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·Original Article·

Selectivity of N170 in the left hemisphere as an electrophysiological marker for expertise in reading Chinese

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Abstract: Objective The left-lateralized N170, an event-related potential component consistently shown in response to alphabetic words, is a robust electrophysiological marker for reading expertise in an alphabetic language. In contrast, such a marker is lacking for expertise in reading Chinese, because the existing results about the lateralization of N170 for Chinese characters are mixed, reflecting complicated factors such as top-down modulation that contribute to the relative magnitudes of N170 in the left and right hemispheres. The present study aimed to explore a potential electrophysiological marker for reading expertise in Chinese with minimal top-down influence. **Methods** We recorded N170 responses to Chinese characters and three kinds of control stimuli in a content-irrelevant task, minimizing potential top-down effects. **Results** Direct comparison of the N170 amplitude in response to Chinese characters between the hemispheres showed a marginally significant left-lateralization effect. However, detailed analyses of N170 in each hemisphere revealed a more robust pattern of left-lateralization — the N170 in the left but not the right hemisphere differentiated Chinese characters from control stimuli. **Conclusion** These results suggest that the selectivity of N170 (a greater N170 in response to Chinese characters than to control stimuli) within the left hemisphere rather than the hemispheric difference of N170 with regard to Chinese characters is an electrophysiological marker for expertise in reading Chinese.

Keywords: N170; Chinese character; left-lateralization

1 Introduction

In the readers of alphabetic languages, visually presented words consistently produce a left-lateralized (larger amplitude in the left hemisphere than in the right hemisphere) N170 component of event-related potentials (ERPs)[1-4]. Because the left-lateralized N170 effect occurs only in adult readers and in children who have received years of reading training[5] but not in pre-school children[3], this electrophysiological response is considered to be a robust marker for reading expertise. In sharp contrast, the existing results about the lateralization of N170 in response to Chinese characters (and Japanese Kanji) are largely mixed. Both bilateral[6-8] and left-lateralized[4,9-12] N170 effects have been reported. Thus, unlike in alphabetic scripts, the lateralization of N170 in terms of the direct comparison of its amplitude across the two hemispheres is unlikely to serve as a marker for

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reading expertise in Chinese. Moreover, determining the factors that cause the conflicting results about N170 with regard to Chinese characters would be helpful not only for characterizing specific aspects of reading Chinese, but also for our understanding of general properties in reading different scripts.

It is possible that both script-type and task-demand contribute to the consistent results of N170 laterality with alphabetic scripts but inconsistent results with Chinese characters. Particularly, there is differential engagement of the left-lateralized phonological system in reading the two types of scripts. Specifically, in reading alphabetic scripts, the phonological system is automatically activated and dominates other processes such as semantic processing, and this may contribute to a reliable left-lateralized N170 effect across different tasks. In contrast, reading Chinese may not automatically engage strong phonological processing[13-15], so there is more room for task-demand to play a more important role in modulating lateralization, resulting in inconsistent manifestations of lateralization of N170 across different tasks. In other words, the lateralization of N170 may be more prone to top-down task modulation for Chinese than for alphabetic scripts. Consistent with this idea, Kim and colleagues[7] used a semantic task (which relies more on the right hemisphere[16]) and showed a bilateral N170. In contrast, Liu and Perfetti (2003)[9] used a phonological task (which mainly activates the left hemisphere[17]) and showed a left-lateralized N170.

The present study aimed to explore a potential electrophysiological marker for reading expertise in Chinese with minimal top-down influence, by recording N170 in response to briefly-presented Chinese characters and control stimuli in a content-irrelevant color-matching task. We chose faces, common objects, and combinations of the strokes in Chinese characters as control stimuli to control for the influence of irrelevant properties, including expertise, phonological and semantic activation, and visual features. Multiple control stimuli were used to better characterize the detailed selectivity of N170 for Chinese characters. In addition to minimizing potential high-level linguistic (particularly phonological) modulation[11,12], the task we used also controlled for differences of attention load across stimulus types. Attentional bias is another common confounding factor in studies of the neuronal correlates of visual perception such as visual word recognition[18,19]. Thus, in addition to the ERP experiment in which a delayed-response task was used to exclude potential influences on ERPs caused by pressing a button, we conducted a behavioral experiment, in which participants were asked to respond immediately after a target stimulus appeared. This allowed for a comparison of behavioral responses between Chinese characters and control stimuli, to rule out potential attentional biases across stimulus types.

