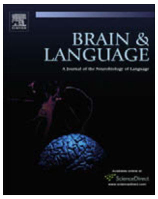
Brain & Language 108 (2009) 56–66

Contents lists available at ScienceDirect

Brain & Language

journal homepage: www.elsevier.com/locate/b&l



Orthographic combinability and phonological consistency effects in reading Chinese phonograms: An event-related potential study

Chun-Hsien Hsu [a], Jie-Li Tsai [b,c], Chia-Ying Lee [b,c,d,*], Ovid J.-L. Tzeng [a,d]

[a] Institute of Neuroscience, National Yang-Ming University, Taiwan
[b] Department of Psychology, National Chengchi University, Taiwan
[c] Research Center for Mind, Brain, and Learning, National Chengchi University, Taiwan
[d] The Institute of Linguistics, Academia Sinica, 128, Section 2, Academia Road 115, Taipei, Taiwan, ROC

ARTICLE INFO

Article history:
Accepted 9 September 2008
Available online 31 October 2008

Keywords:
Chinese characters
Consistency effect
Combinability effect
N170
P200
N400

ABSTRACT

In this study, event-related potentials (ERPs) were used to trace the temporal dynamics of phonological consistency and phonetic combinability in the reading of Chinese phonograms. The data showed a significant consistency-by-combinability interaction at N170. High phonetic combinability characters elicited greater negativity at N170 than did low phonetic combinability characters, and the combinability effect was only found in the reading of high consistency characters. The results support the phonological mapping hypothesis of the reading-related N170 effect and suggest that the earlier stages of visual word recognition are shaped by the mapping of orthography to phonology even in Chinese. Moreover, our data revealed both consistency and combinability effects at P200 and N400, accounted for by the two-stage framework for visual word recognition. That is, characters with high combinability or high consistency facilitated the earlier stages of orthographic or phonological processing which were due to increased activation at the perceptual level; consequently, less positive P200 was demonstrated. In the later stages, high combinability or high consistency characters were associated with a larger semantic neighborhood, which increased semantic competition and exaggerated the N400 effect. These data support the assumption of radical-based inputs proposed by the lexical constituent model. However, the phonetic consistency effects found at N170 and P200 cannot be reconciled with the current framework of the lexical constituent model. A possible revision will be discussed.

1. Introduction

How words are represented in the mental lexicon and how lexical knowledge can be retrieved are central issues in the study of human language processing. In the past few years, research has demonstrated that a word's identification is affected by its neighboring structure. The well-established neighborhood properties of a word include the orthography-to-phonology consistency (i.e., the degree to which similarly spelled words are pronounced similarly) (Taraban & McClelland, 1987), the orthographic neighborhood size (i.e., the number of words that can be created by changing a single letter in a target word) (Andrews, 1989; Coltheart, Davelaar, Jonasson, & Besner, 1977; Grainger, O'Regan, Jacobs, & Segui, 1989; Holcomb, Grainger, & O' Rourke, 2002), and the phonological neighborhood density (i.e., the number of words that can be derived by changing one phoneme in a target word) (Pylkkänen, Stringfellow, & Marantz, 2002). These types of studies are valuable since they provide insight into the organization of lexical knowledge and the processes underlying word recognition. The current study aims to advance our knowledge of the role of the orthographic neighborhood size (the phonetic radical combinability) in the reading of Chinese characters.

1.1. Orthographic neighborhood size effect in alphabetic writing system

In studies of English, the orthographic neighborhood size of a word is defined as the number of words that can be created by changing a single letter of the word while maintaining the original positions of the letters (Coltheart et al., 1977). For example, the word *cheat* has four neighbors (i.e. *cheap*, *chest*, *cleat*, and *wheat*) and the word *cover* has thirteen (a partial list includes *coven, covet, cower, hover, lover, and mover*). Most of the studies in this field use the lexical decision task and report a facilitative neighborhood size effect for low frequency words and its interaction with word frequency (Andrews, 1989; Forster & Shen, 1996; Pollatsek, Perea, & Binder, 1999). Specifically, the response latencies to low- frequency words with many neighbors are shorter than those with few neighbors; however, the neighborhood size effect is negligible

---

* Corresponding author. Address: The Institute of Linguistics, Academia Sinica, 128, Section 2, Academia Road 115, Taipei, Taiwan, ROC. Fax: +886 2 2785 6622.
E-mail address: chiaying@gate.sinica.edu.tw (C.-Y. Lee).

0093-934X/$ - see front matter © 2008 Elsevier Inc. All rights reserved.
doi:10.1016/j.bandl.2008.09.002

or nonexistent for high- frequency words. However, inhibitory neighborhood size and neighborhood frequency effects for low-frequency words have also been reported in studies using various tasks such as the perceptual identification task, progressive demasking paradigm, sentence reading task, and lexical decision task (Grainger & Segui, 1990; Perea, Carreiras, & Grainger, 2004; Pollatsek et al., 1999; Snodgrass & Mintzer, 1993).

Grainger and Jacobs (1996) proposed the multiple read-out model (MROM) to simulate a wide variety of neighborhood effects in different tasks on the basis of three output criteria/processes that underlie the speeded binary lexical decision task. Two of the processes use intralexical information to generate a "yes" response, while the third process uses extralexical information to generate a "no" response in the lexical decision task. The two intralexical sources are (a) local lexical activation of the target word itself and (b) global activity in the mental lexicon induced by a partial activation of the target word's orthographic neighbors. The extralexical source of information is the time criterion. The criterion value set on each of the three information dimensions determines the type ("yes" or "no") and speed of a lexical decision response. When either global or local activation exceeds a criterion, either a word response or "yes" response is made. Hence, the facilitative neighborhood size effect can be explained as follows: when a word has a larger neighborhood size, there is more global activation in the mental lexicon and a faster positive response can be generated. In addition, the MROM introduces a "fast guess" mechanism that can lead to a "yes" response when the total activation in the lexicon exceeds the criterion, even before any specific word representation has reached the threshold criterion. Further, it explains that a lexical decision can be made even before lexical identification is fully complete, especially when the task stresses speed over accuracy. On the other hand, the inhibitory neighborhood size or neighborhood frequency effect reflects the lateral inhibition between the intralexical word units (orthographic neighbors), especially when the task stresses on accuracy or requires deep processes such as accessing a word's meaning. The MROM also implies how lexical activity unfolds over time. For example, a decision made in the earlier stage of processing is mainly determined by the global activation while the local activation plays a much more important role in the later stage of the lexical competition.

To assess the assumption of the MROM, Holcomb, Grainger, and O' Rourke (2002) conducted a lexical decision task in which they manipulated the orthographic neighborhood size of English words and pseudowords. Although their results showed opposing effects of neighborhood size for words and pseudowords in terms of the participants' reaction times, both the words and pseudowords produced a consistent pattern of neighborhood size effect at N400. That is, when the neighborhood size was large, both the words and pseudowords induced greater negative amplitude of N400 than when the neighborhood size was small. They interpreted the data as supporting the MROM and suggested that N400 reflects the global lexical activity induced by both the words and pseudowords. However, other studies found frequency and congruency effects at the syllable level at the frontal P200, whereas these effects at the lexical level were observed at the later N400 (Barber, Vergara, & Carreiras, 2004; Carreiras, Vergara, & Barber, 2005). These findings suggest that P200 reflects the lexical activity triggered by sublexical units, while N400 reflects the lateral inhibition process for suppressing the activity of other items, with the inhibition being stronger for words with larger neighborhoods. It remains unclear whether P200 and N400 reflect the two distinctive mechanisms of MROM, i.e., the global lexical activity in the early phase of processing and the lexical competition of the lateral inhibitory process.

