Position of phonetic components may influence how written words are processed in the brain: Evidence from Chinese phonetic compound pronunciation

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ABSTRACT

Previous studies showed a right visual field (RVF)/left hemisphere (LH) advantage in Chinese phonetic compound pronunciation. Here we contrast the processing of two phonetic compound types: a dominant structure in which a semantic component appears on the left and a phonetic component on the right (SP characters), and a minority structure with the opposite arrangement (PS characters). We show that this RVF/LH advantage was only observed in SP character pronunciation but not in PS character pronunciation. This result suggests SP character processing is more LH lateralized than PS character processing, and is consistent with corresponding ERP N170 data. This effect may be due to the dominance of SP characters in the lexicon that makes readers opt to obtain phonological information from the right of the characters. This study thus shows the overall information distribution of word components in the lexicon may influence how written words are processed in the brain.

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Introduction

It has long been observed that the processes of visual word recognition in alphabetic languages such as English are lateralized to the left hemisphere (LH). Data from fMRI studies show a region inside the left fusiform area (*visual word form area*) responding selectively to written words (e.g., McCandliss, Cohen, & Dehaene, 2003; although some argued this region also responses to stimuli other than words and in tasks other than reading; see, e.g., Price & Devlin, 2003). ERP studies also show that words elicit a larger N170 in the LH compared with strings of symbols (e.g., Maurer, Brandeis & McCandliss, 2005). Consistent with these findings, a classical right visual field (RVF)/LH advantage in reading English words has been consistently reported, demonstrated first in tachistoscopic recognition (e.g., Bryden & Rainey, 1963) and subsequently in other word recognition tasks, including lexical decision (Faust, Babkoff, & Kravetz, 1995) and word naming tasks (Brysbaert & d'Ydewalle, 1990). This RVF/LH advantage has been argued to be linked to the LH superiority in language processing, in particular phonological processing, and shown to interact with sex and handedness (e.g., Voyer, 1996).

In contrast, the recognition of Chinese characters, a logographic writing system, has been shown to have a left visual field (LVF)/right hemisphere (RH) advantage in tasks that mainly depend on the processing of orthography/word forms, (e.g., Tzeng et al., 1979; Cheng & Yang, 1989), and a RVF/LH advantage in tasks that mainly depend on the processing of phonology (e.g., Weekes & Zhang, 1999)[1]. For example, Tzeng et al. (1979) showed a LVF/RH advantage in tachistoscopic recognition of single Chinese characters; this effect has been argued to reflect the RH superiority in handling holistic pattern recognition (e.g., Tzeng et al., 1979), or a more effective activation of lexical knowledge of Chinese characters in the RH compared with the LH, given that no laterality effect was found for pseudo- and non-characters (Cheng & Yang, 1989). As for phonological processing, Weekes and Zhang (1999) reported phonological priming effects on phonetic compound recognition when the characters were presented in the RVF but not the LVF. Yang and Cheng (1999) also showed that in tachistoscopic recognition of Chinese characters, when the orthographic similarity of two alternative items for choice was manipulated, there was an LVF advantage; in contrast, when the phonological similarity of two alternative items for choice was manipulated, there was a RVF advantage. Consistent with the behavioral data, fMRI and ERP studies of Chinese character recognition have generally exhibited a more bilateral or RH-lateralized activation in the visual system compared with English word recognition (e.g., Tan et al., 2000, 2001; Liu & Perfetti, 2003). Hence, Chinese character recognition seems to involve an interaction between the processing preferences of the RH (orthography) and the LH (phonology).

The difference in hemispheric lateralization between English word and Chinese character recognition has been argued to be due to the RH superiority in handling holistic pattern recognition that is required in Chinese character recognition (e.g., Tzeng et al., 1979). Nevertheless, a recent study showed a decreased holistic processing effect in Chinese character recognition in Chinese readers compared with non-Chinese readers (Hsiao & Cottrell, 2009), which is inconsistent with this claim. Alternatively, Maurer and McCandliss (2007) proposed the *phonological mapping hypothesis* and argued that, given that phonological processes are typically LH-lateralized (e.g., Rumsey et al., 1997), specialized processing of visual words in visual brain areas also becomes LH-lateralized. Accordingly, they pointed out that the LH lateralization in English word recognition may be related to the influence of grapheme-phoneme conversion established during learning to read, and this modulation should be less pronounced in logographic scripts such as Chinese.

