by visual examination of the topographical plot and ERP waveform in Appendix E (see also Maurer, Brandeis & McCandliss, 2005).

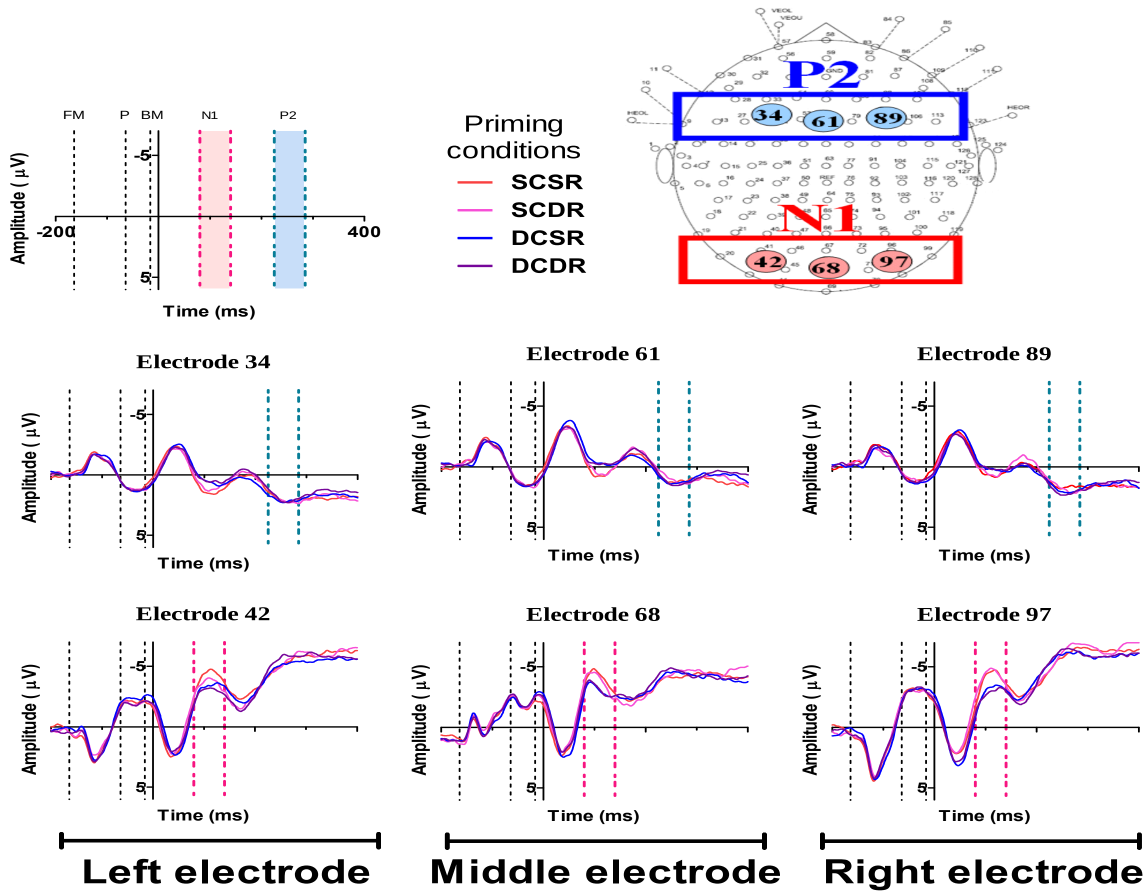


Figure 3. Grand average waveform of the N1 and P2 components under different priming conditions at posterior and centrofrontal regions during 80-140 ms and 225-285 ms respectively.
Note: FM = forward mask, BM = backward mask, P = the presentation of the prime.