1.2. Orthographic neighborhood size effect in the reading of chinese characters

In Chinese, approximately 80% of the characters are phonograms that consist of a semantic radical (usually on the left-hand side) and a phonetic radical (usually on the right-hand side). There is increasing evidence that indicates that reading a complex character involves the processing of its radicals (Chen & Weekes, 2004; Ding, Peng, & Taft, 2004; Feldman & Siok, 1997; Feldman & Siok, 1999; Lee, Tsai, Chiu, Tzeng, & Hung, 2006; Taft & Zhu, 1997). The orthographic neighborhood size effect in the reading of Chinese characters was first addressed by Taft and Zhu (1997). They defined *radical frequency* as the number of characters that share the same radical, regardless of the radical position or radical function. Their data showed a position sensitive effect of radical frequency, i.e., the lexical decision time for characters with high radical frequency was faster than that for characters with low radical frequency. Furthermore, this was true only for the radicals that appeared on the right-hand side of the character.

However, in most Chinese phonograms, the phonetic radical tends to appear on the right and the semantic radical tends to appear on the left. In Taft's study, the radical position might have been confused with the radical function. To avoid this confusion, Feldman and Siok (1997) used the term *radical combinability* (defined by function) rather than *radical frequency* (defined by form). In addition, combinability can be further divided into phonetic combinability and semantic combinability, which are defined as the number of phonograms that share the same phonetic or semantic radical, respectively. By manipulating the radical combinability (for the phonetic and semantic radicals) and radical position in a character decision task, they found facilitative combinability effects for both semantic and phonetic radicals; however, these effects were not reliable within their positions. For the phonetic radicals, the combinability effect was significant in both the left and right positions. On the other hand, for the semantic radicals, the combinability effect was significant only when the semantic radical was on the left. These findings suggest that the radical function should be considered when investigating the radical combinability effect (Feldman & Siok, 1997). This conclusion has been further supported by Chen and Weekes's study (2004) which demonstrated that the combinability effect of the semantic radical can be reversed in semantic category judgment while reading semantic transparent and semantic opaque characters. However, the question of how the function of a phonetic radical affects the orthographic combinability effect remains unanswered in this field.

Perfetti, Liu, and Tan (2005) proposed an interactive constituency model that assumes that the representation of a word consists of three interlocking constituents: orthographic, phonological, and semantic. The input units are radicals and the spatial relationship between the radicals. The radical input and the phonological levels of the model can be regarded as distributed representations, whereas the orthographic and semantic representations can be regarded as localized representations. According to this framework, successful lexical retrieval (word identification) requires full specification of all the three constituents. Furthermore, this model predicted the temporal dynamics of graphic and phonological effects. That is, the radical-based inputs provide facilitation in the early orthographic processing. Furthermore, when a radical activates more than one character to threshold level, the inhibitory process emerges at the lexical level. These assumptions consistent with their study on event-related potentials (ERPs) (Liu, Perfetti, & Hart, 2003) which demonstrated that P200 was reduced when the character shared a radical with the preceding character and interpreted it as a graphic processing component. Meanwhile, the phonological interference effect was found in N400, which indexes character-level competition.

Based on the lexical constituent model, one would predict the reversed phonetic combinability effect in the different stages of lexical processing. A character with larger combinability should display larger facilitative effect on P200 and inhibitory effect on N400 than would a character with small combinability. However, the following question remains: how does the function of a phonetic radical take part in the Chinese lexical process? To address this issue, it is necessary to define the validity of phonetic radicals.

In Chinese, the phonological relationship between a phonogram and a phonetic radical can be addressed by consistency, which indicates whether the pronunciation of a character agrees with those of its orthographic neighbors containing the same phonetic radical. The indices of consistency for English and Chinese are parallel in nature with respect to the representation of the statistical relationship between orthographic forms and their pronunciations. In studies of English, the consistency effect refers to findings suggesting that naming responses are faster and more accurate for words that have orthographic and phonological consistency (e.g., *-ean* in the final position of a word is always pronounced /In/ as in *lean, dean, bean*, etc.). In contrast, naming responses are slower and less accurate for words lacking consistency (e.g., *-int* corresponds to /Int/ in *mint* and to /aInt/ in *pint*). This effect was observed primarily for words that have a low frequency of use (Seidenberg & Waters, 1985; Seidenberg, Waters, Barnes, & Tanenhaus, 1984; Taraban & McClelland, 1987). However, Jared (1997, 2002) demonstrated that high frequency words can also reveal a consistency effect equivalent to that of low frequency words when the summed frequency of friends and enemies in both the high and low frequency words are controlled. The consistency effect was used to support a single mechanism for converting printed words/pseudowords into speech sounds correlating to the statistical mapping we observed between orthography and phonology. On the other hand, previous studies manipulated character frequency and consistency and demonstrated frequency-by-consistency interaction in the naming of Chinese phonograms (Fang, Horng, & Tzeng, 1986; Lee, Tsai, Su, Tzeng, & Hung, 2005; Lee et al., 2004). That is, among low frequency characters, the characters of low consistency had a longer reaction time and lower accuracy than did the characters of high consistency. Parallel to Jared's (1997, 2002) findings, Lee et al. (2005) also demonstrated that provided the summed frequency of friends and enemies was controlled, there was a consistency effect in the reading of high frequency characters. Moreover, Tsai, Lee, Tzeng, Hung, and Yen (2004) investigated participants' eye movements while performing progressive sentence reading, and they found that character consistency had an impact on their fixation duration. These results suggest that the phonological information provided by the phonetic radical played a role in the reading of Chinese phonograms.

In Chinese, consistency is defined by the ratio of the number of characters containing the same phonetic radical with the same pronunciation to the number of characters containing the same phonetic radical (the so-called phonetic combinability). It implies that in learning or developing the statistical mappings between orthography and phonology, orthographic similarity participates in the phonological restructuring of individual word representations. In other words, characters/words in dense neighborhoods may experience more pressure toward restructuring than would characters/words in sparse neighborhoods (Ziegler & Goswami, 2005). Lee et al (2007), which manipulated high or low consistency characters while matching their phonetic combinability, found low consistency characters to elicit more positive P200 in the frontal region and less negative amplitude at N400 than did high consistency characters. This effect can be interpreted as an early orthographic or phonological activation (indexed by P200), associated with a given phonetic radical at the sublexical level and late competition (indexed by N400) among those lexical candidates that share the same phonetic radical. If the similarity-based view of the lexical restructuring process is true, one would expect to see that characters with high phonetic combinability will experience more pressure toward restructuring than will those with low phonetic combinability. In other words, phonograms with high phonetic combinability should display a greater consistency effect than will those with lower phonetic combinability. To test this hypothesis, the present study manipulates phonological consistency and phonetic combinability simultaneously (see Fig. 1) to examine whether the consistency effect would be modulated by the phonetic combinability. We expect the following results: first, the consistency effect found in Lee et al. (2007) will be replicated; second, the consistency effect will be more salient in the reading of high combinability characters. Lee et al. (2007) had demonstrated that the consistency effect can be found to influence different ERP components (such as N170, P200, and N400). Therefore, the answer to whether or not interaction between consistency and combinability can be found in different stages of the lexical process will shed some light on the temporal dynamics of phonological and orthographic processing in the reading of Chinese.

2. Experimental procedure

2.1. Participants

Thirty-five right-handed native Chinese speakers with normal to corrected vision were paid to participate in this study. After artifact rejection, four participants (three males) were excluded from the analysis due to the extremely small number of valid trials in their data (less than 12). The final analysis was conducted with 31 participants (17 males) whose average age was 23. Written consent was obtained from all the participants.