2 Materials and methods

2.1 Experiment 1: Behavioral experiment

2.1.1 Participants Fifteen native-Chinese speakers (8 males, mean age: 21.4 years) participated in the behavioral experiment. They were right-handed undergraduate students with normal or corrected-to-normal vision. Informed consent was obtained.

2.1.2 Stimuli The four types of stimuli were: Chinese characters, cartoon faces, line drawings of common objects[20], and stroke combinations (each was constructed by recombining the strokes of a Chinese character). Each type of stimulus consisted of 30 items (Fig. 1A).

2.1.3 Procedures A trial started with a grid presented at the center of the computer screen for 200 ms, in one of the three colors: yellow, green and red. A texture noise mask then appeared at the same position for 50 ms. After an interval of 700 ms, a target stimulus (one of the four types), subtending 1.3° visual angle, was presented in one of the above three colors for 200 ms (Fig. 1B). Participants were instructed to compare the color of the target stimulus with that of the preceding grid and respond immediately after the display of the target stimulus. All stimuli were presented thrice. Both the order of blocks and the left/right hand response were counterbalanced across participants. Accuracy and reaction time were recorded and analyzed with one-way analysis of variance (ANOVA).

2.2 Experiment 2: ERP experiment

2.2.1 Participants Nineteen right-handed undergraduate

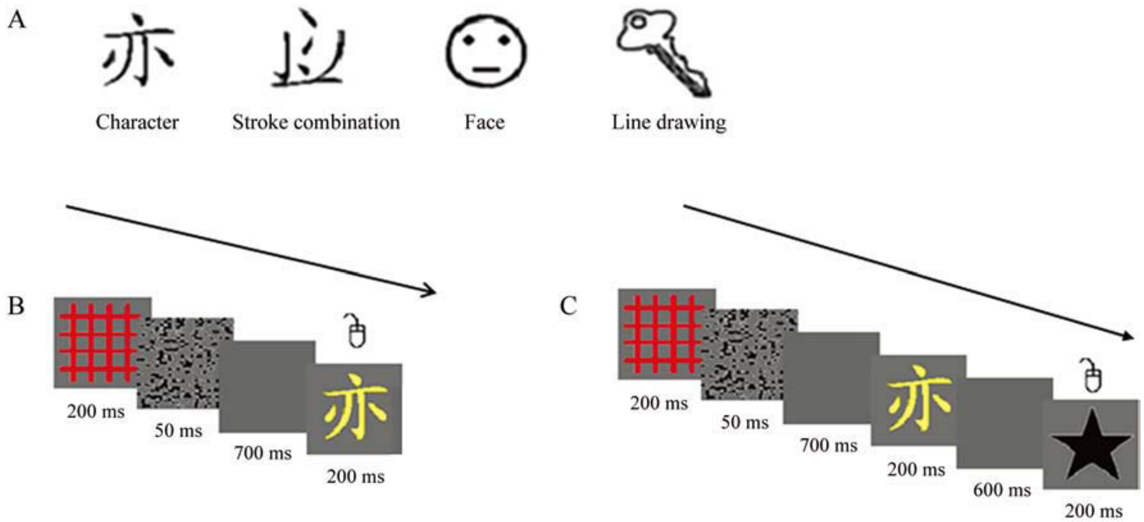

Fig. 1. Examples of stimuli and experimental procedures. A. Examples of stimuli. B. Procedures of the behavioral experiment. C. Procedures of ERP experiment.

students (9 males, mean age: 20.8 years) participated in the ERP experiment. They were native-Chinese speakers with normal or corrected-to-normal vision. Informed consent was obtained.