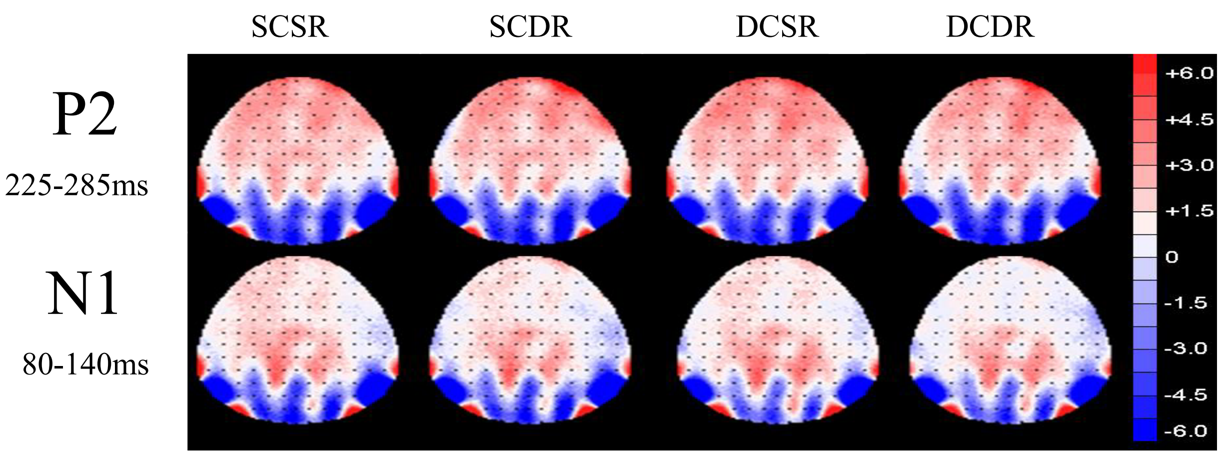


Figure 4. Topographical plots showing activity in different priming conditions.

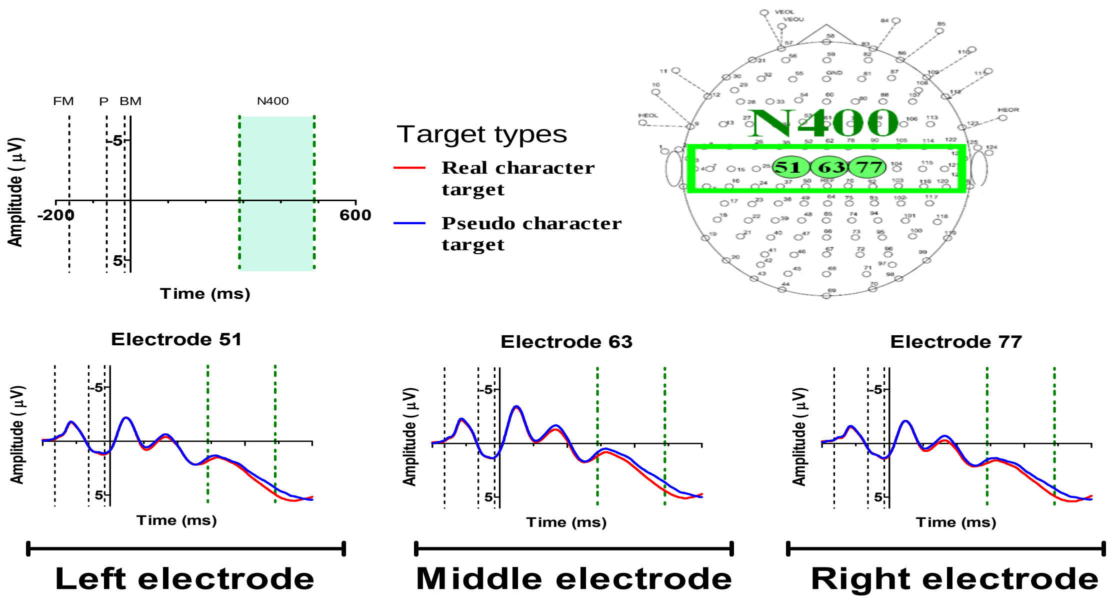


Figure 5. Grand average waveforms at central region during 290 to 490 ms when real character and pseudo character were used as targets.

Note: FM = forward mask, BM = backward mask, P = the presentation of the prime.

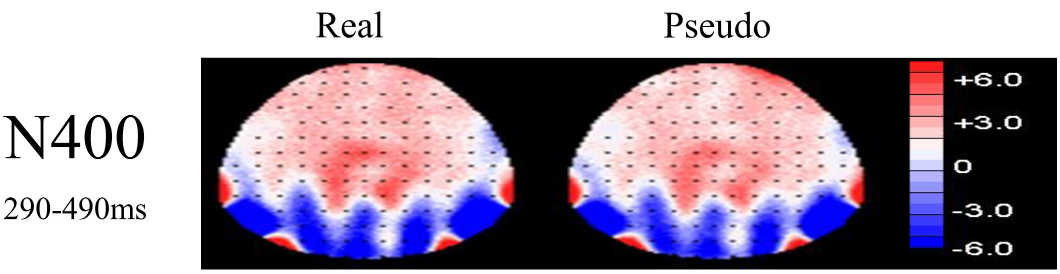


Figure 6. Topographical plots showing activity when different types of targets were used.

N1 (80-140ms)

For the N1 component, the three-way repeated measures ANOVA showed a main effect of configuration, F (1, 32) = 1.57, p < .05, η_p^2 = .60, whereby primes sharing the same configuration as the targets (M = -3.83, SE = 0.52) had a more negative amplitude than primes having different configuration from the targets (M = -2.90, SE = 0.50). No main effects of electrode location, F (2, 64) = 0.16, p = .85, η_p^2 = .01, and radical similarity effect were observed, F (1, 32) = 1.57, p = .22, η_p^2 = .05.