However, some Chinese characters do have a phonological component that has a similar functionality as the grapheme-phoneme mapping in English words[2]. These characters are a dominant type of Chinese characters, phonetic compounds, which comprise about 81% of the 7000 most frequent characters (Li & Kang, 1993). A phonetic compound consists of a semantic radical that usually reflects character meaning, and a phonetic radical that typically provides partial information about character pronunciation (Figure 1). Thus, a phonetic compound character may also have LH phonological modulation during learning to read due to the requirement of mapping its phonetic component to the corresponding pronunciation as part of the character pronunciation, and consequently its processing may become LH-lateralized. Consistent with this claim, Weekes, Chen, and Lin (1998) compared phonological priming effects in the recognition of phonetic compound characters and integrated characters (i.e., characters that do not contain separate radical components, and thus do not have a phonetic radical), and showed that there was a significant phonological priming effect in phonetic compound character recognition, but not in the recognition of integrated characters (see also Weekes and Zhang, 1999).

Among these phonetic compound characters, different structures exist, including left-right, top-bottom, concentric, and other irregular structures (Figure 1). Here we hypothesize that phonetic compounds in different structures may be processed differently in the brain, because the phonologically important part of the characters, i.e., the phonetic radical, appears in different locations in different character structures, and Chinese readers may opt to use phonological information from a location where useful information is most likely to be obtained. For example, about two-thirds of the phonetic compounds have a left–right structure (Hsiao & Shillcock, 2006); among these left-right structured phonetic compounds, about 90% of them have the semantic radical on the left and the phonetic radical on the right (SP characters), and the other 10% have the opposite arrangement (PS characters; Hsiao & Shillcock, 2006; Figure 1). Since SP characters are a dominant structure among phonetic compounds, Chinese readers may opt to use phonological information from the right side of a character more often than any other locations. Thus, the automaticity of phonological processing in SP character recognition may be superior to that in PS character recognition. According to the phonological mapping hypothesis (Maurer & McCandliss, 2007), consequently the processing of SP characters may involve more LH phonological modulation compared with phonetic compounds in other structures. This examination is not possible in any alphabetic languages, since in words of alphabetic languages, phonological information is distributed across the whole word rather than located on one side. The separation of semantic and phonetic components and the dominance of the SP structure in the lexicon provide this unique opportunity for examining whether position of the phonetic components influences how written words are processed in the brain.

Thus, here we aim to investigate whether the recognition of Chinese characters in different structures involves different hemispheric lateralization by examining the processing of two types of phonetic compounds with contrasting structures: SP and PS characters. We conduct a divided visual field study of SP and PS character naming, with pairs of SP and PS characters well matched in terms of character frequency, phonetic radical, visual complexity (defined by the number of strokes), and pronunciation. If the automaticity of phonological processing in SP character recognition is superior to that in PS character recognition due to the dominance of the SP structure, the processing of SP characters will involve more LH phonological modulation compared with PS characters, and consequently there will be a stronger RVF/LH advantage in naming SP characters compared with PS characters. In contrast, if character processing is not influenced by the overall information distribution of word components in the lexicon, there will be a comparable RVF/LH advantage in naming SP and PS characters.

Methods

Materials

The materials consisted of 76 pairs of Chinese phonetic compound characters that have a left-right configuration in traditional Chinese fonts. Characters were carefully chosen so that each SP-PS character pair shared the same phonetic radical and also had the same pronunciation in Cantonese (cf. Hsiao & Shillcock, 2005; Figure 1). Characters in the materials were within a medium to high frequency range of usage in Hong Kong society during 80s and 90s according to a Chinese character frequency database (Ho, 1998); the database stored 663,463 characters used in Hong Kong during 80s and 90s, and the median frequency among all characters was 16, whereas the median of the characters used in this study was 26. Also, there was no significant difference between SP and PS character pairs in terms of character frequency and number of strokes (paired t-test, n.s.; see Supplemental Table 1 for a list of stimuli).

Participants

We recruited 40 native Traditional Chinese readers from Hong Kong (Cantonese speaking), among whom 15 were male and 25 were female. They were all students or staff members at the University of Hong Kong with a mean age of 21 years and 11 months; all right handed according to the Edinburgh handedness inventory (Oldfield, 1971); and all with normal or corrected to normal vision (i.e., with glasses or contact lenses). Participants received some honorarium for their participation.

