

# The Temporal Features of Self-referential Processing Evoked by Chinese Handwriting

Antao Chen<sup>1,2</sup>, Xuchu Weng<sup>1</sup>, Jiajin Yuan<sup>1</sup>, Xu Lei<sup>2</sup>, Jiang Qiu<sup>1</sup>,  
Dezhong Yao<sup>2</sup>, and Hong Li<sup>1</sup>

## Abstract

■ To explore the temporal features and underlying brain structures of self-referential processing, participants were shown examples of Chinese handwriting, half of which were their own and the other half belonged to others, and asked to judge whether the handwriting was their own. In Experiment 1, the task was to categorize the handwriting by pressing the correct key as quickly as possible. In Experiment 2, after the participants recognized the stimuli, they were required to gaze at the handwriting for 3000 msec before making a response rather than responding immediately after stimulus onset. The results showed prominent differences in event-related potentials elicited by *own* and *other* handwriting conditions in the 200–

500 msec and 1000–2000 msec time windows. Dipole analyses of the difference waves, own minus other, were conducted in both of these time windows. There were two dipoles in the 200–500 msec time window localized to the medial-temporal lobe and the anterior cingulate cortex (ACC), and MTL activation preceded ACC activation. Only one dipole at the posterior cingulate cortex was fitted to the 1000–2000 msec time window. These structures were activated sequentially in a temporal course, which provides evidence that the cortex middle structures potentially form a specific self-related processing unit, which is involved in processing various aspects of the self. ■

## INTRODUCTION

Throughout the history of philosophy and psychology, the question of the self has been one of the most salient problems (Northoff et al., 2006; Gillihan & Farah, 2005; Northoff & Bermpohl, 2004). Early research on this topic demonstrated a mnemonic advantage for information that is processed in a self-referential manner (Kelley et al., 2002; Rogers, Kuiper, & Kirker, 1977). Two putative explanations have been proposed for the self-reference effect in memory (Gillihan & Farah, 2005; Kelley et al., 2002). One suggests that the self is a unique cognitive structure that possesses extraordinary or additional mnemonic abilities (e.g., Northoff et al., 2006; Northoff & Bermpohl, 2004; Craik et al., 1999; Rogers et al., 1977). The other proposes that the memory enhancement afforded to self-reference can be interpreted as an extension of the basic depth-of-processing effect (e.g., Symons & Johnson, 1997; Klein & Loftus, 1988; Ferguson, Rule, & Carlson, 1983; Bower & Gilligan, 1979). Despite the clarity of these competing viewpoints, it is difficult to evaluate them with purely behavioral measures (Heatherston, Macrae, & Kelley, 2004; Kelley et al., 2002). Behavioral studies have been limited by their reliance on response

time measures, which require overt response and represent the combined effects of multiple stages of information processing (Gray, Ambady, Lowenthal, & Deldin, 2004). In order to avoid these problems, researchers have recently resorted to the investigation of the neural mechanisms of self-referential processing to further the understanding of the corresponding mental processes.

Following Craik et al. (1999), researchers have paid increasing attention to the brain mechanism of the self. Differences among studies of the neural mechanisms of self-related processing are mainly in stimuli and methods. Different aspects of self-related processing may be elicited by different stimuli (Gillihan & Farah, 2005), for example, face recognition (Turk et al., 2002; Keenan, Nelson, O'Connor, & Pascual-Leone, 2001), and agency of action (Blakemore & Frith, 2003; Farrer & Frith, 2002) could be used to explore the physical self, whereas trait adjectives (Kelley et al., 2002; Craik et al., 1999) and autobiographical memory (Gray et al., 2004; Fink et al., 1996) could be used to explore the psychological self. Behavioral (e.g., Keenan et al., 1999), neuropsychological (e.g., Turk et al., 2002), neuroimaging (e.g., Kelley et al., 2002; Craik et al., 1999), and electrophysiological (e.g., Gray et al., 2004) methods have been applied in studies of self-processing. The early studies were mainly behavioral and neuropsychological, and demonstrated some potential neural bases of self-related processing, such as laterality. With

<sup>1</sup>Southwest University, Chongqing, China, <sup>2</sup>University of Electronic Science and Technology of China, Chengdu, China

the development of neuroimaging techniques, involvement of more specific brain structures in self-referential processing have been reported, such as the anterior cingulate cortex (ACC) and the posterior cingulate cortex (PCC; for reviews, see Uddin, Iacoboni, Lange, & Keenan, 2007; Northoff et al., 2006; Gillihan & Farah, 2005; Northoff & Bermpohl, 2004).