There was a two-way interaction between electrode location and configuration, F (2, 64) = 6.08, p < .05, η_p^2 = .16. With alpha (α) level adjusted to 0.02 for multiple comparisons, further analyses of one-way ANOVAs at each electrode site found a significant difference between the same configuration and different configuration conditions at electrode site 42, F (1, 32) = 23.56, $p < .02$, $\eta_p^2 = .424$, at electrode site 68, F (1, 32) = 29.16, $p < .02$, $\eta_p^2 = .48$ and electrode site 97, F (1, 32) = 46.67, $p < .02$, $\eta_p^2 = .59$. The effect size (η_p^2) was the largest at the right electrode 97, thus indicating that the effect of configuration was manifested most profusely there. In the other two-way interaction, the results indicated a significant electrode location by radical similarity interaction, F (1.67, 55.33) = 4.98, $p < .05$, $\eta_p^2 = .16$, $\varepsilon = .83$. Post-hoc one-way ANOVA at each electrode location showed a significant radical similarity effect at the left electrode site 42, F (1, 32) = 9.02, $p < .02$, $\eta_p^2 = .22$, whereby the amplitude of the evoked potential was more negative when primes had the same radicals as the targets (M = -3.60, SE = 0.55) than primes had different radicals from the targets (M = -3.12, SE = 0.50). No significant radical effects at electrode site 68, F (1, 32) = .39, $p = .54$, $\eta_p^2 = .01$, and electrode site 97, F (1, 32) = .01, $p = .94$, $\eta_p^2 = .00$ were found.

Three-way interaction among electrode, configuration and radical similarity was also observed, F (2, 64) = 4.66, $p < .05$, $\eta_p^2 = .13$. Figure 7 illustrated the relationship of the four priming conditions at each electrode location. Post-hoc configuration by radical similarity ANOVAs for each electrode location was administered. At all three electrode locations (42, 68, 97), the main effects of configuration were observed, F_{42} (1, 32) = 23.56, $p < .05$, $\eta_p^2 = .42$; F_{68} (1, 32) = 29.16, $p < .05$, $\eta_p^2 = .48$; F_{97} (1, 32) = 46.67, $p < .05$, $\eta_p^2 = .59$. The evoked potential amplitude in conditions using primes with same configuration as the targets (M_{42} = -3.73, SE = 0.53; M_{68} = -3.89, SE = 0.54; M_{97} = -3.89, SE = 0.65) was always more negative than primes with different configurations from the targets (M_{42} = -2.99, SE = 0.52; M_{68} = -3.10, SE = 0.54; M_{97} = -2.64, SE = 0.59). However, only at the left electrode 42 was the main effect of radical similarity indicated, F (1, 32) = 9.02, $p < .05$, $\eta_p^2 = .22$, where a more negative amplitude was evoked in conditions with primes having the same radicals as the targets (*M* = -3.60, *SE* = 0.55) than primes with different radicals (*M* = -3.12, *SE* = 0.50).

P2 (225-285ms)

For the P2 ERP component, the results showed significant main effect of electrode, F (2, 64) = 11.62, $p < .05$, $\eta_p^2 = .27$. Post-hoc pairwise comparisons revealed that the evoked potential had a smaller positivity at the central electrode 63 (*M* = 1.18, *SE* = 0.49) than the left electrode 34 (*M* = 2.00, *SE* = 0.47) (p <.05)and the right electrode 89 (*M* = 1.86, *SE* = 0.39) ($p < .05$). No other significant comparisons and effects were observed (all p's > .05).

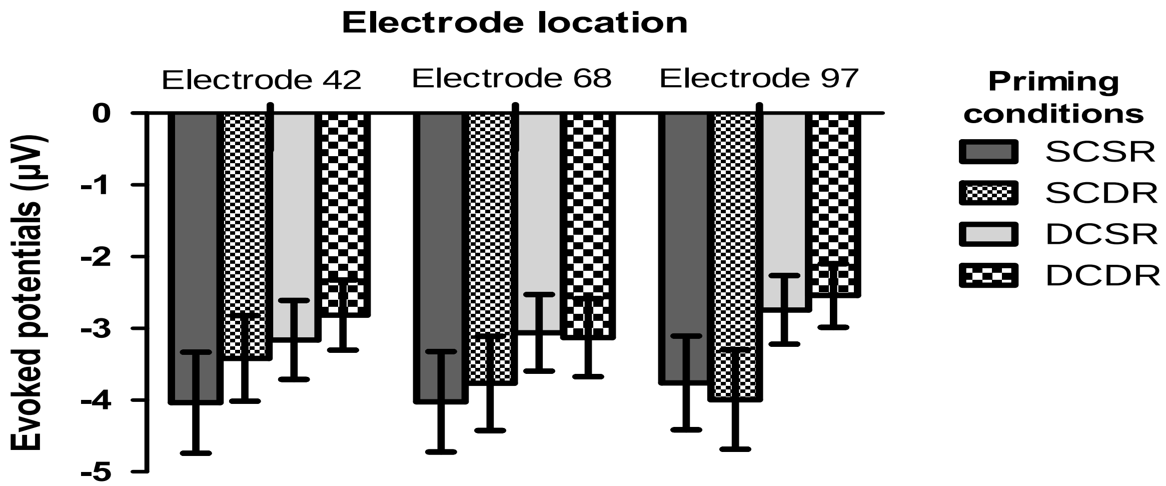


Figure 7. Mean Amplitude and Standard Error of the four priming conditions at the 3 electrode sites (i.e. 42, 68, 97) of the N1 component between 80-140 ms.