Design

The design consisted of two within-subject variables: position of the phonetic radical (PS vs. SP), and visual field (LVF vs. RVF). The dependent variable was the time taken to start a correct pronunciation (correct response times). In order to avoid any priming effect, each participant only saw each character once during the experiment, either in the LVF or RVF; the visual field presentation condition for each character was counterbalanced among participants. In other words, in the experiment two Latin square groups were created, with characters presented in the opposite visual field between the two groups. To account for this difference in Latin square group among the participants, we included a Latin-square variable as a between-subject variable in the design (Pollatsek & Well, 1995; Brysbaert, 2007). Participants were asked to sit in front of a computer screen, at a viewing distance of 50 cm; under this viewing distance, each character subtended about 1.2 degree of visual angle. To avoid presenting characters within the foveal vision, characters were presented 1.2 degree of visual angle away from the center of the screen (Figure 2).

Procedure

Figure 3 shows the experiment procedure. Each naming trial started with a 500 ms central fixation cross; participants were told to look at the cross when it appeared. The fixation cross was followed by a 150 ms presentation of the target character in either the LVF or the RVF (Figure 2). Participants were asked to pronounce the character as fast and accurately as possible; their response time and accuracy was recorded. A central fixation cross was presented after the presentation of the character, and the fixation cross disappeared after the onset of participants' pronunciation. The screen then turned blank until the experimenter pressed a button to start the next trial. Occasionally in some trials a very small digit was presented instead of a character for 90 ms at the center of the screen; participants were also asked to name the digit when it appeared. This design was to make sure that they were accurately looking at the fixation cross before the presentation of the characters/digits. We removed data from participants who had accuracy lower than 0.8 in the digit-naming task, since it may suggest that the participants did not always accurately fixate at the center of the screen during the experiment (e.g., Brysbaert, 1994; Hunter, Brysbaert, & Knecht, 2007)[3].

The recorded response time was the time difference between the onset of the character presentation and the onset of the participants' pronunciation; it was measured through a voice key trigger in the PST serial response box, and the experiment was controlled through the software E-Prime (Psychology Software Tools, Inc.). Only the response times in the trials with a correct pronunciation were analyzed. In the experiment, the presentation order of each pair of PS and SP characters and the presented visual field for each character were counterbalanced among the participants. Before the experiment, the participants performed a practice session with characters not included in the materials.

Results

In the accuracy data, participants had high naming accuracy since the stimuli were medium- to high- frequency characters. The overall accuracy was .946, and it was .940 and .952 for naming PS and SP characters respectively. There was no significant difference in accuracy between naming PS and SP characters (paired t-test, n.s.).

In the response time data, the results showed a significant main effect of position of the phonetic radical ($F(1, 38) = 27.133$, $p < 0.001$): SP characters were named faster than PS characters; and a significant main effect of visual field ($F(1, 38) = 8.345$, $p < 0.01$): characters were named faster when they were presented in the RVF compared with the LVF. In addition, there was a significant interaction between visual field and position of the phonetic radical ($F(1, 38) = 5.909$, $p < 0.05$): there was a RVF advantage in naming SP characters ($F(1, 38) = 13.868$, $p = 0.001$; see Figure 4); in contrast, no visual field difference was observed in naming PS characters ($F < 1$). When we examined the data in the two visual fields separately, participants were significantly faster in naming SP characters than naming PS characters when the characters were presented in the RVF ($F(1, 38) = 27.213$, $p < 0.001$; Figure 4); in contrast, this difference was not significant when the characters were presented in the LVF. The results thus showed that the processing of SP and PS characters involves different hemispheric lateralization. In other words, position of the phonetic component influences how Chinese phonetic compounds are processed in the brain. This result suggests that the overall information distribution of word components in the lexicon may influence how visual words are processed in the brain.

Discussion

Here we aimed to investigate whether position of phonetic components influences how visual words are processed in the brain through examining the processing of two types of phonetic compound characters with contrasting structures: SP characters (i.e. a semantic component on the left and a phonetic component on the right) and PS characters (i.e. the opposite arrangement). We hypothesized that the dominance of the SP structure in the lexicon makes Chinese readers opt to use the right component of a character as the location from which useful phonological information is most likely to be obtained, and thus the phonological information can be more efficiently extracted and processed in SP characters compared with PS characters; consequently the processing of SP characters involves more LH phonological modulation (Maurer & McCandliss, 2007), and thus more LH lateralized, compared with PS characters. Our result was consistent with this hypothesis; it showed a significant interaction between character type and position of the phonetic component: there was a RVF/LH advantage in naming SP characters; in contrast, no visual field difference was observed in naming PS characters (Figure 4). When examining data in the LVF and the RVF separately, there was no significant difference in response times between naming SP and PS characters when they were presented in the LVF/RH; in contrast, when they were presented in the RVF/LH, SP characters were pronounced significantly faster than PS characters (Figure 4). This result supports the hypothesis that the observed difference in hemispheric lateralization in naming SP and PS characters was due to the LH phonological modulation in SP character processing but not in PS character processing.