2.2. Experiment design and materials

A list of 120 Chinese phonograms, configured horizontally with a semantic radical on the left and a phonetic radical on the right, were selected from the Academia Sinica Balanced Corpus (Huang & Chen, 1998). The corpus is based on more than 5 million words (approximately 10 million characters) culled from textbooks, newspapers, works of literature, popular works of fiction and nonfiction, and transcripts. These phonograms were divided into four conditions (see Fig. 1) by manipulating their phonological consis-

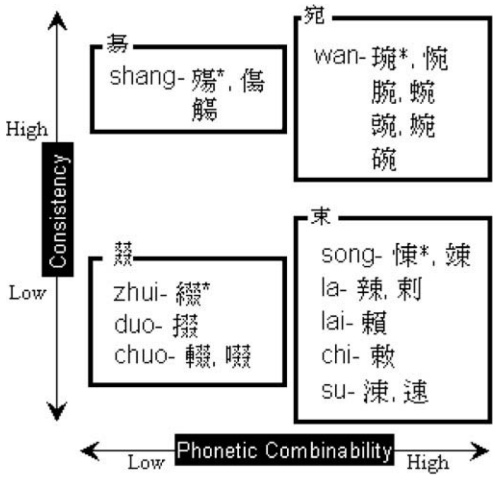


Fig. 1. Example characters from different levels of phonetic consistency and combinability 殤, 琬, 綴, 悚 with orthographic neighborhoods sharing the same phonetic radical.

tency (high vs. low) and phonetic combinability (high vs. low). The index for phonetic combinability and consistency was calculated based on 3697 phonograms. Phonetic combinability was defined as the number of phonograms that share a phonetic radical; characters with the same pronunciation within a group of characters were classified as "friends." Phonological consistency was indexed by the proportion of the number of friends to phonetic combinability. Table 1 illustrates the characteristics of each condition. Each target character was paired with a homophone for the homophone judgment task. The aim of this task was to ensure that the phonology of a target was processed without an overt naming response that might cause muscular noise during the electroencephalogram (EEG) recording. To ensure that the participants knew the correct pronunciations of the target characters, each target character was followed by a homophone as a "yes" trial. To balance the response, another group of 120 non-homophone pairs was created for "no" trials. The mean correctness of all the participants was 88% (ranging from 73% to 99%).

2.3. Procedure

The participants were seated in front of a monitor, at a distance of approximately 60 cm, in an acoustically shielded room. Each participant was given 20 practice trials and 240 randomized experimental trials in three test sessions. The participants were permitted to take breaks between test sessions for as long as they required. The duration of the experiment was approximately 30 m for each participant. A trial consisted of a cross fixation for 500 ms and the display of a target character for another 500 ms. The participants were asked to silently name the target character. The target character was then replaced with a blank space for 1000 ms before a probe character was presented. The participants were asked to decide whether the target character and probe character were homophones by pressing a button on the mouse as quickly and accurately as possible. The index finger indicated "yes" and the middle finger "no." The correctness of the responses and reaction times were recorded. After the disappearance of the probe character, the capital letter "B" was presented in boldface for 1600 ms as a signal for the participants to blink quickly, if necessary, before the next trial.

2.4. EEG recording and preprocessing

The EEG was recorded from 64 Ag/AgCl electrodes (QuickCap, Neuromedical Supplies, Sterling, USA) with a common vertex reference located between Cz and CPz. The data were re-referenced off-line to the average of the right and left mastoids for further analysis. Vertical eye movements (VEOG) were recorded by a pair of electrodes placed on the supra- and infraorbital ridges of the left eye. Horizontal eye movements (HEOG) were recorded by a pair of electrodes placed lateral to the outer canthus of the right and left eyes. A ground electrode was placed on the forehead anterior to Fz. Electrode impedance was kept below 5 KΩ. The EEG signal was continuously recorded and digitized at a rate of 500 Hz. The signals were amplified with SynAmps2 ® (Neuroscan, Inc.) amplifiers at a band-pass filter of 0.05–100 Hz for off-line analysis.

For the off-line analysis, the continuous wave was low-pass filtered below 50 Hz (zero phase shift mode, 12 dB) and then epoched with 100-ms pre-stimulus intervals and 922-ms post-stimulus intervals. The pre-stimulus interval (−100 ms–0 ms) was used for baseline correction. Trials contaminated by eye movement or with voltage variations larger than 60 μV were rejected. Next, the data were low-pass filtered below 30 Hz (zero phase shift mode, 12 dB). The ERPs of the four conditions were computed for every participant at every electrode site by averaging the corresponding trials with correct responses.

3. Result

Figs. 2 and 3 present the grand averaged ERPs of the four conditions at the representative electrodes. The first component was N170, which was defined as the most negative peak at around 170 ms at bilateral-posterior sites. The second component was P200, which was a positive wave distributed at the frontal-central sites, peaking at around 220 ms. The third component was N400, which was a slow negative wave. It peaked at around 350 ms and was characterized as centroparietal distribution. The analysis of N170 was performed by comparing the negative peak amplitude within the time window from 100 to 200 ms. For the analyses of P200 (170–270 ms) and N400 (300–450 ms), the effects of consistency and combinability were compared using the mean amplitude values from the time windows of interest. Repeated measure ANOVAs were performed on these components, with consistency, phonetic combinability, and electrodes—which refers to a set of electrodes at different recording locations on the scalp—as some of the within-subject factors. For each ANOVA, the Greenhouse–Geisser adjustment to the degrees of freedom was applied to correct for the violations of sphericity associated with repeated measures. Accordingly, for all the F tests with more than one degree of freedom in the numerator, the corrected p-value is reported. The post-hoc tests were carried out using Tukey's procedure.

3.1. N170

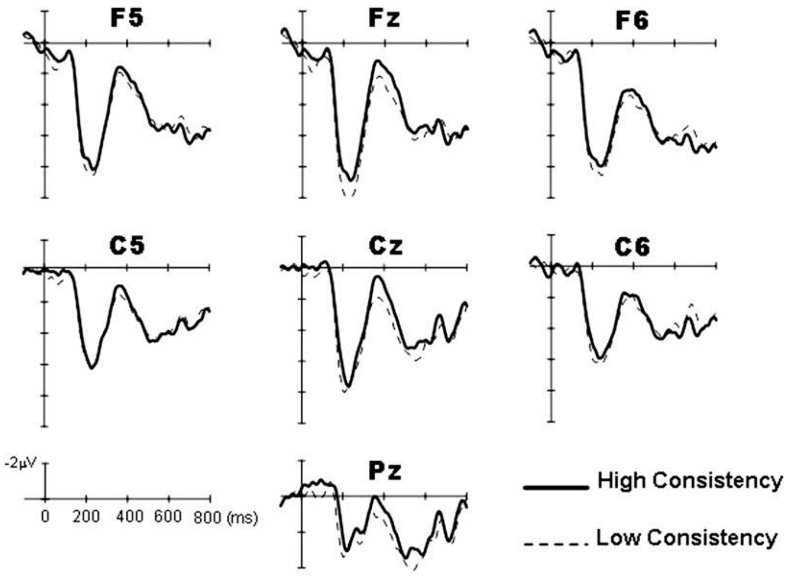
Four pairs of electrodes (P5/6, P7/8, PO5/6, and PO7/8) from the left and right posterior areas were selected, since the reading-related N170 effect was prominent in these regions of the scalp (Maurer, Brandeis, & McCandliss, 2005). The peak amplitude of N170 was analyzed by a four-way ANOVA with consistency (high and low), combinability (high and low), hemisphere (left and right), and electrodes as within-subject factors. Neither character consistency ($F(1,30) = 0.119$, $p > .1$) nor phonetic combinability ($F(1,30) = 1.108$, $p > .1$) showed significant main effects. However, the three-way interaction among consistency, combinability, and electrodes was significant ($F(3,90) = 4.824$, $p < .05$, $\varepsilon = .6$). Post-hoc tests showed that the interaction between consistency and

Table 1
Indexes of mean consistency, phonetic combinability, character frequency, number of strokes, and semantic combinability in the four conditions of this experiment

