The hemispheric difference of semantic processing of Chinese characters in two dimensions as revealed by ERPs

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An experiment was conducted to examine the hemispheric dominance in semantic processing of Chinese characters. Results showed that N1 is the earliest component that reflects the semantic processing of Chinese characters. Although N1 of the left hemisphere is larger in amplitude, that of the right hemisphere is shorter in latency. Based on these findings, the authors propose that the left hemisphere does not start processing until the necessary information has been transferred from the right hemisphere. Once the left hemisphere starts processing, its intensity is stronger. Thus, it is more appropriate to differentiate hemispheric processing dominance into two dimensions: speed and intensity. Moreover, the semantic cognition onset of Chinese characters occurs from 100 ms to 160 ms in the posterior perceptual processing area of brain. *NeuroReport* 12:3697–3701 © 2001 Lippincott Williams & Wilkins.

Key words: Chinese characters; Event-related potentials; Hemispheric dominance; Two dimensions

INTRODUCTION

The relationship between brain hemispheres in language cognition has been extensively investigated. For English words, most studies with visual half-field presentation showed that the left hemisphere is dominant in processing. For processing Chinese characters, however, the research with visual half-field presentation showed three incompatible results. First, the left hemisphere is dominant. This kind of experiments has shown that the reaction time is faster and the error probability is lower following presentation of right visual field than after presentation in the left visual field [1–3]. Second, the right hemisphere is dominant. Hatta [4] and Sasanuma *et al.* [5], using both Japanese Kanji (similar to Chinese character) and Kana, have shown that there is a tendency for right hemispheric dominance in using Kanji, and left hemispheric dominance in using Kana. Third, balanced contributions from both hemispheres have also been found. For example, Guo and Yang [6] have shown that in decisions regarding orthography, phonology and semantics of Chinese characters, there is no reaction time difference between presentations in the two visual fields. The discrepancies between the above three experimental results may be due to the difference in methodology. It may also reflect the unexplored complexity of the relationship between the two hemispheres in processing language.

Much of the above research on Chinese language employs classical methods of reaction time and performance. As a result, the time courses in cognitive processing of the two hemispheres are not clear. Event-related potentials (ERPs), on the other hand, is very powerful in showing both latency and amplitude of its components that represent the two dimensions of speed and intensity in cognitive processing respectively. However, few ERP research has been conducted in Chinese language. Bentin *et al.* [7] examined the time course and scalp distribution of electrophysiological manifestations of the visual word recognition mechanism with ERP, and their findings agree with the functional neuroanatomy of word recognition systems. Yet, they did not investigate the relationship between hemispheres with the two dimensions of speed and intensity. Khateb *et al.* [8] investigated the time course of the hemispheric involvement in the processing of semantic category information with ERP, and suggested that information can be transferred rapidly (~150 ms) from the right hemisphere to the language-dominant left hemisphere, but they did not report the ERP amplitude of the two hemispheres. The present research aims at investigating the relationship between hemispheres on speed and intensity in the semantic processing of Chinese characters with ERPs.

MATERIALS AND METHODS

Sixteen undergraduates (eight male and eight female), 18–21 years of age were paid to serve as subjects. All were right-handed with normal vision or corrected-visual acuity. Subjects were seated in a sound-attenuated room, in front of a table with a chinrest for inhibiting head movements, and with a PC screen for displaying Chinese characters.

The distance from the eye to the computer screen was 1.5 m. EEG was recorded from five electrodes according to the international 10-20 system: Fz, Cz, Pz, P3-T5 and P4-T6. The electrode P3-T5 was located at the center of P3 and T5, and P4-T6 at the center of P4 and T6. These two electrodes were located on the junctures of the temporal, parietal and occipital lobes, the posterior perceptual processing areas of left and right hemispheres respectively. Linked-mastoids were used as the reference for EEG electrodes. Vertical electrooculogram (VEOG) and horizontal electrooculogram (HEOG) were recorded with two pairs of electrodes, one placed above and below the right eye, and another 10 mm from the lateral canthi. Subjects were grounded with a mid-forehead electrode 5 mm below the hair line. All EEG and EOG electrodes were nonpolarizing sintered Ag-AgCl disc (Nihon Kohden, Japan). Electrode impedance was maintained $<5\,k\Omega$ after skin cleaning with OMNI prep paste. EEG and EOG were amplified by Nihon Kohden AD-611G DC amplifiers with a bandpass of 0–50 Hz. All stimuli, signals of trigger and markers of stimuli were produced with a PC-586. EEG, EOG, trigger signal and category markers of stimuli were recorded with another PC-586. Data were digitized at a sampling rate of 500 Hz by using a 12 bit A/D converter. ERPs were extracted off-line with an epoch of 5120 ms (including 490 ms prestimulus baseline). In averaging, various artifacts resulting from EOG, DC drift, overflow and body movement, etc. were automatically eliminated. Trials with peak-to-peak deflections $>80\,\mu V$ in any channel were excluded from the average. The actual number of individual trials per ERP waveform ranged from 51 to 60 trials. The ERP amplitude (peak-to-peak) and peak latency were measured.