The current results are consistent with an ERP study of Chinese character recognition contrasting the processing of SP and PS characters reported by Hsiao, Shillcock, and Lee (2007). In the ERP study, participants performed a sequential homophone judgment task with characters being centrally presented one at a time while their EEGs were recorded; the characters spanned less than one degree of visual angle and thus fell within the foveal vision. Similar to the current study, the materials consisted of 75 pairs of SP and PS characters, and each pair shared the same phonetic radical, had the same pronunciation, and were matched in terms of token frequency and semantic radical visual complexity (defined by number of strokes). The results showed a significant interaction between character type (SP vs. PS) and hemisphere in N170 amplitude: SP character elicited larger N170 (N1) amplitude than PS characters in the LH, whereas PS characters elicited larger N170 amplitude than SP characters in the RH. Nevertheless, it was unclear whether N170 was actually larger in the LH than in the RH for SP characters compared with PS characters, since this analysis was not conducted in the study. Thus, here we reanalyzed the ERP data of SP and PS characters separately, in order to examine whether the processing of SP characters is more lateralized to the LH compared with the processing of PS characters, as suggested by the current behavioral results.

In this ERP data reanalysis, instead of using an averaged mastoid (ear) reference (Hsiao et al., 2007), we used the common average (i.e., average over all scalp sites) as the reference to avoid the concern that the mastoids are very close to the active region of the N170 component (i.e., the inferior-temporal region). In contrast, the common average reference has been recommended by recent guidelines for scalp electrophysiological research (Picton et al., 2000) based on the theory that a constant zero average is maintained across the scalp (Bertrand, Perrin, & Pernier, 1985)[4]. It also has been shown to be the reference that most optimally captures categorical and hemispheric differences in N170 (Joyce & Rossion, 2005). We used the same artifact rejection methods as reported in Hsiao et al. (2007). The N170 component was identified at around 180-220 ms post-stimulus. Electrodes that had the most prominent peaks in N170 were selected for analysis, and were paired between the two hemispheres. The electrodes selected for analyses in the LH were PO7 and PO5; those in the RH were PO8 and PO6[5]. The N170 amplitude was measured over a 50 ms window centered on the peak latency of the maximum amplitude in the grand-averaged data, separately for different conditions (Hsiao et al., 2007). The data included 16 male and 16 female participants.

Our reanalysis confirmed that there was a significant interaction between character type and hemisphere in N170 amplitude ($F(1, 26) = 16.265$, $p < 0.001$); this effect did not interact with the electrodes we selected ($F(1, 26) = 1.505$, n.s.)[6]. In addition, when we analyzed the data of SP and PS characters separately, we observed that SP characters elicited significantly larger N170 in the LH compared with the RH ($F(1, 29) = 4.982$, $p < 0.05$; this effect did not interact with the electrodes we selected, $F(1, 29) < 1$, n.s.); in contrast, PS characters elicited N170 in both hemispheres with comparable amplitude ($F(1, 27) = 0.590$, n.s.; Figure 5)[7]. N170 amplitude has been shown to be a reliable measure for hemispheric asymmetry in the recognition of visual categories such as faces and words (Mercure et al., 2008; Maurer et al., 2005), and a correspondence between ERP and behavioral data can usually be observed even when different paradigms are used between them. For example, behaviorally the RVF/LH advantage in English word processing in divided visual field studies (e.g., Brysbaert & d'Ydewalle, 1990) is consistent with the larger N170 amplitude in the LH than in the RH when English words are centrally presented (e.g., Rossion et al., 2003); also, the LVF/RH advantage in face processing in the behavioral data (e.g., Levine & Koch-Weser, 1982) is consistent with the larger N170 amplitude in the RH than in the LH when faces are centrally presented (Rossion et al., 2003). Similarly, the ERP effect reported here matched well with the behavioral naming data; they provided different but complementary pieces of evidence showing that the processing of SP characters is more lateralized to the LH compared with the processing of PS characters.