	High consistency		Low consistency	
	High combinability	Low combinability	High combinability	Low combinability
Consistency index	0.87(0.10)	0.98(0.07)	0.21(0.09)	0.30(0.09)
Phonetic combinability	10.17(2.76)	3.20(0.76)	11.37(2.68)	3.60(0.93)
Character rrequency (per 10 million)	27.77(19.36)	31.60(22.96)	32.53(23.68)	34.63(25.18)
Number of strokes	13.20(3.46)	15.53(4.20)	13.47(4.27)	14.37(4.73)
Semantic combinability	72.00(51.42)	80.97(46.79)	75.73(51.85)	76.23(52.47)

Note. Standard deviations are given in parentheses.

a. High Combinability Characters



b. Low Combinability Characters

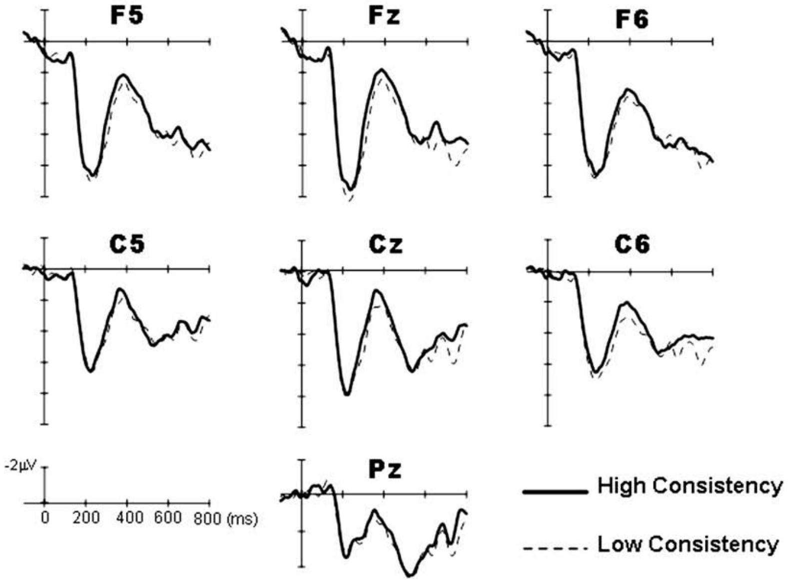


Fig. 2. Grand averaged ERPs at represented electrodes from (a) high combinability characters and (b) low combinability characters.

combinability was significant at PO7/8 ($F(1,30) = 6.130$, $p < .05$), PO5/6 ($F(1,30) = 7.756$, $p < .01$) and P5/6 ($F(1,30) = 6.300$, $p < .05$). Specifically, there were significant phonetic combinability effects in the reading of high consistency characters at PO7/8 ($F(1,30) = 7.089$, $p < .05$), PO5/6 ($F(1,30) = 6.227$, $p < .05$) and P5/6 ($F(1,30) = 5.799$, $p < .05$). Fig. 3 indicates that at bilateral-poster sites, high consistency/high phonetic combinability characters elicited more negative N170 than did high consistency/low phonetic combinability characters. However, the combinability effect in the reading of low consistency characters was not significant for any electrode ($p > .1$).

3.2. P200

Lee et al. (2007) suggested a left centrofrontal distribution of the consistency effect at P200. Accordingly, nine left anterior electrodes (F1, FZ, F3, FC1, FCZ, FC3, C1, CZ, and C3) were chosen for analyzing P200. The mean amplitude of P200 was analyzed by a three-way ANOVA that included consistency, combinability, and electrodes as within-subject factors. The data revealed a significant consistency effect ($F(1,30) = 11.789$, $p < .01$), i.e., low consistency characters demonstrated more positive P200 than did high consistency characters. Further, low phonetic combinability characters revealed more positive P200 than did high phonetic combinability characters, although this difference was only marginally significant ($F(1,30) = 2.9$, $p = .09$). No other two-way or three-way interaction was found to be significant ($p > .1$).

3.3. N400

The analysis of N400 was divided into a midline analysis and a lateral analysis since this component was distributed over the

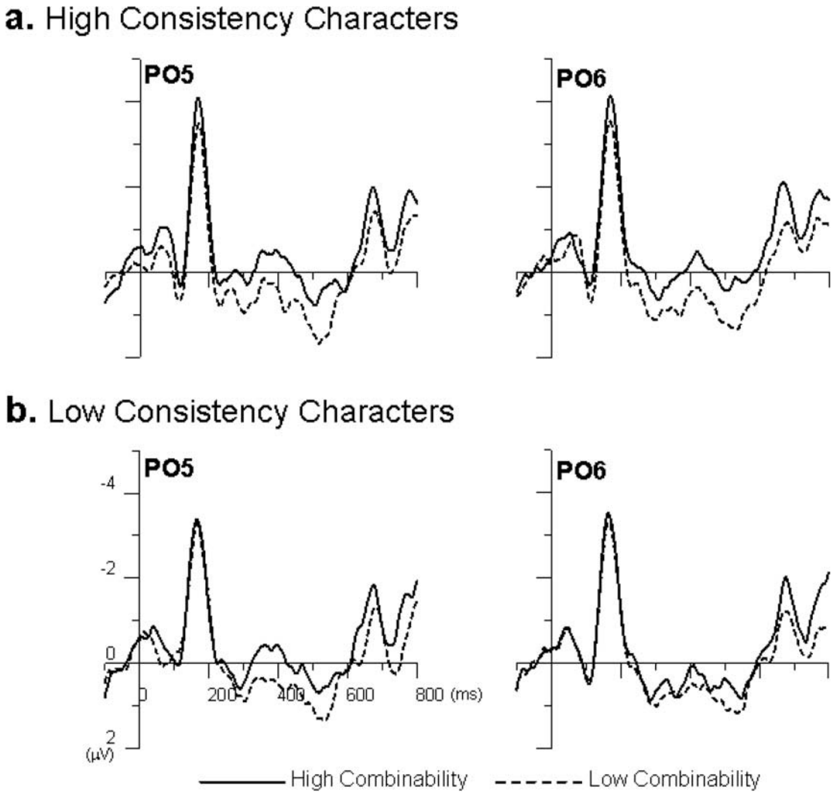


Fig. 3. Grand averaged ERPs of (a) high consistency characters and (b) low consistency characters at two posterior electrodes.

entire scalp. Five electrodes (FZ, FCZ, CZ, CPZ, and PZ) were defined as the electrode variable for the midline N400. Another ten electrodes (F5/6, FC5/6, C5/6, CP5/6, and P5/6) were selected for the lateral N400. Accordingly, the midline N400 was tested by a three-way ANOVA, which included character consistency, phonetic combinability, and electrodes as within-subject factors, while the lateral N400 was tested by a four-way ANOVA, which included character consistency, phonetic combinability, hemisphere, and electrodes as within-subject factors.

The midline analysis showed a significant consistency effect ($F(1,30) = 11.716$, $p < .01$). High consistency characters revealed more negative N400 than did low consistency characters. However, the phonetic combinability effect ($F(1,30) = 3.413$, $p = .07$) was not significant. None of the interactions were significant ($p > .1$). The lateral analysis revealed significant main effects of consistency ($F(1,30) = 10.492$, $p < .01$) and combinability ($F(1,30) = 5.826$, $p < .05$). High consistency characters revealed more negative N400 than did low consistency characters. In addition, high phonetic combinability characters revealed more negative N400 than did low phonetic combinability characters. These two effects interacted neither with each other nor with hemisphere and electrodes ($p > .1$).