One special feature of the software for ERP analysis used in the present experiment is that when a few channels with contaminated EEGs are rejected, uncontaminated EEGs of other channels in the same trial can still be averaged. This novel method economizes stimulus trials and shortens the experimental period. This is important for experiments like this one with long epoch (5120 ms) and with DC amplification that can easily produce an artifact of DC drift in a few channels [9]. Moreover, it is important for this experiment because no more appropriate Chinese characters can be selected to serve as the stimulus.

The present experiment aims at investigating the relationship between hemispheres in semantic processing of Chinese characters. Accordingly, the stimulus was presented in a visual half-field for observing hemispheric processing and a paradigm was used to more exactly reveal the semantic processing of Chinese characters. In this paradigm, the priming reduced the processing of the phonology and orthography of the target character, and the task of semantic association strengthened its semantic processing. The stimulus configuration is showed in Fig. 1.

The movement of subjects' eyes was monitored by HEOG so as to ensure that the data were obtained from visual half-field. A tone of 220 ms was given as the warning signal. The priming Chinese characters were presented in the center of the computer screen with a duration of 200 ms. The size of the characters was 30×30 mm with a visual angle of 1.2°. The size and duration of target characters were the same as the priming characters, but were presented in the left visual field (hereinafter LVF) or the right visual field (hereinafter RVF) of the screen in random order so that subjects could not predict the position of presentation. The distance between the internal edge of the character and the center of the screen was 30 mm, and the horizontal visual angle was 2.4°. The interval (from offset to onset) between the tone and the priming character was 1210 ms, and that between the priming and the target character was 1300 ms. The interval from the target to the tone of the next trial was 4400 ms. Half of the 120 pairs of priming-target characters were used as the stimuli for each visual half-field.

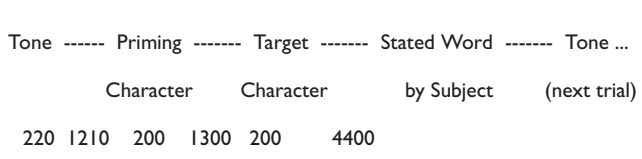

Fig. 1. The paradigm configuration. Time unit: ms.

The subjects knew that the priming and target characters are the same in phonology and they share common components in orthography. For example, when the priming character was 丁 then the target character was 釘, both sound 'ding' and look similar; when the priming character was 阝, then the target character was 房, both sound 'fang' and look similar. Subjects were instructed to focus their attention on the center of screen to attend to the phonology and the orthography of the priming character when it was presented. When the target character was presented, they were required to construct a two-characters word that is an associate of the target word. After the target disappeared from the screen, they orally reported the two-character word composed. Some practice trials were run until the subject's performance was correct and skilled. In reading a Chinese Character, there are processing in phonology, orthography, and semantics. In this procedure, the subjects would spend less mental resources in processing the phonology and orthography of the target character because they learned them from the priming character before the target was presented, but spend comparatively more mental resources in processing its semantics because their task was the semantic association. This paradigm is thus capable of examining the semantic processing more exactly.

Because the concrete words and abstract words are different in cognitive processing [10] and the processing brain mechanism [11], in order that all the associated words could be processed similarly, the every target character was so chosen that when the two-character word was produced with it, the word could only express a concrete object. That is, the associated words can only belong to the concrete words in this experiment.