Here we argue that the most parsimonious account for the observed processing differences between SP and PS characters in hemispheric asymmetry may be the dominance of SP characters in the lexicon that makes Chinese readers opt to obtain phonological information from the right side of a character, and thus the automaticity of phonological processing in SP character recognition is superior to that in PS character recognition; consequently SP character processing involves more LH phonological modulation (Maurer & McCandliss, 2007) compared with the processing of PS characters[8]. The separation of semantic and phonetic components and the dominance of SP characters in the Chinese lexicon provide this unique opportunity to show how visual word processing can be influenced by the overall information distribution of word components in the lexicon. Here we compared the processing of SP and PS characters because of their contrasting structures and the dramatic difference in type frequency in the lexicon (i.e., nine to one); we predict that when compared with other types of phonetic compounds that do not have a typical left-right structure, the processing of SP characters will still have a stronger LH lateralization due to the dominance of SP characters in the lexicon, although this speculation requires further examination.

The difference in lateralization between the processing of SP and PS characters may also be explained by their difference in the regularity of the relationship between character pronunciation and pronunciation of the phonetic radical. It has been reported that among SP characters, there is a higher percentage of characters that have the same pronunciation as their phonetic radical (i.e. regular characters) compared with PS characters (Hsiao & Shillcock, 2006)[2]. The phonetic radical of a regular character provides more useful information towards the character pronunciation compared with that of an irregular character, whose pronunciation only shares the same onset or rhyme as, or is completely different from the character pronunciation. Thus the recognition of regular characters may involve more phonological processing compared with the recognition of irregular characters. This factor may also contribute to the lateralization difference between SP and PS characters, in addition to the dominance of SP characters in the lexicon.

Alternatively, our current results may also be explained under the split fovea assumption. Recent research has suggested that human foveal representation may be split along the vertical midline, with the two halves initially contralaterally projected to the two hemispheres (e.g., Brysbaert, 2004; Lavidor & Walsh, 2004; for a review, see Ellis and Brysbaert, in press), as opposed to bilaterally projected as previously thought (e.g., Huber, 1962; Stone, Leicester, & Sherman, 1973). Under this split fovea assumption, a centrally fixated SP character will have its phonetic radical initially projected to the LH, where phonological processes are typically lateralized, whereas the phonetic radical of a PS character will be initially projected to the RH (Figure 6). It has been shown that when people are viewing individual characters, they fixate at the center of the characters most often (e.g., Hsiao & Cottrell, 2009). Thus, it is possible that when Chinese readers are learning to read individual characters, they receive more phonological modulation in the LH when learning to read SP characters compared with PS characters, and this learning experience may result in different hemispheric lateralization in processing SP and PS characters. Note however that Jordan and Paterson (2009) have recently questioned the viability of the split fovea theory by pointing out potential problems in maintaining accurate fixations in experiments that required participants to fixate a particular location within a centrally presented word, and in the accuracy of reporting results from previous studies that were claimed to support the split fovea theory (see also Jordan et al., 2009; and the reply in Ellis and Bryesbaert, in press). Thus, it remains controversial whether foveal representation is split and initially contralaterally projected to different hemispheres, and whether the effect observed here is due to the dominance of SP characters in the lexicon or the direct access of the phonetic component of an SP character to the LH according to the split fovea claim also requires further examination.

In summary, here we show that position of the phonetic components influences how written words are processed in the brain. We provide both behavioral and ERP data and show that the two types of Chinese phonetic compound characters with opposite phonetic component positions, SP and PS characters, are processed differently in the brain: the processing of SP characters is lateralized to the LH, whereas the processing of PS characters is bilaterally distributed. We argue that this result may be due to the dominance of SP characters in the lexicon that makes Chinese readers opt to obtain phonological information from the right side of a character, and consequently the processing of SP characters receives more LH phonological modulation compared with the processing of PS characters, and results in more LH lateralization. The separation of semantic and phonetic components in Chinese orthography and the existence of a dominant structure (SP characters) provide an unique opportunity for this examination; it shows that the overall information distribution of word components in the lexicon can influence how written words are processed in the brain.

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Acknowledgments

We are grateful to the HKU Seed Funding Program for Basic Research (project #10400471 to J.H. Hsiao) and the Research Grant Council of Hong Kong (project # HKU 744509H to J.H. Hsiao). We thank the editor and three anonymous reviewers for helpful comments.