3.4. Distribution

A distributional analysis with the time window as a factor was conducted to test whether the consistency effects on P200 and N400 have different topographical distributions. Twenty electrodes across the scalp were selected for analyzing the scalp distribution, which included electrodes on left-lateral sites (F5, FC5, C5, CP5, and P5), left-medial sites (F1, FC1, C1, CP1, and P1), right-medial sites (F2, FC2, C2, CP2 and P2) and right-lateral sites (F6, FC6, C6, CP6, and P6). In the 170–270 ms and 300–450 ms time windows, the difference waves of consistency effects (low minus high) in high and low phonetic combinability conditions were normalized separately according to the procedure described in McCarthy and Wood (1985). A five-way ANOVA including time windows (P200 vs. N400), combinability (high vs. low), hemisphere (left vs. right), laterality (medial vs. lateral), and caudality as within-subject factors was performed. The analysis showed a significant three-way interaction between time windows, hemisphere and caudality ($F(4,120) = 3.486$, $p < .05$, $\varepsilon = .79$). Post- hoc tests showed that the two-way interaction between hemisphere and caudality was more significant at P200 ($F(4,120) = 10.742$, $p < .001$, $\varepsilon = .737$) than at N400 ($F(4,120) = 3.675$, $p = .03$, $\varepsilon = .807$). For P200, caudality effect at P200 was significant in both the left hemisphere ($F(4,120) = 19.423$, $p < .0001$, $\varepsilon = .372$) and the right hemisphere ($F(4,120) = 10.30$, $p < .001$, $\varepsilon = .388$). Specifically, in the left hemisphere, anterior electrodes revealed larger consistency effects than did the posterior electrodes (F5/1 versus P5/1: $p < .01$; FC5/1 versus P5/1: $p < .01$). However, in the right hemisphere, only central electrodes revealed larger P200 consistency effects than did posterior electrodes (C6/2 versus P6/2: $p < .05$). As for N400, the caudality effect at N400 was pronounced in the left hemisphere ($F(4,120) = 15.224$, $p < .0001$, $\varepsilon = .417$) and less significant in the right hemisphere ($F(4,120) = 8.156$, $p < .01$, $\varepsilon = .438$). In the left hemisphere, central electrodes revealed larger N400 consistency effects than did the posterior electrodes (FC5/1 versus P5/1: $p < .01$; C5/1 versus P5/1: $p < .05$). However, no any paired comparison of electrodes was significant in the right hemisphere. The distributional analysis demonstrated that the consistency effects at P200 and N400 have different distributional characteristics.

3.5. Reanalysis based on phonological alternatives and phonological family size

According to Lee et al. (2007), phonological alternatives is defined as the number of pronunciations associated with a given phonetic radical, while phonological family size is defined as the number of homophones within a selected phonological subgroup. In this study, the simultaneous manipulation of phonological consistency and combinability implies that the difference in terms of phonological alternatives and phonological family size between high and low consistency will be much larger in the reading of high combinability characters than in the reading of low combinability characters. Based on the two-stage framework, the P200 indexes reflect the variation in the mappings between orthography and phonology, while the N400 indexes reflect the lexical competition within the selected pronunciations (phonological subgroup). In addition to the interaction at N170, we expected to observe interaction between consistency and combinability at both P200 and N400. However, the data did not support this hypothesis. One possible explanation for the current findings is that we did not directly manipulate the phonological family size and phonological alternatives. Instead, we assumed that these two indices might covariate with the manipulation of consistency and combinability.

To further explore this possibility, we directly examined the phonological alternatives and phonological family sizes for all the stimuli. The mean of these values is provided in Table 2. The repeated ANOVA measures revealed a significant interaction between consistency and combinability (phonological alternative: $F(1,29) = 6.883$, $p < .05$; phonological family size: $F(1,29) = 35.980$, $p < .001$). However, when examining the distribution of the two indexes, we found that the phonological family sizes of highly consistent and combinable characters ranged from 4 to 12, which partially overlapped with those of the other three conditions (which ranged from 1 to 5). The phonological family sizes for some of these characters (ranging from 4 to 5) could be smaller, and it is not necessary to display their difference between such characters and the low consistency/ high combinability characters.

To further examine whether the difference between the phonological family sizes of high and low consistency characters with high combinability is insufficient to show consistency-by-combinability interaction at P200 and N400, we performed an additional analysis by deleting seven items from the high consistency/high combinability condition whose phonological family sizes were lower than 5. The family sizes of the remaining 23 items averaged at 7.74 and ranged from 6 to 12. Two participants were excluded from further analysis due to an insufficient number of accepted trials in their data. Fig. 4 provides the reanalyzed ERP waveforms of all four conditions and illustrates the consistency effects in the high and low combinability conditions. The same designs of repeated-measure ANOVAs used in the previous analyses were performed on the corrected data sets to examine whether consistency-by-combinability interaction could be found at N170, P200, and N400. A planned comparison will be performed to test for simple main effects of consistency on high and low combinability characters.

3.5.1. N170

Identical to the previous analysis, the peak amplitude of N170 was analyzed with a four-way ANOVA including the within-subject factors of consistency, combinability, hemisphere, and electrodes (P5/6, P7/8, PO5/6, and PO7/8). Neither character consistency ($F(1,28) = .52$, $p > .1$) nor phonetic combinability ($F(1,28) = 1.792$, $p > .1$) showed significant main effects. The two-way interaction between consistency and combinability ($F(1,28) = 4.813$, $p < .05$), and the three-way interaction among consistency, combinability, and electrodes ($F(3,84) = 4.137$, $p < .05$, $\varepsilon = .7$) were significant. Post-hoc tests demonstrated that the interaction between consistency and combinability was significant at PO7/8 ($F(1,28) = 11.936$, $p < .01$), P5/6 ($F(1,28) = 10.010$, $p < .01$) and PO5/6 ($F(1,28) = 14.116$, $p < .001$). Specifically, there were significant phonetic combinability effects in high consistency characters at PO7/8 ($F(1,28) = 12.951$, $p < .01$), P5/6 ($F(1,28) = 9.024$, $p < .01$) and PO5/6 ($F(1,28) = 11.857$, $p < .01$). That is, high consistency/high phonetic combinability characters elicited more negative N170 than did high consistency/low phonetic combinability characters at bilateral-posterior sites. However, the combinability effect in the reading of low consistency characters was not significant for any electrode ($p > .1$). On the other hand, the simple main effects of consistency were significant in high phonetic combinability characters at PO7/8 ($F(1,28) = 9.452$, $p < .01$), P5/6 ($F(1,28) = 6.015$, $p < .05$) and PO5/6 ($F(1,28) = 10.286$, $p < .01$). That is, high consistency/high phonetic combinability characters elicited more negative N170 than did low consistency/high phonetic combinability characters. However, the consistency effect in the reading of low combinability characters was not significant for any electrode ($p > .1$).

3.5.2. P200

The mean amplitude of P200 was analyzed by a three-way ANOVA that included consistency, combinability, and electrodes as within-subject factors. The data revealed a significant consistency effect ($F(1,28) = 8.346$, $p < .01$). Low consistency characters revealed more positive P200 than did high consistency characters. The main effect of combinability was not significant ($F(1,28) = 2.456$, $p = .13$), although the tendency of low phonetic combinability characters remain to reveal more positive P200 than did high phonetic combinability characters. The two-way interaction between consistency and combinability was not significant ($F(1,28) = 1.244$, $p = .27$). However, the planned comparison revealed a significant consistency effect in the reading of high combinability characters ($F(1,56) = 7.514$, $p = .008$) thought not in the reading of low combinability characters ($p > .1$).