N400 (290-490 ms)

For the N400 ERP component, a significant main effect of electrode was found, F (1.07, 34.14) = 59.39, $p < .05$, $\eta_p^2 = .65$, $\varepsilon = .53$. Post hoc pair-wise comparisons indicated that the amplitude of the evoked potential was most negative going at the right electrode 77 (*M* = -5.97, *SE* = 0.78), followed by the central electrode 63 (*M* = 1.98, *SE* = 0.44) and left electrode 51 (*M* = -0.36, *SE* = 0.43). The amplitudes at these electrode sites were all significantly different from each other (all p's < 0.05). Also, the main effect of lexicality has also approached significance, F (1, 32) = 4.33, $p < .05$, $\eta_p^2 = .12$. The evoked potential amplitude of pseudo characters (*M* = -0.54, *SE* = 0.25) were more negative than real characters (*M* = -0.36, *SE* = 0.29). In addition, a significant interaction between electrode and lexicality was found, *F* (1.24, 39.76) = 5.86, $p < .05$, $\eta_p^2 = .16$, $\varepsilon = .62$. With alpha level adjusted to 0.02 to account for multiple comparisons, post-hoc one-way repeated measures ANOVA at each electrode location was conducted. Significant lexicality effect was found at the central electrode 63, *F* (1, 32) = 9.15, $p < .02$, $\eta_p^2 = .22$ where the amplitude evoked by pseudo characters (*M* = 1.74, *SE* = .43) was more negative going than that of real characters (*M* = 2.22, *SE* = .47). No significant lexicality effect was found at the left electrode 51, *F* (1, 32) = 4.57, $p = .04$, $\eta_p^2 = .13$, and the right electrode 77, *F* (1, 32) = 2.23, $p = .15$, $\eta_p^2 = .07$.

To summarize the main ERP findings, the N1 component indicated a main effect of configuration at all three electrode sites, and the interaction effect of electrode and configuration demonstrated that the configuration effect was strongest at the right electrode 97. Primes sharing the same configuration with the targets elicited a more negative N1 than primes with different configuration. Moreover, the two-way interaction of electrode and radical showed that the effect of radical similarity was only exhibited at the left electrode 42. The amplitude of the evoked potential was more negative for primes sharing the same radicals with the target than primes with different radicals. The three-way interaction of electrode, radical and configuration revealed the separate effects of radical similarity and configuration at electrode 42. At N400 component, a main effect of lexicality and an interaction effect of lexicality and electrodes were observed. The results showed that pseudo character targets elicited a more negative-going potential than the real character targets at the central electrode site 63 but not at the left electrode 51 and the right electrode 77.

Discussion

The main purpose of this study was to investigate whether structural configuration is involved in character processing and how it contributes to visual recognition of Chinese. This was done by collecting behavioral data on response latency, and using the early ERP components N1 and P2 as indicators of orthographic processing. The behavioral results demonstrated that lexical judgment was faster when prime and target shared the same radicals than when they did not. Lexical judgment was also significantly affected by the interaction between radical and configuration, in which the effect of radical similarity was only manifested when the primes had the same configuration as the targets. These results suggest that radical and configuration have an interdependent relationship. Interestingly, the ERP results seem to suggest otherwise. Strong configuration effect was found at the N1 component in left, middle and right electrodes. Furthermore, the N1 component also revealed significant three-way interaction, indicating independent effects of configuration and radical similarity in the left posterior occipital-temporal region (electrode 42).

An effect of configuration was observed at the posterior regions during 80 - 140 ms post onset of target with a slightly greater effect at the right electrode site than the left. Greater negativity was elicited when prime had the same configuration as that of the target, thus implying an enhanced activation of the target which required less effort to process. This result is concordant with previous work on alphabetic script that N1 (or N170) reflects visual word form processing (Simon, Bernard, Largy, Lalonde & Rebai, 2004) and orthographic discrimination (Bentin et al., 1999). However, while left-lateralized hemispheric dominance for orthographic processing but right dominance for non-orthographic processing were reported in alphabetic scripts (Bentin et al., 1999), the configuration effect found in the present study was greatest in the right hemisphere. This is unsurprising because processing of structural configuration requires holistic processing of the spatial organization which the right hemisphere is more superior in (Ellis, Young, & Anderson, 1988).