Footnotes

[1] In addition, Tzeng et al. (1979) showed a RVF/LH advantage in tachistoscopic recognition of Chinese two-character words.

[2] Note however that in these characters, the mapping from a phonetic component to its pronunciation is not as fine-grained as the grapheme-phoneme conversion in alphabetic languages. The pronunciation of a phonetic component within a character is at the syllable level; in some cases it has the same pronunciation as the character (i.e. regular characters), in some other cases it shares the same pronunciation onset or rhyme with the character, or has a completely different pronunciation from the character (i.e. irregular characters).

[3] We removed two participants since their accuracy in the digit-naming task was lower than 0.8. Two new participants were then recruited to replace the removed data, and they both had accuracy over 0.8 in the digit-naming task.

[4] Note that this zero reference is based on the assumption that the head is a perfect sphere and the scalp is densely sampled with equal space between electrodes. It has been suggested that to properly implement it, the sampling of the scalp should be reasonably dense (A minimum of 20 electrodes is required; the more electrodes, the better; see Katznelson, 1981; Dien, 1998), and the electrodes should provide a reasonable sample of sites below the Fpz-Oz equator line (Picton et al., 2000; Dien, 1998). Nevertheless, the implementation of this technique is usually limited by the standard EEG caps and equipment available. In the current study, a standard Neuroscan 64 channel EEG cap was used (see Hsiao et al., 2007, Figure 4, plus M1 and M2 on the left and right mastoids), and thus there were only two electrodes (M1 and M2) below the Fpz-Oz equator line.

[5] In Hsiao et al. (2007), we selected four most prominent electrodes in each hemisphere (LH: PO7, PO5, P7, P5; RH: PO8, PO6, P8, P6) for N170 analysis. In contrast, here we selected only two most prominent electrodes in each hemisphere (e.g., For SP characters, PO7, PO5 in the LH, paired with corresponding electrodes in the RH: PO8, PO6), since P7 and P5 had lower N170 amplitude than PO7 and PO5, and including P7 and P5 in the analysis made N170 amplitude of selected electrodes inhomogeneous. Indeed, if we included P7 and P5 (and paired with P6 and P8 in the RH) in the current analysis, there was a significant interaction between electrodes and the hemispheric asymmetry effect observed in SP characters ($F(3, 87) = 3.119$, $p < 0.05$): the hemispheric asymmetry effect was only observed in the two most prominent electrodes (LH: PO7, PO5, paired with RH: PO6, PO8), but not in the other electrodes (P7, P5, P6, and P8).

[6] Note that there were missing data in some participants since they did not have a prominent peak within the 50ms window around the peak latency of the grand average data in some conditions.

[7] In Figure 5 there was a hemispheric asymmetry effect in the P1 component independent of stimulus type. The functional significance of this component remains controversial. It may reflect low-level visual properties of the stimuli (Rossion et al., 2003), and its asymmetry may reflect a more RH-lateralized activation in the visual system in Chinese character processing (For more details, see Hsiao et al., 2007).

[8] In Hsiao et al. (2007), the interpretation for the observed interaction between hemisphere and character type (SP vs. PS characters) in N170 amplitude was the difference in visual complexity between semantic and phonetic radicals: phonetic radicals are usually more visually complex than semantic radicals. Nevertheless, this

factor alone is not able to explain why a lateralization effect was observed in SP characters but not in PS characters here.

Figure 1. Examples of Chinese phonetic compound characters: left-right (SP and PS characters), top-bottom, and concentric. The SP and PS characters have the same phonetic radical and the same pronunciation [coi3] in Pinyin.

Figure 2. Divided visual field presentation. During the experiment, characters were presented 1.2 degree of visual angle away from the center of the screen to avoid the foveal vision.

Figure 3. Experiment Procedure.

Figure 4. Results of the naming experiment. The error bars show standard errors (** $p < 0.01$; *** $p < 0.001$).

Figure 5. Corresponding ERP data (with characters centrally presented): SP characters elicited larger N170 amplitude in the LH than the RH; in contrast, PS characters elicited comparable N170 amplitude in both hemispheres.

Figure 6. Illustration of the contralateral projection of the two radicals during learning to read SP and PS characters, according to the split fovea claim.