3.5.3. N400

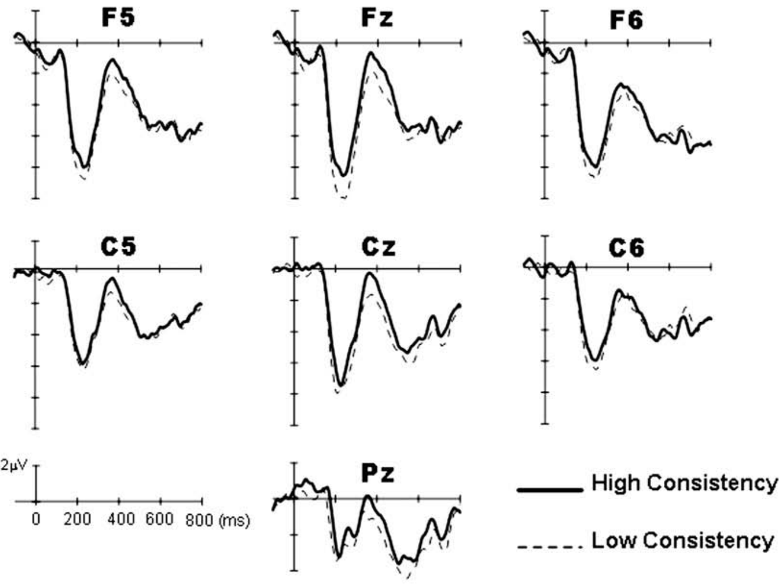
Identical to the previous analysis, the mean amplitude of N400 was divided for a midline analysis and lateral analysis. The midline N400 was tested by a three-way ANOVA, which included character consistency, phonetic combinability, and electrodes as within-subject factors, while the lateral N400 was tested by a four-way ANOVA, which included character consistency, phonetic combinability, hemisphere, and electrodes as within-subject factors.

The midline analysis showed a significant consistency effect ($F(1,28) = 6.813$, $p < .05$), i.e., high consistency characters revealed more negative N400 than did low consistency characters. The

Table 2
Mean phonological family size and alternatives

	High consistency		Low consistency	
	High combinability	Low combinability	High combinability	Low combinability
Phonological family size				
Mean (*SD*)	6.73(2.41)	2.13(0.82)	1.43(1.25)	0.17(0.46)
Range	4 ∼ 12	2 ∼ 4	1 ∼ 5	1 ∼ 3
Phonological alternatives				
Mean (*SD*)	2.2(0.92)	1.20(0.55)	5.03(1.63)	3.00(1.14)
Range	1 ∼ 5	1 ∼ 3	2 ∼ 8	2 ∼ 6

a. High Combinability Characters



b. Low Combinability Characters

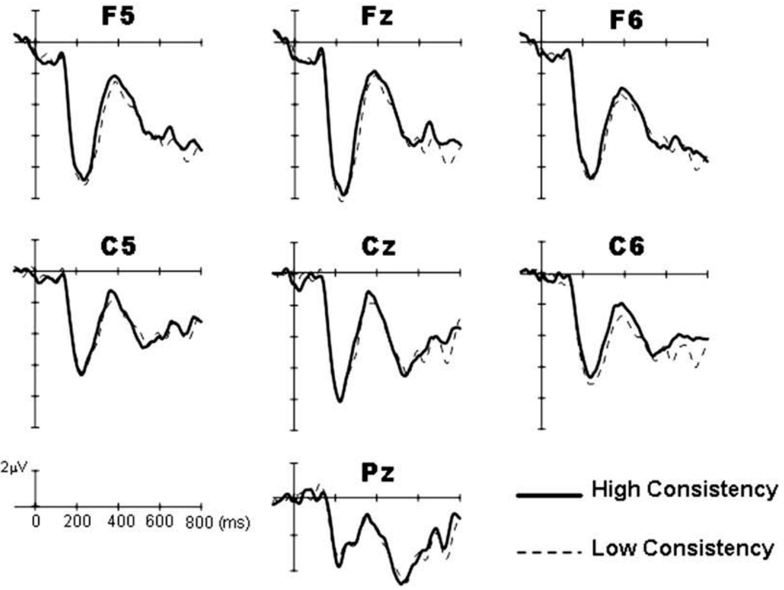


Fig. 4. Reanalyzed ERPs at represented electrodes from (a) high combinability characters and (b) low combinability characters.

phonetic combinability effect ($F(1,28) = 2.137$, $p = .15$) and the consistency-by-combinability interaction ($F(1,28) = 1.352$, $p = .25$) were not significant. The planned comparison demonstrated a significant consistency effect in the reading of high combinability characters ($F(1,56) = 7.514$, $p = .008$), but not in the reading of low combinability characters ($p > .1$).

The lateral analysis revealed a significant consistency effect ($F(1,28) = 8.098$, $p < .01$) and a marginally significant combinability effect ($F(1,28) = 3.841$, $p = .06$). High consistency characters revealed more negative N400 than did low consistency characters. In addition, high phonetic combinability characters revealed more negative N400 than did low phonetic combinability characters. The consistency-by-combinability interaction was not significant ($F(1,28) = 0.003$, $p = .95$). The planned comparison showed a marginally significant consistency effect in the reading of high combinability characters ($F(1,56) = 3.808$, $p = .050$), and a significant consistency effect in the reading of low combinability characters ($F(1,56) = 4.137$, $p = .04$).

In summary, for N170, the combinability effect was only found in the reading of high consistency characters; further, characters with higher phonetic combinability elicited greater negativity at N170 than did those with lower phonetic combinability. Moreover, the planned comparison showed that low consistency/high combinability characters produced more positive P200 and less negative N400 than did high consistency/high combinability characters.

4. General discussion

The present study aims to explore the relationship between phonetic combinability and phonological consistency in the reading of Chinese phonograms. The main findings reveal a significant interaction between phonetic combinability and consistency at N170 and consistency and combinability effects at P200 and N400. These findings supported those in Lee et al. (2007) regarding the consistency effect and further suggest the interplay between orthographic density and the mapping of orthography to phonology in the different stages of lexical processing. The various aspects of the psychological processes involved in reading linked to N170, P200, and N400 will be discussed separately below.

4.1. N170

Interaction between phonetic combinability and consistency was found at N170 in the bilateral occipital area, which demonstrated that high phonetic combinability/high consistency characters elicited greater negativity at N170 than did low phonetic combinability/high consistency characters. The data are congruent with the perceptual expertise account of N170. Studies have suggested the N170 component as an index of orthographic detection at the initial perceptual categorization stage (Bentin, Mouchetant-Rostaing, Giard, Echallier, & Pernier, 1999; Maurer et al., 2005; Rossion, Joyce, Cottrell, & Tarr, 2003). Increased N170 responses were elicited in the stimulus category with which a person has extensive visual experience, such as the identification of faces (Rossion et al., 2003) and the identification of birds/dogs (Tanaka & Curran, 2001). These results suggest that extensive visual experience with an object category leads to fast, specialized processing within the first 200 ms. In addition, the reading-related N170 effect can be found in the contrasts between words and strings of meaningless symbols, forms, consonant strings, or shapes (Maurer et al., 2005; Schendan, Ganis, & Kutas, 1998). The perceptual expertise account may also account for the combinability effect found at N170 in the current study and suggests that radical analysis occurs in the earlier stages of Chinese reading. High combinability characters imply larger orthographic neighborhoods, thus, they elicit greater activation at the perceptual level than do low combinability characters.

The consistency-by-combinability interaction found at N170 suggests that the mapping of orthography to phonology influences the earlier stages of orthographic processing (Goswami & Ziegler, 2006; Lee et al., 2007). This effect provides further support for the phonological mapping hypothesis of the N170 word effect (Maurer & McCandliss, 2007), according to which the left lateralization of the reading-related N170 may reflect the involvement of spelling-to-sound mapping during visual word recognition. Cross-linguistic studies have shown that the reading of pseudowords elicits a left-hemisphere modulation at N170 in German, but not in English (Maurer et al., 2005). A study involving Koreans who were educated in both Chinese and written English reported a left-lateralized N170 effect for both English and Korean words but a bilateral N170 effect for Chinese characters and pictures (Kim, Yoon, & Park, 2004). The prominent difference in the comparisons between German and English, and between English and Chinese lies in the level of orthography-to-phonology transparency. Such cross-linguistic differences provide support for the phonological mapping hypothesis of the left-lateralized N170 effect. In addition, the consistency-by-combinability interaction found in the current study was a bilateral effect rather than a left-lateralized effect. This also confirms the following proposition of the phonological mapping hypothesis: "The left-lateralization of the N170 responses to visual words should be more pronounced in scripts using grapheme-phoneme conversion rules, but less pronounced in logographic scripts which are based on lexical morphemes" (Maurer & McCandliss, 2007).