In contrast, the effect of radical was found at the left posterior region during 80-140 ms. When the prime and target share the same radicals, greater amplitude of the N1 component was observed. This represents an increased activation of and less effort to process the target. It should be highlighted that even though the pseudo character prime may share the same radicals with the target, the positions of the radicals in primes and targets were always different. For instance, if the target was 姚 (/jiu4/, handsome), with the radicals '女' (/neoi5/, girl) and '兆' (/siu6/, sign), then the two priming conditions with the same radicals as the target would be SCSR (e.g. ) and DCSR (e.g. **)**. According to Dufau, Grainger and Holcomb (2008), N1 is sensitive to even slight positional difference of letter strings between primes and targets, and this difference of letter locations resulted in less negativity in N1. Therefore, it is reasonable to argue that the priming observed in this study was not due to mere visual overlap of similar features but rather, the effect of the radicals as a processing unit. The notion that N1 is able to reflect linguistic process is supported by McCandliss, Posner and Givon (1997) on visual word learning.

While the role of radicals in character recognition has been reported, the realization of the effect was different from the observation of this study. Liu, Perfetti and Hart (2003) found 'graphic similarity (p. 1242)' effect which originated from shared radicals at P200 (or P2) in the occipital and pre-central motor areas instead of N1. Yet, in this study, no radical similarity effect was found at P2. This discrepant finding might be due to the experimental tasks they used in which meaning or pronunciation judgments were made. In their task, a character was first presented for 140 ms, which allowed sufficient time for phonological processing to take place, before the presentation of the target character for the participant to make judgment. As Hsu, Tsai, Lee and Tzeng (2009) found phonological consistency effect at P2, the findings of Liu et al. (2003) might be due to orthographic or phonological processing instead of radical effect alone.

Lexicality effect was observed at N400, in which pseudo character targets elicited a larger N400 amplitude than real character targets. This implies more effort was required to process the pseudo character targets than the real character targets. The lexicality found is compatible with past findings (Holcomb, Grainger & O'Rouke, 2002; Kiyonaga, Midgley, Holcomb & Grainger, 2007) and thus, validated the results of the lexical judgment task.

The findings of the present study are generally compatible with the Lexical Constituency Model (Perfetti et al., 2006) in that the model postulates the roles played by radical and configuration. However, it specifies that character in the orthography level is only activated by 'radical written in the sequence specified in the radical slot' (Perfetti et al., 2005, p. 49). In other words, it is the combined effect of configuration and radical which sends activation to the orthography level. However, our findings clearly demonstrate independent effects of configuration and radical. Therefore, to accommodate our observation, the LCM will have to be modified by separating the input (radical) level into input by configuration and radical. This is illustrated in Figure 8.

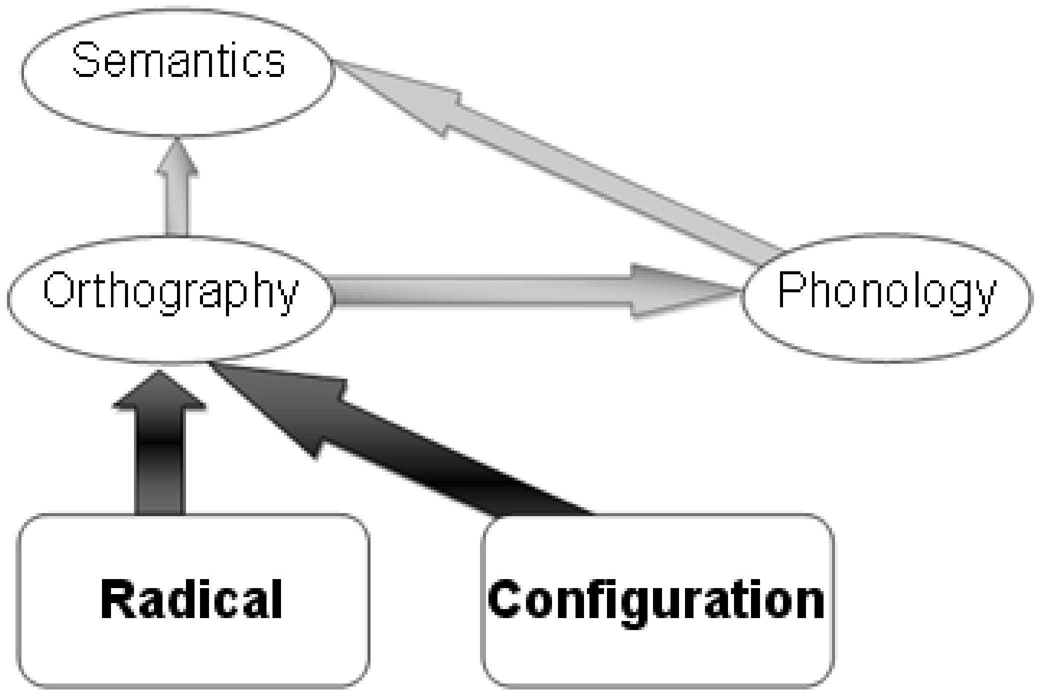


Figure 8. A modified Lexical Constituency Model (LCM) (Perfetti & Liu, 2006)