These studies of the self have raised an important question: Is the processing of the self special? In the literature, contradictory opinions have been proposed (Gillihan & Farah, 2005; Heatherton et al., 2004). Northoff and Bermpohl (2004) argued that the self is processed uniquely in the brain because distinct regions of the cortex middle structures (CMS) are specifically related to subfunctions in self processing. This hypothesis is supported by cluster and factor analyses of the coordinates of brain activity during self-related tasks in different domains (Northoff et al., 2006) and some empirical data (e.g., D'Argembeau et al., 2007). On the contrary, Gillihan and Farah (2005) suggested that whether the self is distinctive should be judged according to four criteria: anatomical specificity, functional uniqueness, functional independence, and species specificity. After reviewing the various operationalizations of self and how studies' findings related to the conclusions drawn based on these criteria, they proposed that the claims for the special status of self-related processing were premature. Gillihan and Farah proposed that if some methodological difficulties could be overcome, the hypothesis of a unique response to the self could be examined better. Northoff et al. (2006) also admitted that more studies are needed to examine various inferences regarding the CMS, and pointed out that more attention must be placed on the temporal aspects of self-related processing.

It is well known that one advantage of event-related potentials (ERPs) is high temporal resolution. Therefore, ERP studies of self-referential processing may provide more detailed information in the temporal domain. Berlad and Pratt (1995) found that P300 amplitude was larger in response to a participant's own name compared to other words, which suggests that stimulus relevance has an additional effect on P300 amplitude beyond rarity. Ninomiya, Onitsuka, Chen, Sato, and Tashiro (1998) found that P3 amplitude in response to a subject's own face was significantly larger than that of an unfamiliar face or red square, suggesting that his or her own face caused an emotional response other than an orientation response. Michel, Trevor, and Kenneth (2002) found that the effect of self-referential processing was reflected in both the P3 and later P500. The amplitudes of the two components became larger to words that reflected the subject's true identity, and although the P3 was believed to reflect the stage of the yes/no decision, the P550 may reflect the personal relevance of the terminal word. Gray et al. (2004) found that P3 amplitude elicited by self-referential stimuli was larger than that elicited by control stimuli and P3 latency indicated that self-referential processing may happen at a higher level of cognitive processing involving selective attention.

Similarly, Perrin et al. (2005) found that P3 amplitude was significantly greater when seeing one's own first name than when seeing common first names. In a recent study, Watson, Dritschel, Obonsawin, and Jentszsch (2007) proposed that the size of the N400 may indicate the extent to which information is discrepant with an individual's self concept. With regard to ERP research, consistent results suggest that self-referential processing causes increased P3 amplitude. As to the larger N400 elicited by positive self words in Watson et al. (2007), there was little negative amplitude and a peak in the P300 time window, which could be regarded as a late positive complexity. However, these results are too simple to provide detailed information about the neural correlates of self-referential processing. These limitations are caused by the chosen stimulus material, experimental procedures, or methods. To utilize the high temporal resolution of ERPs, some improvements in both methods and stimuli are necessary.

The stimuli used in these studies are diverse and different stimuli may activate different aspects of self processing, which may be a main cause of inconsistent results, especially the activated brain structures among neuroimaging studies. Although the concept of the self is thought to include distinct aspects, the psychological self has been regarded as the core aspect of self (Northoff et al., 2006). It is reasonable to assume that when the psychological self is activated, the corresponding brain activation could be used to evaluate whether the self is specific. According to previous studies, trait adjectives and autobiographical stimuli explore the psychological self (Gillihan & Farah, 2005). Episodic memory and semantic processing are also elicited by these stimuli (e.g., Kelley et al., 2002; Craik et al., 1999); however, many studies have found that it is difficult to dissociate autobiographical memory from episodic memory (Levine et al., 1998).

In the present study, we employed a novel stimulus, subjects' own handwriting, to explore self-referential processing. We believe that the response to one's own handwriting would reflect the self. This hypothesis stems from an idea formed by Yang Xiong (BC 22), a famous thinker of the West Han Dynasty that handwriting is a drawing of the mind (cf. Zhou & Tao, 2004; Ren & Feng, 2001) and can characterize a person's internal mental world and psychological character. Because self-referential stimuli are experienced as strongly related to one's self (Northoff & Bermpohl, 2004; Kelley et al., 2002; Craik et al., 1999), one's own handwriting should represent a kind of self-referential stimuli. In fact, many studies have established a positive relationship between handwriting, especially holistic handwriting characteristics, and personality characteristics (Lowis & Mooney, 2001; van Rooij & Hazelzet, 1997), which suggests that handwriting incorporates personality information. It is possible that seeing one's own handwriting is similar to seeing a self-portrait, and that handwriting may activate processing of the psychological self or core self.

In order to accurately record the temporal course of self-referential processing, the high temporal resolution of the ERP technique was applied and dipole analyses of difference waves were conducted. Despite its inherent limitations, dipole analysis can provide some data for the interpretation of the ERP difference wave. Accordingly, the temporal course and underlying neural substrates of self-referential processing were explored. In Experiment 1, participants were required to judge whether presented handwriting was their own or not by pressing two different keys immediately after recognizing stimulus. In Experiment 2, rather than responding immediately, participants were instructed to gaze silently at the handwriting for 3000 msec during which they judged whether the handwriting was theirs or not. We believe that responses to their own handwriting in Experiment 1 are related to more primary cognitive processes, such as attention, perception, and memory, but that Experiment 2 may evoke more complex self-referential processing.