4.2. P200 and N400

This study demonstrated that low consistency characters produced more positive amplitude at P200 and less negative amplitude at N400 than did high consistency characters. This finding replicates Lee et al.'s (2007) results and supported the two-stage framework for lexical access by using P200 and N400 to index the earlier and later stages of lexical processing. For low consistency characters, more phonological alternatives can be associated with a given phonetic radical. This will cause greater interference at the phonological level and thus show greater positivity at P200. On the other hand, given that phonetic combinability is matched between the high and low consistency conditions, the phonological family size within a selected pronunciation or phonological subgroup of high consistency characters will be larger than that within a similar subgroup of low consistency characters. Therefore, high consistency characters would involve greater semantic competition at this stage and display greater N400 than would low consistency characters. The same framework can be used to explain the combinability effect found at P200 and N400, wherein high phonetic combinability characters demonstrated less positive P200 and more negative N400 than did low phonetic combinability characters. According to the two-stage framework, high combinability (more orthographic neighbors) facilitates character processing at the orthographic level due to larger orthographic activation, consequently demonstrating less positivity at P200. A larger neighborhood size increases semantic competition, which in turn, exaggerates the N400 effect (Holcomb, Grainger, & O' Rourke, 2002).

The raw analysis of P200 and N400 demonstrated significant main effects of consistency and combinability. However, there was no interaction between these two factors. Although the two-stage framework can account for these main effects, the hypothesis that the consistency effect should be more salient in the reading of phonograms with high phonetic combinability was not supported. Lee et al. (2007) suggested that the number of alternative pronunciations and the phonological family size associated with a given character may be reflected at P200 and N400. This study did not manipulate the phonological family size and phonological alternatives directly and assumed that these two indexes would covariate with the manipulation of consistency and combinability. To be more specific, a word with larger combinability also implies that it has a larger phonological family size. By examining the phonological alternatives and phonological family sizes for all the stimuli, we found seven high consistency and high combinability characters with relatively small phonological family sizes. After deleting these items, the planned comparison in the reanalysis revealed a significant consistency effect at P200 and N400 in the reading of high combinability characters. These findings support our speculation and suggest that in the reading of Chinese phonograms, early specification of the pronunciations is carried out by selection among the phonological alternatives associated with a given phonetic radical. Then, presumably, semantic competition is performed in the later stages among the candidates within a phonological family. Most importantly, the lexical processing of character recognition correlates to the statistical mapping we observed between orthography, phonology, and semantics. Therefore, the orthography-to- phonology transformation is not determined solely by the consistency between orthography and phonology but also by the orthographic neighborhood size of the constitution (e.g., the phonetic and semantic radicals) of the characters. Nevertheless, these results showed a tendency toward a larger consistency effect in the reading of high phonetic combinability characters at P200 and N400 which were mainly based on post-hoc reanalysis. Further investigation is needed to verify how different aspects of phonological consistency influence the reading of Chinese, in terms of the number of alternative pronunciations and the phonological family size.

4.3. Implications for models of chinese character recognition

The current findings regarding combinability effects at P200 and N400 further support the lexical constituency model. Based on this model, the radical-based inputs predict that words with high combinability (i.e., those with more orthographic neighbors sharing the same radical) result in larger orthographic activation facilitate character processing at the early orthographic level, and display less positive P200. In the later stage, a radical activates more characters that share the same radical to reach the threshold, and greater inhibition emerges at the lexical level and is reflected by a larger N400. The data were congruent with previous studies that demonstrated that P200 was reduced when a character shared a radical with the preceding character and interpreted it as a graphic processing component (Liu et al., 2003). Meanwhile, this model emphasizes threshold-style, rather than cascade-style, activation of phonology. The idea is that in an alphabetic system, the word-level level units do not wait for a complete specification of all the letter units before activating word–level phonology, which is the so-called cascade style (Coltheart, Rastle, Perry, Langdon, & Ziegler, 2001). However, in Chinese, the word-level phonology is not activated prior to a full orthographic specification of the characters, which is the threshold style. Based on this assumption, the model predicts no phonological effect at the sublexical stage. Furthermore, characters sharing the same phonetic radical but corresponding to a variety of pronunciations should elicit greater phonological interference or competition at the lexical stage. However, our data showed an interaction between phonetic combinability and consistency at N170 and a phonetic consistency effect at P200, which suggest that the phonological computation starts from the sublexical stage. Furthermore, given that phonetic combinability was matched between the high and low consistency conditions, the reading of high consistency characters, in fact, elicited greater N400 than did the reading of low consistency characters. These findings cannot be reconciled by the current threshold-style lexical constituent model and suggested that the greater N400 for the reading of high consistent characters resulted from the lexical competition within a phonological family.

5. Conclusion

In conclusion, the data presented in this study support Lee et al.'s (2007) findings regarding the consistency effect on several ERP components that index the various stages of lexical processing. Furthermore, our data demonstrates that the mapping of orthography to phonology interacts with the orthographic neighborhood density. N170 has been used to index the perceptual expertise effect. Our data revealed that characters with larger orthographic neighborhoods (i.e., characters that share the same phonetic radical) elicit greater N170 negativity, supporting the hypothesis that a radical acts as a functional unit in Chinese character recognition. Moreover, the combinability effect at N170 was modulated by phonological consistency, which supports the phonological mapping hypothesis and suggests that the earlier stages of the visual word recognition process are shaped by the mapping of orthography to phonology even in Chinese. On the other hand, the presented combinability and consistency effects at P200 and N400 suggest that both orthographic and phonological analyses are involved in the early stages of radical activation and in the later stages of lexical identification for Chinese character recognition. The reanalysis directly addressed the possible contribution of phonological alternatives and family size to the consistency effect observed at P200 and N400 and suggested that the phonetic consistency effect mainly originated from phonograms with high combinability and large neighborhoods. Such a modulation effect may not be accounted for by the lexical constituent model with the prior assumption of threshold-style activation. Instead, we suggest that the consideration of cascaded-style processing and the implementation of the feedback connections between orthographic, phonological, and semantic lexicons in the framework of Chinese character recognition might be able to reconcile the current findings. Future computational and experimental studies could further examine the relationship between semantic and phonetic radicals and their interaction with orthography, phonology, and semantics.

Acknowledgments

This work was supported by grants from Taiwan National Science Council (NSC 94-2411-H-001-068, 95-2413-H-010-002-and NSC 96-2628-H-001-058) and the theme project of brain, cognition and behavioral science from Academia Sinica, Taiwan (AS-93-TP-C05). The authors thank two anonymous reviewers for their detailed comments on this paper. Their thanks also go to Chad Yang for his comments and assistant on an earlier draft of the paper.

References

Andrews, S. (1989). Frequency and neighborhood effects on lexical access: Activation or search? *Journal of Experimental Psychology. Learning, Memory and Cognition, 15*(5), 802–841.

Barber, H., Vergara, V., & Carreiras, M. (2004). Syllable-frequency effects in visual word recognition: Evidence from ERPs. *NeuroReport, 15*(3), 545–548.

Bentin, S., Mouchetant-Rostaing, Y., Giard, M. H., Echallier, J. F., & Pernier, J. (1999). ERP manifestations of processing printed words at different psycholinguistic levels: Time course and scalp distribution. *Journal of Cognitive Neuroscience, 11*(3), 235–260.

Carreiras, M., Vergara, M., & Barber, H. (2005). Early event-related potential effects of syllabic processing during visual word recognition. *Journal of Cognitive Neuroscience, 17*(11), 1803–1817.