As shown in Figure 8, configuration and radical send separate activation to the orthography level. In this framework, it is assumed that the activation elicited by radical is stronger than that of configuration. This is so assumed despite the ERP results showing a strong configuration effect. We propose that because activation from configuration, e.g. the left-right configuration, is distributed to a large pool of characters as more than 60% of Chinese characters (Lui et al., 2010) contain that configuration. However, the activation from a radical is only distributed to a selected and limited group of characters containing that radical.

Therefore, information of the configuration and the radicals is extracted from the prime, and sends separate activation to the orthography level. Relevant information from the prime will then be assimilated with the information of the target stimulus. For instance, for the target stimulus '姚' (/jiu4/, handsome), the SCSR pseudo character prime '' activates characters with the same left-right configuration at the orthography level like '佔' (/zim3/, occupy), 媽 (/maa1/, mother). At the same time, the prime also activates characters with one or more identical radicals like '姚' (/jiu4/, handsome), '媽' (/maa1/, mother), '窕' (/tiu5/, slim). Relative to the other characters like '媽' and '窕' which only consist of one identical radical with that of the prime, the target '姚' receives more activation because it contains both identical radicals as the prime. In other words, in the SCSR priming condition, the target '姚' receives activation from configuration and also, from both radicals of the prime. This results in the SCSR priming condition having the fastest latency response behaviorally among the four conditions, and also, significantly faster than conditions with different radicals like the SCDR and DCDR conditions.

The response latency of the DCSR priming condition was also found to be significantly faster than that of the SCDR condition. In the DCSR condition where the pseudo character '' is used as prime and '姚' as target, characters with the top-bottom configuration will be activated, like ‘委’ (/wai2/, appoint), ‘窕’ (/tiu5/, slim); and also, characters with the same radicals will be activated, like ‘委’, ‘窕’, ‘姚’. Even though the character ‘委’ and ‘姚’ both receives two sources of activation, because of the assumption that radical sends stronger activation, the target ‘姚’ is the most activated as it receives double activation from both radicals of the prime as compared to 委, which receives activation from the radical‘女’(/neoi5/, girl) and configuration. On the other hand, in the SCDR condition where the pseudo character‘’is used as a prime, the target only receives activation from the configuration. Therefore, as radical provides greater facilitation, the DCSR condition was significantly faster than that of the SCDR condition.

Having argued for the more important role of the radical in lexical processing, it is intriguing that the DCSR and DCDR priming condition were not significantly different. However, we also note that the difference between the two conditions barely missed the significance threshold when adjusted for multiple comparisons ($p = 0.008$).

Indeed, the present findings converge with studies which observed the role of configuration (Yeh & Li, 2002). The more salient configuration effect in Yeh and Li (2002), compared to the subtle effect in this study, may be due to the more perceptually-driven visual search task they used. Thus, the theoretical implications of this study not only acknowledge the subtle role played by structural configuration during character recognition, but also contribute to the investigation of position specificity of radical. Furthermore, models that do not postulate the role of configuration, for instance, like the Multi-Level Interactive-Activation Model proposed by Taft (2006), may not be able to accommodate the findings from the present study.

Limitation of the present study and future research

One experimental limitation of this study may be the limited trials left for analyzing the P2 component after artifact rejection. This may account for the null effects of radicals and configuration observed at P2. Presently, the configuration effect was only manifested at N1 but not at other components. If a manifestation of this effect was found at P2 or even N400, a stronger account of configuration being involved in character recognition but not at low-level perceptual processes which were usually reflected by N1, could be formulated. Therefore, to further our understanding of the possible roles played by configuration, more participants should be recruited in future study using the same experimental paradigm.

Conclusion

The ERP and behavioral results complemented each other and confirmed the role played by configuration and radicals in character recognition. This has subsequently led to a modification to the LCM proposed by Perfetti et al. (2006) to accommodate the separate activation by configuration and radicals. The present findings and its theoretical implications no doubt enrich and enhance our understanding of lexical processing of Chinese characters.