RESULTS

Figure 2 shows the grand average ERPs of the whole experiment. Each curve contains three groups of ERP components produced by the tone, the priming and the target characters respectively. Corresponding to the aim of this experiment mentioned above, the data analysis is focused on the ERP evoked by the target characters at P3-T5 and P4-T6, which represent the posterior perceptual processing areas of both hemispheres. All the data were normalized. ANOVA and *t*-tests were conducted for data

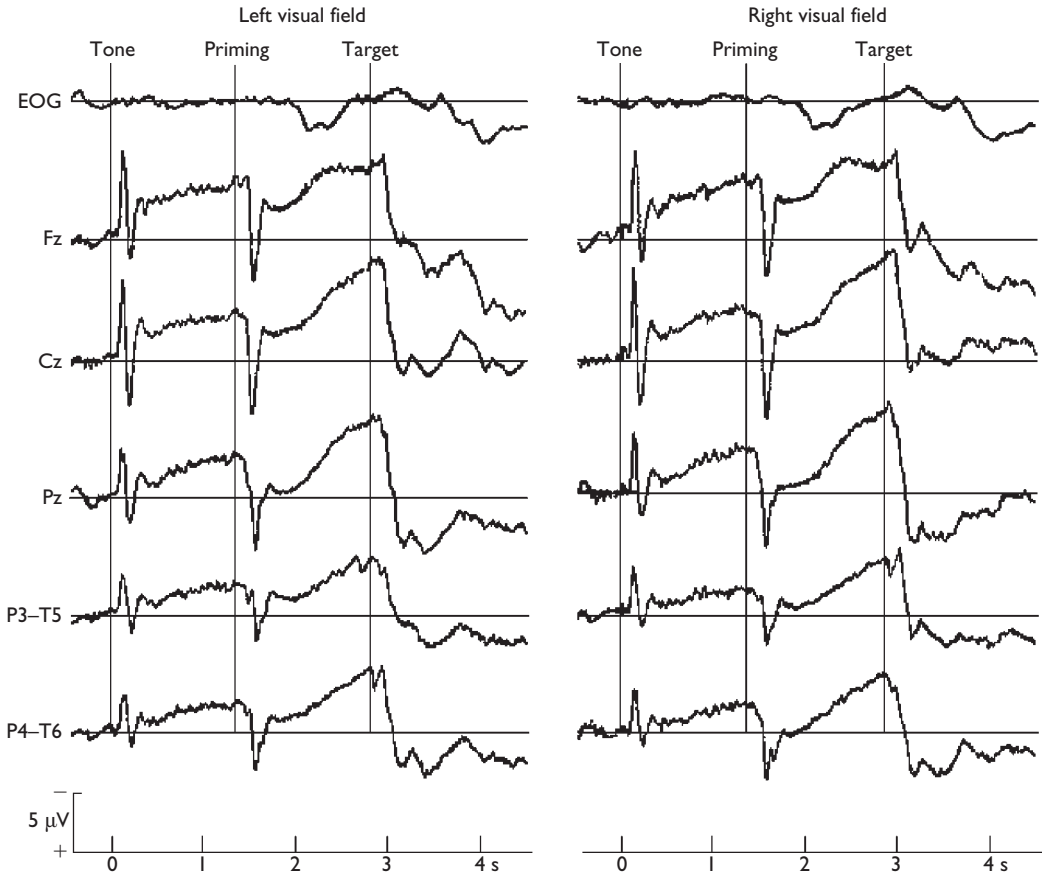

Fig. 2. The grand average ERP of the whole experiment.

statistics. The results attaining statistical significance are mentioned in this report.

P1 and N1 Figure 3 shows an enlarged segment of ERP at P3-T5 and P4-T6 in Figure 2, from 40 ms before to 200 ms after the presentation of the target character, such that P1 and N1 at these two electrode sites, which represent the two hemispheres, for the two visual half-fields can be observed clearly. In the present experiment with visual half-field presentation, the stimulus would be directly projected to the contralateral hemisphere. The transferring to the ipsilateral hemisphere, however, depends on an additional neurological pathway. Thus it is necessary to analyze the data under these two conditions of transferring separately. The relationships both between the left and right hemispheres for the equal transferring (contralateral/ipsilateral) and between the contralateral and ipsilateral transfers for the equal hemisphere (left/right) were examined.

The contralateral P1 were significantly shorter than the ipsilateral P1 in peak latency for both hemispheres ($t(15) = 2.96$, $p < 0.01$; $t(15) = 3.01$, $p < 0.01$). There was no significant difference between the contralateral N1 and ipsilateral N1 in peak latency. The left hemisphere N1 were significantly longer than the right hemisphere N1 in peak latency for both contralateral ($t(15) = 2.47$, $p < 0.05$) and ipsilateral transfers ($t(15) = 2.81$, $p < 0.05$).