2.2.2 Stimuli All stimuli were the same as in *Experiment 1*.

2.2.3 Procedures The task and procedures were similar to those in *Experiment 1* except that participants made a delayed response, to exclude potential influences on ERPs caused by button pressing. Specifically, following the target stimulus, there was another blank interval of 600 ms and a response cue (a five-pointed star) was presented for 200 ms (Fig. 1C). Participants were not allowed to respond until the response cue appeared.

2.2.4 Electrophysiological recording and analysis The electroencephalogram (EEG) was recorded from 64 Ag/AgCl electrodes (NeuroScan Inc., EI Paso, TX) and an electrode between Fpz and Fz served as ground. Both vertical and horizontal electrooculograms were also recorded for eye-blink correction and an electrode located between Cz and CPz served as the reference (an average reference transformation was used in later data analysis). All channels were amplified with a DC-100 Hz band-pass filter and digitized at 1 000 Hz. Resistances across all the electrodes were kept below 5 kΩ.

The EEG signals were digitally filtered (0.5–30 Hz band-pass) and segmented into epochs of 800 ms (including 100 ms pre-stimulus baseline), and regulated by baseline correction. Only trials in which participants made correct behavioral responses entered the next analyses. Similar to the procedure used in recent studies[1,10], five pairs of channels in the occipito-temporal areas were selected according to the topographic maxima in the negative field over both hemispheres (i.e., P7/P8, PO7/PO8, PO5/PO6, PO3/PO4, and CB1/CB2). Peak amplitudes of the N170 component were obtained on these channels by recording the minimum values of the ERPs during 100 ms and 200 ms after stimulus onset. The N170 values were averaged for each hemisphere and analyzed with ANOVA with two within-subject factors: stimulus category (characters, line drawings, faces, stroke combinations) and hemisphere (left, right). Bonferroni correction was used to avoid multi-comparison errors.

3 Results

3.1 Results of the behavioral experiment Mean accuracy and reaction time (RT) are shown in Table 1. The main effects for both accuracy [$F_{(3, 42)} = 2.47$, $P = 0.10$] and RT [$F_{(3, 42)} = 0.72$, $P = 0.50$] were not significant. This is not surprising given that the task performed by the subjects was content-irrelevant.

3.2 Results of the ERP experiment The grand-average ERPs of the selected channels in response to the four stimulus types are shown in Fig. 2. A negative deflection peaking at ~170 ms was clearly visible for each stimulus type over bilateral occipito-temporal sites.

The averaged peak amplitude of N170 in response to each stimulus type in each hemisphere is displayed in Fig. 3.

Table 1. Reaction time and accuracy in behavioral experiment [mean (SD)]

Character	Face	Stroke combination	Line drawing	
Accuracy (%)	96.9 (2.5)	97.3 (2.2)	97.7 (1.6)	96.5 (2.5)
Reaction time (ms)	484 (111)	484 (102)	488 (106)	490 (107)

ANOVA showed a significant main effect of stimulus type [$F_{(3, 54)}$ = 13.77, P <0.001] and a significant interaction effect of stimulus type by hemisphere [$F_{(3, 54)}$ = 5.65, P = 0.006].

Comparisons of N170 amplitude between the left and right hemispheres revealed a marginally significant left-lateralized effect for Chinese characters (P = 0.08), but not for stroke combinations (P = 0.66), faces (P = 0.14), or line drawings (P = 0.60).