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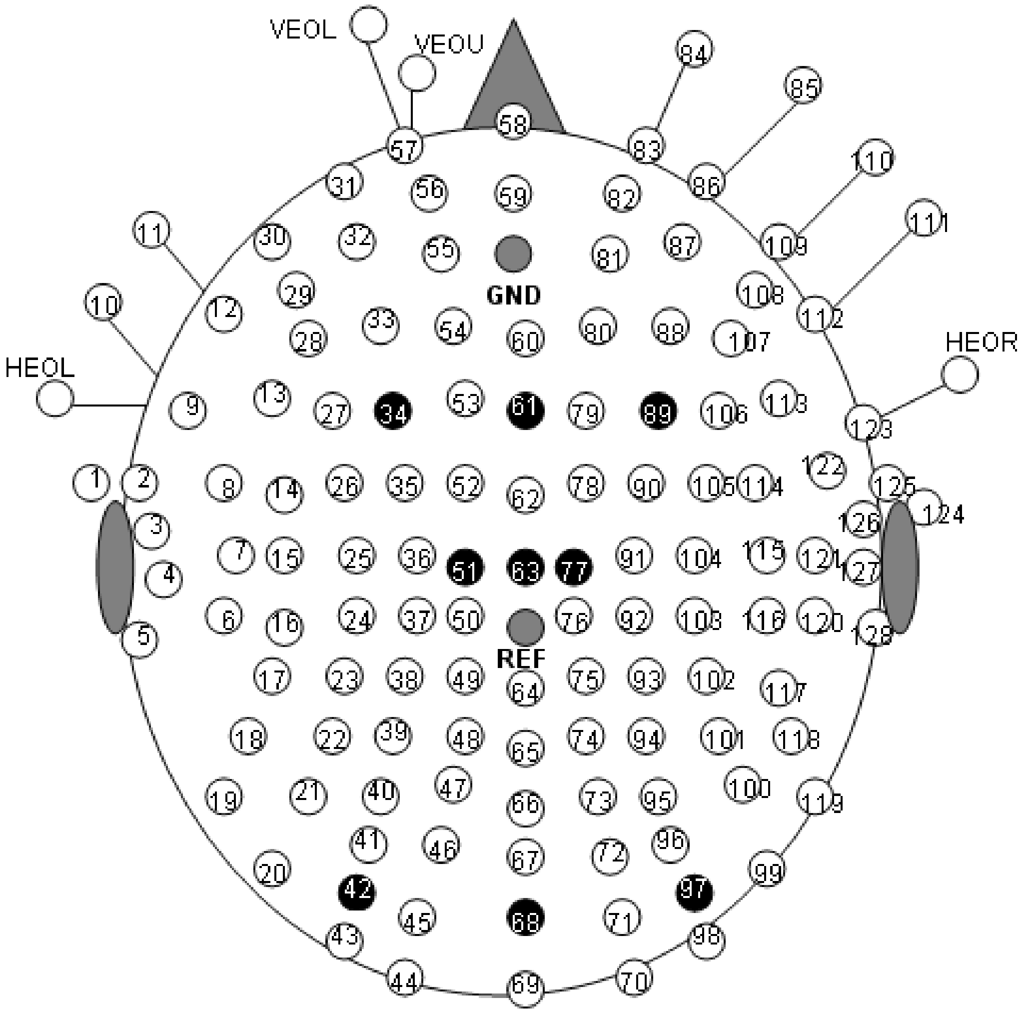
APPENDICES

Appendix A: A table of target words and primes used in the lexical decision task.

Target		Priming conditions					
Real	**Pseudo**	**SCSR**	**DCSR**	**SCDR**	**DCDR**	**SCSY**	**DCDY**
肛	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	▮▮	☰
牡	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	▮▮	☰
咀	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	▮▮	☰
弦	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	▮▮	☰
孤	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	▮▮	☰
帖	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	▮▮	☰
劾	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	▮▮	☰
姚	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	▮▮	☰
昧	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	▮▮	☰
矜	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	▮▮	☰
盼	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	▮▮	☰
峴	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	▮▮	☰
烘	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	▮▮	☰
恥	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	▮▮	☰
桶	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	▮▮	☰
舶	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	▮▮	☰
粒	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	▮▮	☰
瓶	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	▮▮	☰
豉	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	▮▮	☰
訟	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	▮▮	☰
斬	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	▮▮	☰
酣	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	▮▮	☰
欺	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	▮▮	☰
碰	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	▮▮	☰
馴	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	▮▮	☰
賑	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	▮▮	☰
蝙	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	▮▮	☰
鋪	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	▮▮	☰
默	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	▮▮	☰
穌	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	▮▮	☰

Appendix B: Electrode montage



Note. The filled black dots indicate the electrodes used for analysis of N1 component (electrode 42, 68, 97), P2 component (electrode 34, 61, 89) and N400 component (electrode 51,63,77). The filled grey dots indicate the reference electrode (REF) and the ground electrode (GND).