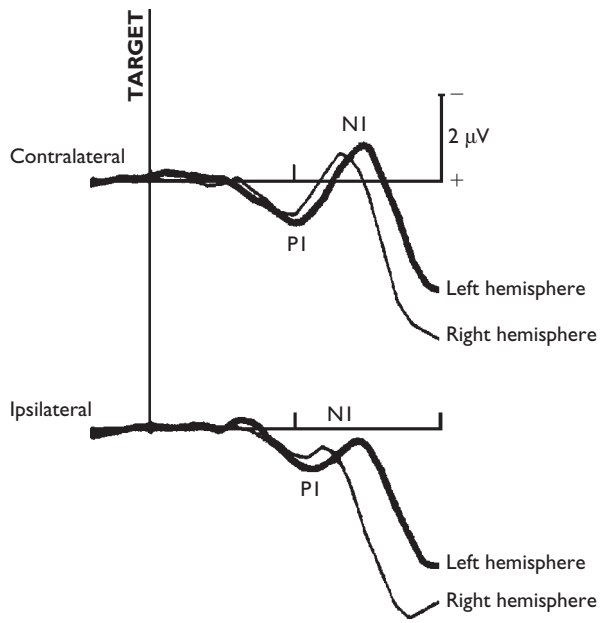

Fig. 3. The comparison of P1 and N1 for the two hemispheres and the two visual fields. Top panel: contralateral transfer; Bottom panel: ipsilateral transfer; Thick curves: left hemisphere (electrode site P3-T5); Thin curves: right hemisphere (electrode site P4-T6).

The amplitudes of left hemisphere N1 were significantly larger than that of the right hemisphere N1 for both contralateral ($t(15) = 2.18$, $p < 0.05$) and ipsilateral ($t(15) = 2.95$, $p < 0.01$) transfer. The amplitudes of the contralateral N1 were significantly larger than that of the ipsilateral N1 for both the left ($t(15) = 4.08$, $p < 0.001$) and the right hemispheres ($t(15) = 3.87$, $p < 0.005$).

Difference wave between right and left visual field: The difference waves (Fig. 4) were obtained by subtracting ERP elicited by the RVF presentation from that by the LVF presentation (left minus right) at each electrode cite. At the left hemispheric electrode site (P3-T5), the original N1 was negative (upwards, see Fig. 3), but the difference wave of N1 tended downwards (showing a polarity inversion). This difference wave actually equals the ipsilateral ERP (left hemisphere for LVF) minus the contralateral ERP (left hemisphere for RVF). The polarity inversion means that the amplitude of N1 evoked by contralateral transfer is larger than that evoked by ipsilateral transfer. At the right hemispheric electrode site (P4-T6), the polarity of the difference wave was still negative because in this case, it is the contralateral ERP (right hemisphere for LVF) minus the ipsilateral ERP (right hemisphere for RVF). Therefore, Fig. 4 confirms the above finding that the amplitude of N1 is larger with a contralateral visual field presentation than that with an ipsilateral transfer. This is a feature of an exogenous component, the polarity inversion of P1 can also be observed in Fig. 4. After the difference wave of N1, a positivity and a negativity peaking around 220 ms and 270 ms, respectively at each of the five sites can be observed in Fig. 4. These latencies should be in the zones of P2 and N2. They do not reveal the polarity inversion.

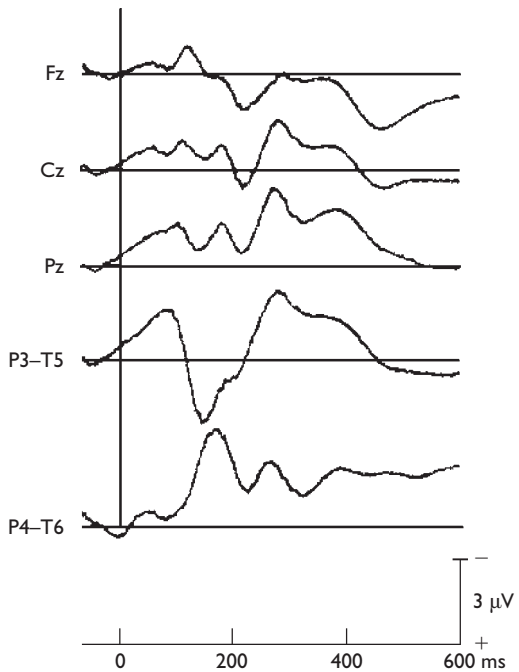

Fig. 4. The difference-wave between the left and right visual fields.