We next compared the N170 in response to Chinese characters with other stimulus types separately in each hemisphere. In the left hemisphere, the amplitude of N170 in response to Chinese characters was higher than those to line drawings (P <0.001), faces (P = 0.063), and stroke combinations (P = 0.002), and faces and stroke combinations evoked a larger N170 than line drawings (faces *versus* line drawings, P = 0.054; stroke combinations *versus* line drawings, P = 0.02). In the right hemisphere, there was

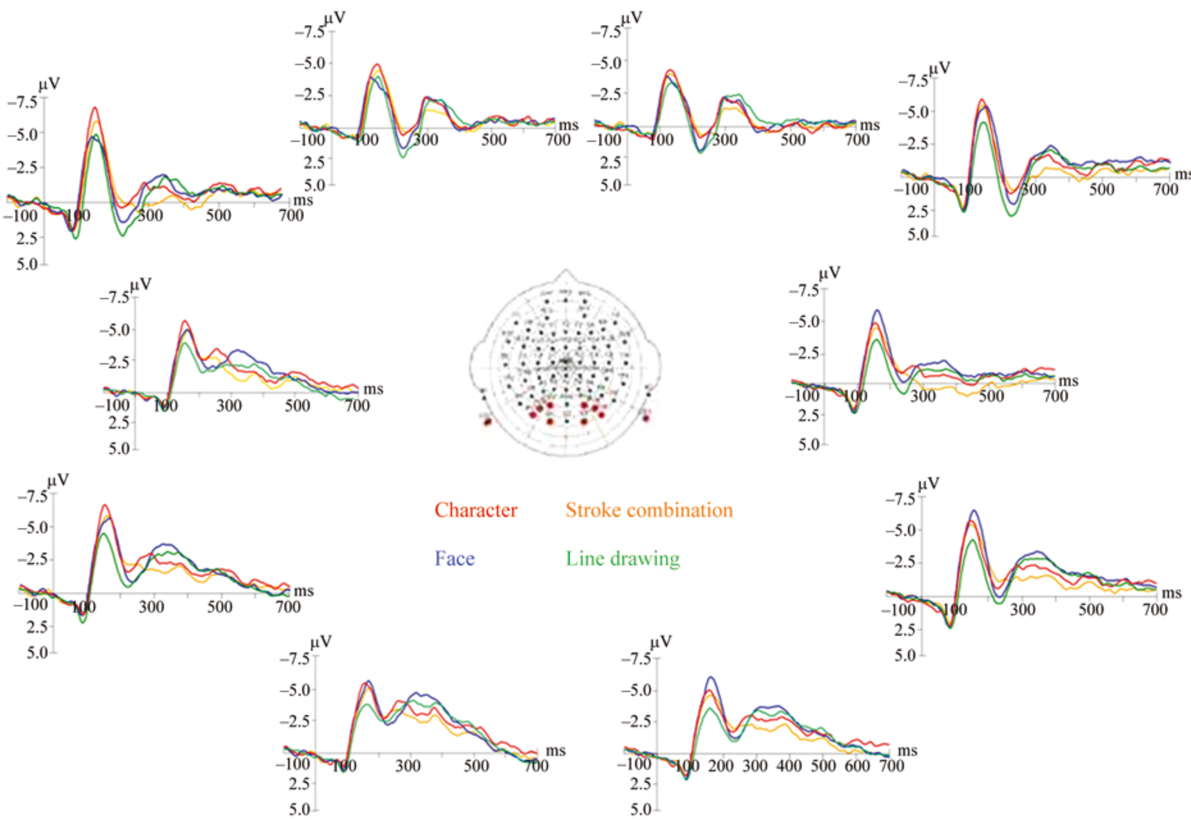

Fig. 2. Grand averaged ERP waves in response to four types of stimuli at bilateral posterior electrode sites.

no N170 difference between characters and faces ($P = 1.00$), or between characters and stroke combinations ($P = 0.98$), but line drawings evoked a significantly smaller N170 than characters ($P = 0.003$), faces ($P = 0.003$), and stroke combinations ($P = 0.004$). There was no significant difference between stroke combinations and faces ($P = 0.15$).