Figure 1

採	彩	盟	圍
S P	P S	Top-bottom	Concentric

Figure 2

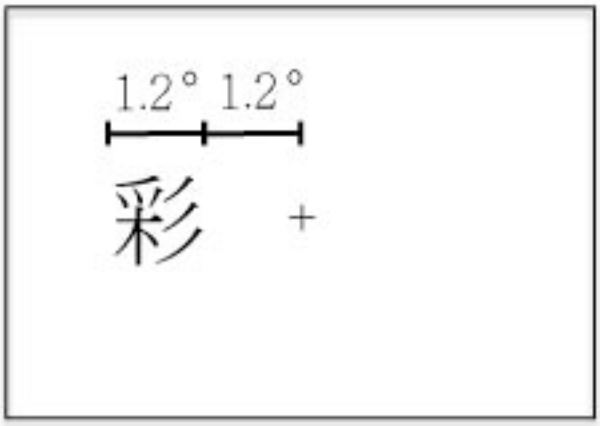

Figure 3

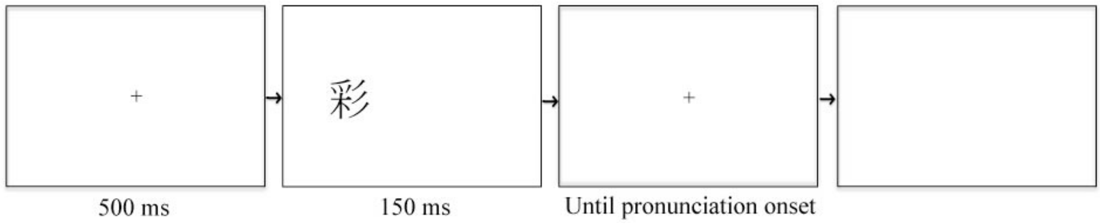

Figure 4

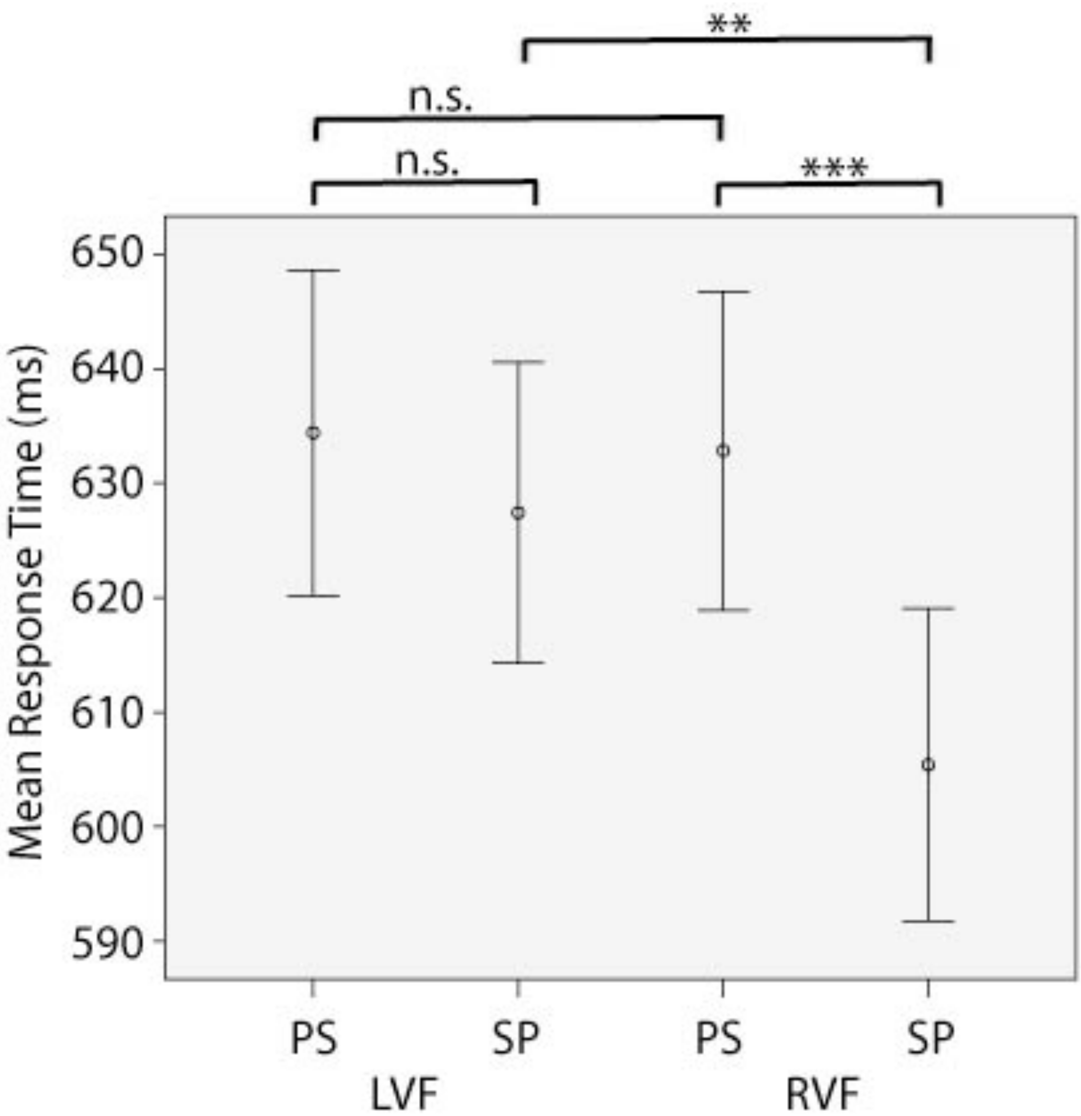
**
n.s.
n.s.
***
650
640
630
620
610
600
590
Mean Response Time (ms)
PS
SP
PS
SP
LVF
RVF