Chen, M. J., & Weekes, B. S. (2004). Effects of semantic radicals on Chinese character categorization and character decision. *Chinese Journal of Psychology, 46*, 179–195.

Coltheart, M., Davelaar, E., Jonasson, J. T., & Besner, D. (1977). Access to the internal lexicon. In S. Domic (Ed.), *Attention and performance VI* (pp. 535–555). San Diego, CA: Academic Press.

Coltheart, M., Rastle, K., Perry, C., Langdon, R., & Ziegler, J. (2001). DRC: A dual route cascaded model of visual word recognition and reading aloud. *Psychological Review, 108*(1), 204–256.

Ding, G., Peng, D., & Taft, M. (2004). The nature of the mental representation of radicals in Chinese: A priming study. *Journal of Experimental Psychology. Learning, Memory and Cognition, 30*(2), 530–539.

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

Feldman, L. B., & Siok, W. W. T. (1997). The role of component function in visual recognition of Chinese characters. *Journal of Experimental Psychology. Learning, Memory and Cognition, 23*(3), 776–781.

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

Forster, K. I., & Shen, D. (1996). No enemies in the neighborhood: Absence of inhibitory neighborhood effects in lexical decision and semantic categorization. *Journal of Experimental Psychology. Learning, Memory, and Cognition, 22*, 696–713.

Goswami, U., & Ziegler, J. C. (2006). A developmental perspective on the neural code for written words. *Trends in Cognitive Sciences, 10*(4), 142–143.

Grainger, J., & Jacobs, A. M. (1996). Orthographic processing in visual word recognition: A multiple read-out model. *Psychological Review, 103*(3), 518–565.

Grainger, J., O'Regan, K., Jacobs, A., & Segui, J. (1989). On the role of competing word unites in visual word recognition: The neighborhood frequency effect. *Perception and Psychophysics, 45*(3), 189–195.

Grainger, J., & Segui, J. (1990). Neighborhood frequency effects in visual word recognition: A comparison of lexical decision and masked identification latencies. *Perception Psychophysics, 47*(2), 191–198.

Holcomb, P. J., Grainger, J., & O' Rourke, T. (2002). An electrophysiological study of the effects of orthographic neighborhood size on printed word perception. *Journal of Cognitive Neuroscience, 14*, 938–950.

Huang, C.-R., & Chen, K.-J. (1998). *Academia Sinica balanced corpus (version 3). Taipei.* Taiwan: Academia Sinica.

Jared, D. (1997). Spelling-sound consistency affects the naming of high-frequency words. *Journal of Memory and Language, 36*(4), 505–529.

Jared, D. (2002). Spelling-sound consistency and regularity effects in word naming. *Journal of Memory and Language, 46*(4), 723–750.

Kim, K. H., Yoon, H. W., & Park, H. W. (2004). Spatiotemporal brain activation pattern during word/picture perception by native Koreans. *Neuroreport, 15*(7), 1099–1103.

Lee, C. Y., Tsai, J. L., Chan, W. H., Hsu, C. H., Hung, D. L., & Tzeng, O. J. (2007). Temporal dynamics of the consistency effect in reading Chinese: An event-related potentials study. *NeuroReport, 18*(2), 147–151.

Lee, C. Y., Tsai, J. L., Chiu, Y. C., Tzeng, O. J. L., & Hung, D. L. (2006). The early extraction of sublexical phonology in reading Chinese pseudocharacters: An event-related potentials study. *Language and Linguistics, 7*(3), 619–636.

Lee, C. Y., Tsai, J. L., Kuo, W. J., Yeh, T. C., Wu, Y. T., Ho, L. T., et al. (2004). Neuronal correlates of consistency and frequency effects on Chinese character naming: An event-related fMRI study. *Neuroimage, 23*(4), 1235–1245.

Lee, C. Y., Tsai, J. L., Su, E. C. I., Tzeng, O. J. L., & Hung, D. L. (2005). Consistency, regularity, and frequency effects in naming chinese characters. *Language and Linguistics, 6*(1), 75–107.

Liu, Y., Perfetti, C. A., & Hart, L. (2003). ERP evidence for the time course of graphic, phonological, and semantic information in Chinese meaning and pronunciation decisions. *Journal of Experimental Psychology. Learning, Memory, and Cognition, 29*(6), 1231–1247.

Maurer, U., Brandeis, D., & McCandliss, B. D. (2005). Fast, visual specialization for reading in English revealed by the topography of the N170 ERP response. *Behavioral and Brain Functions, 1*, 13.

Maurer, U., & McCandliss, B. D. (2007). The development of visual expertise for words: The contribution of electrophysiology. In E. L. Grigorenko & A. Naples (Eds.), *Single-word reading: Cognitive, behavioral and biological perspectives*. Mahwah, NJ: Lawrence Erlbaum Associates.

McCarthy, G., & Wood, C. C. (1985). Scalp distributions of event-related potentials: An ambiguity associated with analysis of variance models. *Electroencephalography and Clinical Neurophysiology, 62*(3), 203–208.

Perea, M., Carreiras, M., & Grainger, J. (2004). Blocking by word frequency and neighborhood density in visual word recognition: A task-specific response criteria account. *Memory & Cognition, 32*(7), 1090–1102.

Perfetti, C. A., Liu, Y., & Tan, L. H. (2005). The lexical constituency model: Some implications of research on Chinese for general theories of reading. *Psychological Review, 112*(1), 43–59.

Pollatsek, A., Perea, M., & Binder, K. S. (1999). The effects of "neighborhood size" in reading and lexical decision. *Journal of Experimental Psychology: Human Perception and Performance, 25*, 1142–1158.

Pylkkänen, L., Stringfellow, A., & Marantz, A. (2002). Neuromagnetic evidence for the timing of lexical activation: An MEG component sensitive to phonotactic probability but not to neighborhood density. *Brain and Language, 81*, 666–678.

Rossion, B., Joyce, C. A., Cottrell, G. W., & Tarr, M. J. (2003). Early lateralization and orientation tuning for face, word, and object processing in the visual cortex. *NeuroImage, 20*, 1609–1624.

Schendan, H. E., Ganis, G., & Kutas, M. (1998). Neurophysiological evidence for visual perceptual categorization of words and faces within 150 ms. *Psychophysiology, 35*(3), 240–251.

Seidenberg, M. S., & Waters, G. S. (1985). Spelling-sound effects in reading: Time-course and decision criteria. *Memory and Cognition, 13*(6), 557–572.

Seidenberg, M. S., Waters, G. S., Barnes, M. A., & Tanenhaus, M. K. (1984). When does irregular spelling or pronunciation influence word recognition? *Journal of Verbal Learning & Verbal Behavior, 23*(3), 383–404.

Snodgrass, J. G., & Mintzer, M. (1993). Neighborhood effects in visual word recognition: Facilitatory or inhibitory. *Memory and Cognition, 21*(2), 247–266.

Taft, M., & Zhu, X. (1997). Submorphemic processing in reading Chinese. *Journal of Experimental Psychology. Learning, Memory and Cognition, 23*(3), 761–775.

Tanaka, J. W., & Curran, T. (2001). A neural basis for expert object recognition. *Psychological Science, 12*(1), 43–47.

Taraban, R., & McClelland, J. L. (1987). Conspiracy effects in word pronunciation. *Journal of Memory and Language, 26*(6), 608–631.

Tsai, J. L., Lee, C. Y., Tzeng, O. J. L., Hung, D. L., & Yen, N. S. (2004). Use of phonological codes for Chinese characters: Evidence from processing of parafoveal preview when reading sentences. *Brain and Language, 91*(2), 235–244.

Ziegler, J. C., & Goswami, U. (2005). Reading acquisition, developmental dyslexia and skilled reading across languages: A psycholinguistic grain size theory. *Psychological Bulletin, 131*(1), 3–29.