Appendix C: Post-hoc multiple comparisons with mean difference ($M_{difference}$) in ms between conditions and the significance level (p) of the difference

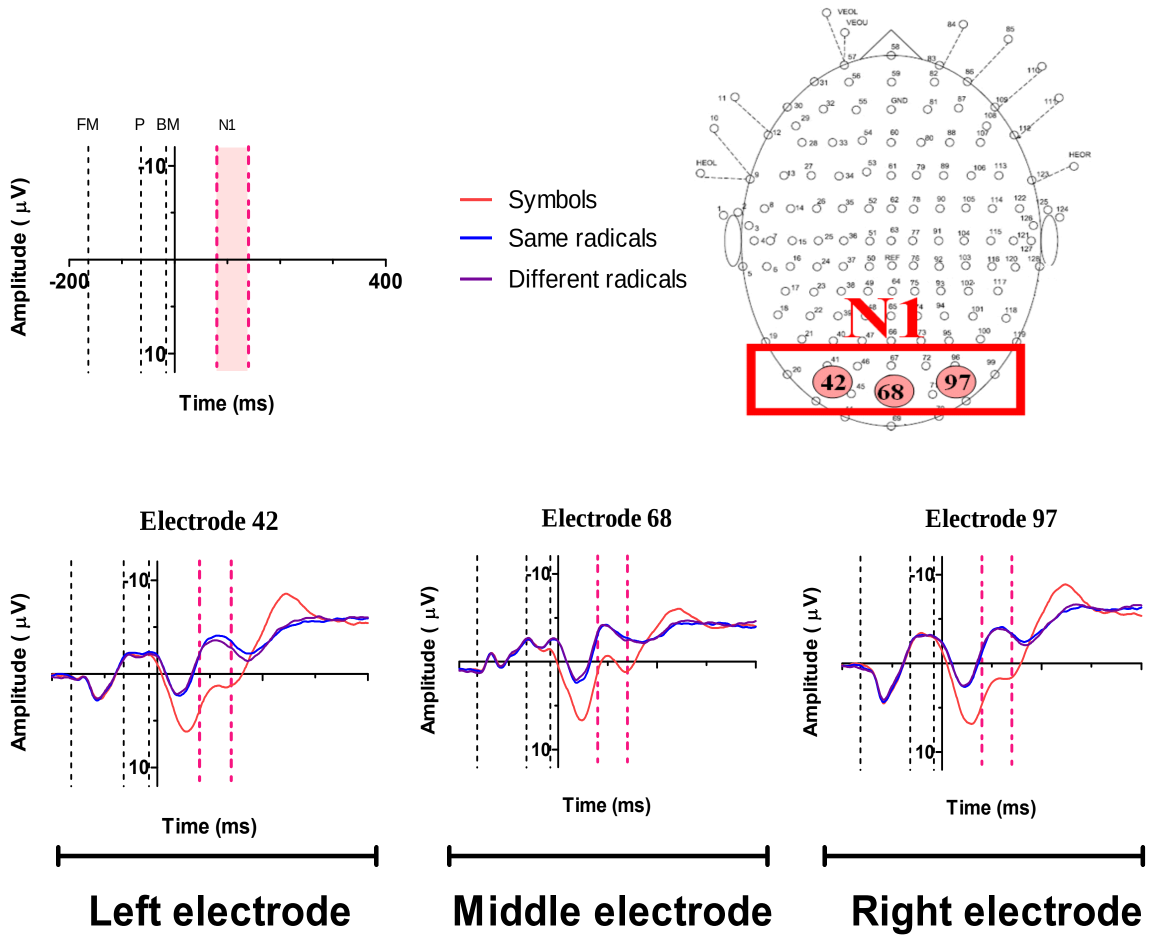
Pairwise comparisons	**Participant analysis**			**Item analysis**		
	$M_{difference}$	Sig. (*p*)		$M_{difference}$	Sig. (*p*)	
SCSR vs SCDR	-31.58	0.00	*	-33.77	0.00	*
SCSR vs DCSR	-11.84	0.05		-11.29	0.16	
SCSR vs DCDR	-20.70	0.00	*	-19.32	0.01	
SCDR vs DCDR	10.88	0.03		14.45	0.12	
DCSR vs DCDR	-8.86	0.06		-8.03	0.29	
DCSR vs SCDR	-19.74	0.00	*	-22.477	0.02	

Note. *p < 0.008

Appendix D: A table showing the mean error rates (%) in participant analysis and item analysis

Conditions	Example		Participant Analysis		Item analysis	
	Prime	Target	M_1	SE	M_2	SE
SCSR		峴	8.19	0.86	7.47	1.40
DCSR		峴	7.76	0.79	7.90	1.36
SCDR		峴	8.08	0.73	7.47	1.24
DCDR		峴	6.91	0.78	6.06	1.03
SCSY		峴	7.28	0.77	7.47	1.49
DCSY		峴	7.44	0.86	6.39	1.19

Appendix E: (1) Grand average waveforms at posterior region and (2) topographical plots showing activity during 290 to 490 ms when symbols and radicals were used as primes.



Note: FM = forward mask, BM = backward mask, P = the presentation of the prime.