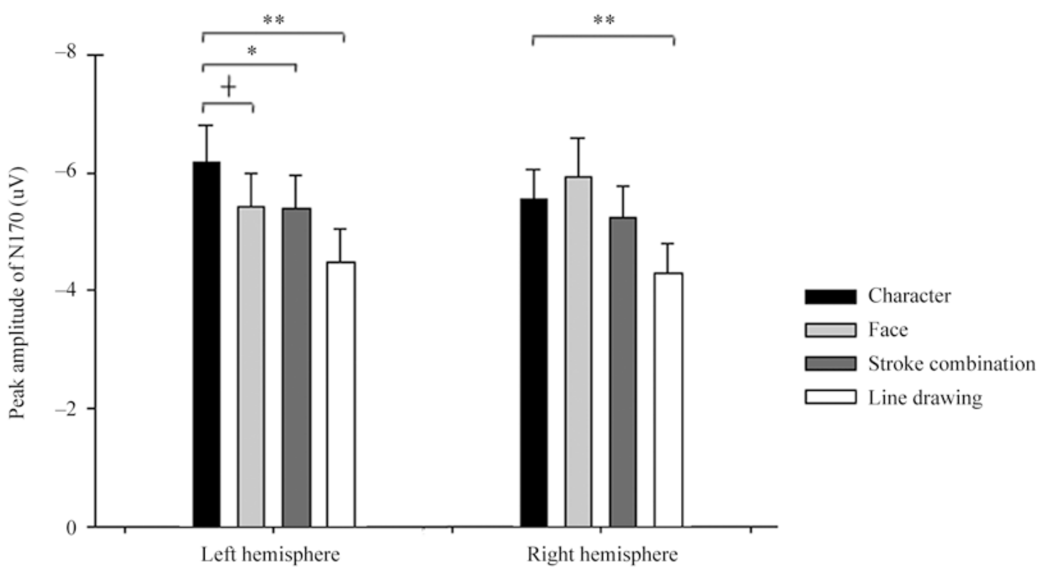

Fig. 3. Averaged N170 peak amplitudes for the four stimulus types in each hemisphere. **P <0.01, *P <0.05, ^{+}P <0.1. Error bars represent standard errors.

4 Discussion

With the goal of identifying a potential electrophysiological marker for reading expertise in Chinese, we examined the properties of N170 in response to Chinese characters and three other types of control stimuli, in a task designed to minimize the influences of high-level linguistic modulation on N170[11,12]. Moreover, the present study included an additional behavioral experiment to further ensure that there was no difference in attentional load across different visual stimuli. In various commonly-used passive viewing and one-back repetition detection tasks, participants are often faster in response to target letters embedded in native than non-native words[21] and more accurate at detecting repetitions of orthographic stimuli (such as a string of alphabetic letters) than at detecting repetitions of non-orthographic stimuli (such as a string of meaningless symbols)[3,4,22]. Therefore, the increased N170 in response to orthographic stimuli reported in these studies may be partly explained by attentional bias to this particular stimulus. In contrast, in the current study, we did not find any behavioral response difference across the four stimulus types, whether it was measured as accuracy or reaction time. Hence, the task we used here not only minimized the influence of high-level linguistic modulation but also effectively controlled for possible confounding caused by different attentional loads between orthographic and non-orthographic stimuli.

By directly comparing the amplitudes of N170 in response to Chinese characters between the left and right hemispheres, we found a marginal left-lateralization of N170 for Chinese characters in a task with minimal contributions from top-down modulation. This result is in line with the existing literature[6-8] that the left-lateralized effect on N170 for Chinese characters is not as consistent as in studies with alphabetic scripts, which typically produce a very significant left-lateralization effect[1-4]. More importantly, the marginally significant hemispheric effect, together with the mixed results for lateralization of N170 to Chinese characters in the literature, highlights that a direct hemispheric comparison of N170 in response to characters is not a sensible approach to address the issue of N170 lateralization, and cannot serve as a robust neuronal marker for Chinese reading expertise.