DISCUSSION

According to the physiology of the visual system, a stimulus presented in a visual half-field is transferred first to the contralateral hemisphere, which can generate an earlier response. In the results reported above, the latency of P1 (~100 ms) was consistent with this regular pattern: the P1 evoked by contralateral transfer was earlier than that by ipsilateral transfer. However, the N1 latency (~160 ms) was inconsistent with this regular pattern: both contralateral and ipsilateral N1 occurred almost at the same time. Such results suggest that the latency of N1 is not completely determined by its physiological transferring mechanism, but must be modulated by a certain cognitive processing on the target Chinese character. That the latency of P1 but not N1 is completely determinable by the physiological transferring mechanism also suggests that P1 has the property of an exogenous component, but N1 has the property of an endogenous component. On the other hand, as mentioned in the results above, the amplitudes of the contralateral N1 were significantly larger than that of the ipsilateral N1 for both the left and the right hemispheres, and the difference wave of N1 and P1 inversed their polarity at P3-T5 in Fig. 4. This is accountable by physiological transferring mechanism, suggesting that N1 reserves the property of an exogenous component. Thus N1 is a mixed component of exogenous and endogenous component. After the difference wave of N1, the difference waves of P2 and N2 appeared. They showed no polarity inversion at P3-T5 indicating that P2 and N2 are larger with LVF presentation than with RVF presentation regardless of whether it is the contralateral or ipsilateral presentation. This result suggests that P2 and N2 are determined by their respective cognitive processing and are not affected by the physiological transferring mechanism. Such features of P1, N1, P2 and N2 suggest that the N1 is the earliest component that reflects the cognitive processing of Chinese character. This semantic processing should occur in the interval between the peaks of P1 and N1, that is 100–160 ms after the onset of targets.

As mentioned above, the present results also showed that N1 of the left hemisphere occurred later but with amplitude larger than that of the right hemisphere. These findings suggest that the left hemisphere does not start processing until the necessary information has been transferred from the right hemisphere. But once the left hemisphere starts processing, its intensity is stronger. Thus, hemispheric dominance should be differentiated into two dimensions: speed and intensity. The dominance is different in these two dimensions for the two hemispheres in cognitive processing of Chinese characters.

The above reported ERP components were evoked by the target character, which was primed by the preceding priming character with the same phonology and partial orthography of the target. The subjects would spend less mental resources in processing the phonology and orthography of the target character because they learned the phonology and orthography before the target was presented, i.e. the phonology and orthography were the prompt and the repeated stimuli, but spend comparatively more mental resources in processing its semantics. This role of priming has been proved by various experiments. For example, Raichle *et al.* [12] found that the brain reduces

its reaction for repeated stimulation in PET recording. In addition, several other recent functional neuroimaging studies have explored priming on a variety of cognitive tasks. Each of these studies showed that the posterior perceptual processing areas of the two hemispheres, where P3-T5 and P4-T6 in the present experiment were located, are activated during cognitive tasks. Their activation is reduced when the stimuli are primed (for a review see [13]). Thus all the above-mentioned cognitive processing of Chinese character in this experiment mainly refers to the processing of the semantics, not phonology nor orthography. In addition, the relationship between hemispheres only is confined in the activities of their posterior perceptual processing areas in the present experiment. On the hemispheric dominance for the other brain regions in these two dimensions, especially the anterior frontal lobe, further investigation is needed.

CONCLUSION

First, the present data show that N1 is the earliest component that reflects the semantic processing of Chinese characters. The N1 of the right hemisphere responds with shorter latency and smaller amplitude, and the N1 of the left hemisphere, though longer in latency, is greater in amplitude. On the basis of these results, the authors propose that the left hemisphere does not start processing until the necessary information has been transferred from the right hemisphere. Once the left hemisphere starts processing, its intensity is stronger. Thus it is more appropriate to differentiate hemispheric processing dominance into two dimensions: speed and intensity. Second, the semantic cognition onset of Chinese characters occurs from 100 ms to 160 ms in the posterior perceptual processing area of brain.

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