Figure 5

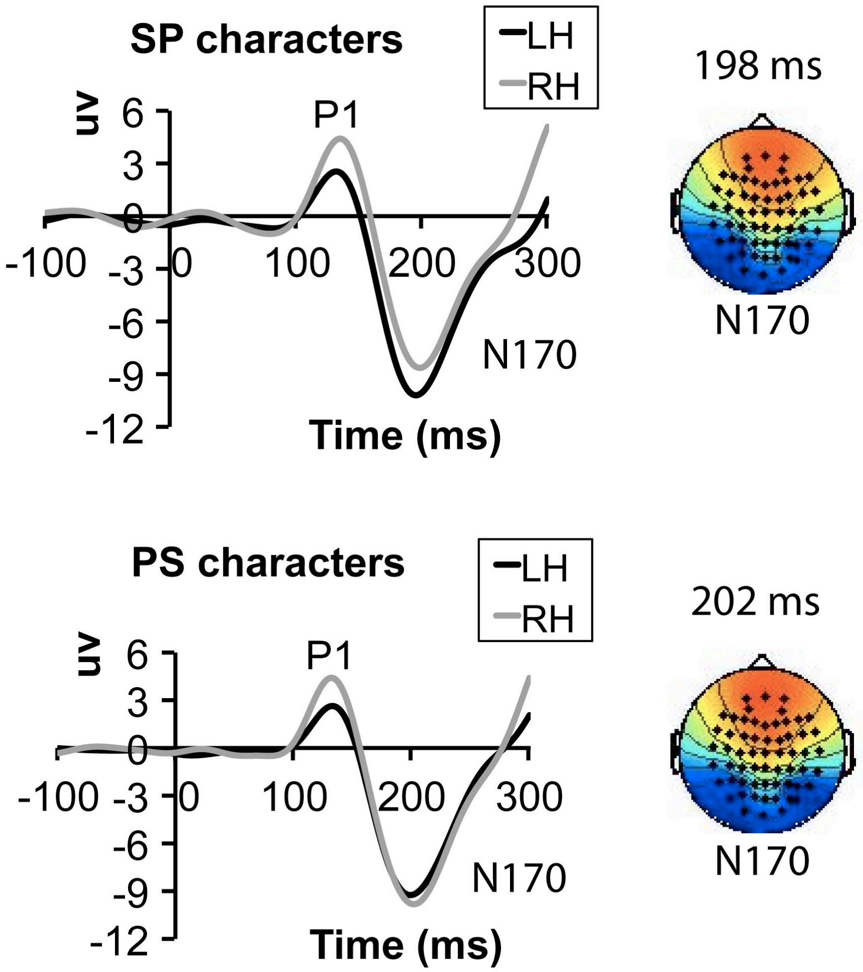
SP characters
LH
RH
198 ms
uv
6
3
0
-3
-6
-9
-12
-100
0
100
200
300
P1
N170
Time (ms)
N170
PS characters
LH
RH
202 ms
uv
6
3
0
-3
-6
-9
-12
-100
0
100
200
300
P1
N170
Time (ms)
N170

Figure 6