Hemispheric comparison of an ERP response to a particular type of stimulus has been widely used to examine lateralization of the processing of this stimulus type. However, lateralization of N170 revealed by this approach alone is questionable, because it is based on an oversimplified assumption that the two hemispheres are anatomically symmetrical. Taking face perception as an example, numerous neuropsychological and neuroimaging studies have provided convincing evidence that face perceptual processes are strongly right-lateralized[23-26], and some studies did show a larger N170 in the right hemisphere than in the left hemisphere[2]; still, many studies also reported the N170 to faces to be bilateral[27-29]. We therefore took an alternative approach – to carefully compare the N170 in response to characters with other control stimuli within each hemisphere, which does not rely on the above assumption. With this new approach, we found that, in the left hemisphere, the N170 in response to Chinese characters was significantly larger than all three control stimulus types, whereas in the right hemisphere no significant difference in N170 was found between Chinese characters and non-orthographic stimuli other than line-drawings.

We chose faces as a control stimulus type because adult readers have extensive experiences/expertise with both faces and words[30]. Moreover, both types of stimuli are processed both at categorical and individual levels[31-34]. Although faces share many properties in common with written words, we still found a larger N170 effect for Chinese characters than for faces in the left but not the right hemisphere. This finding strongly suggests that there exists a specific association between the left hemisphere and the processing of Chinese characters, similar to the well-documented association between the left hemisphere and the processing of alphabetic words. Although the larger N170 effect for Chinese characters than for faces in the left hemisphere may be partly attributable to the right-lateralized effect for faces, our results on N170 in response to the other two types of control stimuli do support the selectivity of Chinese characters in the left hemisphere.

We further found that Chinese characters evoked a stronger N170 than stroke combinations in the left hemisphere, but in the right hemisphere the amplitudes of N170 in response to both stimulus types were not significantly different. As the visual complexity of both stimulus types was closely matched, the larger N170 to Chinese characters than stroke combinations cannot be attributed to differences in low-level visual features between the two stimulus types.

Interestingly, Chinese characters evoked a larger N170 than line-drawings of common objects at about an equal effect size in both hemispheres. This finding is consistent with the majority of studies showing a larger N170 in response to orthographic stimuli (letter strings, regardless whether they constitute unpronounceable consonant strings or pronounceable pseudowords and real words) than to line-drawings of common objects[2,7,35]. As orthographic stimuli and common objects engage approximately the same degree of phonological and semantic processing, the current finding strengthens the earlier suggestion that a greater N170 in response to orthographic stimuli than to common objects may be explained by the difference in processing levels — orthographic stimuli are processed both at the individual and categorical levels but common objects are typically processed only at the categorical level[31-34]. Our finding of a higher N170 in response to characters than to objects in both hemispheres, together with the finding of a significant character–stroke difference only in the left hemisphere, again suggests that the left hemisphere is specifically associated with the processing of orthographic information.

Although the primary focus of the present study was to identify a potential neuronal marker for Chinese reading expertise, our findings also contribute to the understanding of the neuronal basis of N170 in response to both Chinese and alphabetic words. An important theoretical implication of the study is that the N170 in response to written words has both universal and specific properties. On the one hand, we provided clear evidence that the processing of Chinese characters is specialized in the left hemisphere, which is essentially identical to the conclusion drawn from a large number of studies with alphabetic languages—there is a specific association between visual word processing and the left hemisphere[1-4,36]. It is possible that the selectivity of N170 within the left hemisphere, relative to the result of hemispheric comparison, is a more robust neuronal marker even for alphabetic scripts. In addition, we believe it would be helpful to use content-irrelevant tasks such as the one used in the present study to investigate to what extent lateralization of the N170 to alphabetic words is modulated by task demands. On the other hand, our study did show some specific properties of N170 for Chinese characters, e.g., a much smaller difference in terms of the N170 amplitude in response to characters across the two hemispheres.

In conclusion, our study revealed a novel pattern of lateralization of N170 in response to visual words— higher orthographic selectivity (larger N170 to Chinese characters than to control stimuli) within the left hemisphere rather than a simple hemispheric difference in N170 amplitude. This selectivity within the left hemisphere instead of the hemispheric difference for characters is a potential electrophysiological marker for expertise in reading Chinese. We thus propose to carefully analyze N170 within each hemisphere in reference to multiple types of control stimuli instead of a direct hemispheric comparison. Future research will show whether this approach and this pattern of lateralization can be extended to other writing systems.

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