## EXPERIMENT 1

### Methods

#### Participants

Thirteen native Chinese undergraduate students were paid participants (7 men), with their ages ranging from 18 to 20 and averaging 19.8 ( $SE = 0.6$ ). All subjects were physically and mentally healthy, right-handed, and had normal or corrected-to-normal vision. The study was approved by the local Review Board for Human Participant Research. All subjects signed an informed consent form for the experiment.

#### Stimuli

One hundred 14-character verse pairs were picked out randomly from ancient Chinese poetry, and then written by each subject. The writing for each pair was then scanned and saved as an electronic file for later use. The height and the width of handwriting stimuli were controlled so that the size of each picture in the file was small, with height below 4 cm and width less than 12 cm. For each trial in the experiment, one such picture was presented (Figure 1), that is, one verse pair was pre-

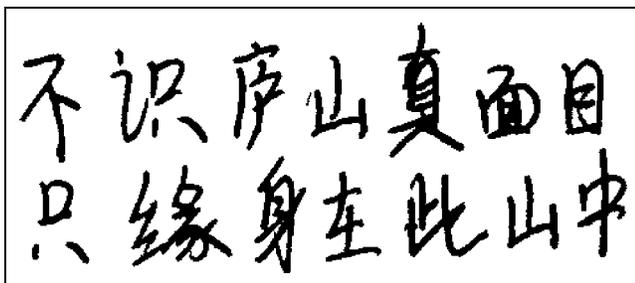


Figure 1. An example of handwriting from a participant.

sented at a time. The distance between subjects' eyes and the display screen was about 1.5 m, and thus horizontal and vertical visual angles were about  $4.6^\circ$  and  $1.6^\circ$ , respectively.

#### Experimental Design

The same participants were recalled approximately two months after writing the verse pairs for stimulus materials. During the experiment, each participant typed his or her name to load the experimental program written for him or her. Among the presented verse pairs, half of the material was his or her own handwriting and the other half consisted of handwriting combinations composed equally of the other 12 subjects' handwriting samples.

To exclude the effect of semantic processing, the content of the classical poem was the same for both kinds of handwriting; therefore, only the writing style was different. The handwriting samples were randomly presented in each trial and participants were asked to respond by pressing a different key for each of the two kinds of handwriting. Response times and EEG data were recorded when participants categorized the handwriting samples.

#### Procedure and Task

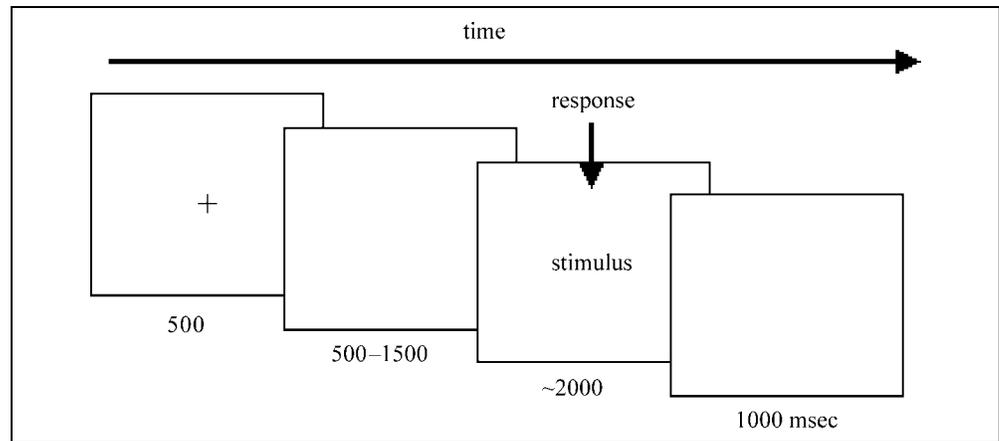
The screen background was white. Each trial was initiated with a small black cross presented for 500 msec; next, a written verse pair was presented 500–1500 msec after the offset of the little black cross for 2000 msec. Each subject was asked to press the J key on a keyboard to indicate that the verse pair was in their *own* handwriting or to press the F key to indicate that the pair was written by someone else (*other* handwriting). The subject was required to respond as fast and as accurately as possible; each response was followed by a white, blank screen lasting for 1000 msec (Figure 2).

Before the formal experiment, each subject participated in 10 practice trials (5 trials of their own handwriting and 5 of others' handwriting). The formal experiment was divided into three blocks: The first two were 60 trials (30 trials were their own writing and 30 were others' writing), whereas the third block consisted of 80 trials (40 trials were their own writing). In this way, a total of 100 formal trials were included in each condition.

#### Electroencephalogram Recording

The electroencephalogram (EEG) was recorded from 64 scalp sites using tin electrodes mounted in an elastic cap (Brain Products, GmbH, Germany), with the average reference on the left and right mastoids, and a ground electrode placed on the medial aspect of the frontal scalp. Horizontal and vertical electrooculograms (EOGs) were recorded. The EEG and EOG were amplified using a DC-100 Hz bandpass and continuously sampled at 500 Hz. All

**Figure 2.** Illustration of handwriting categorization in Experiment 1.

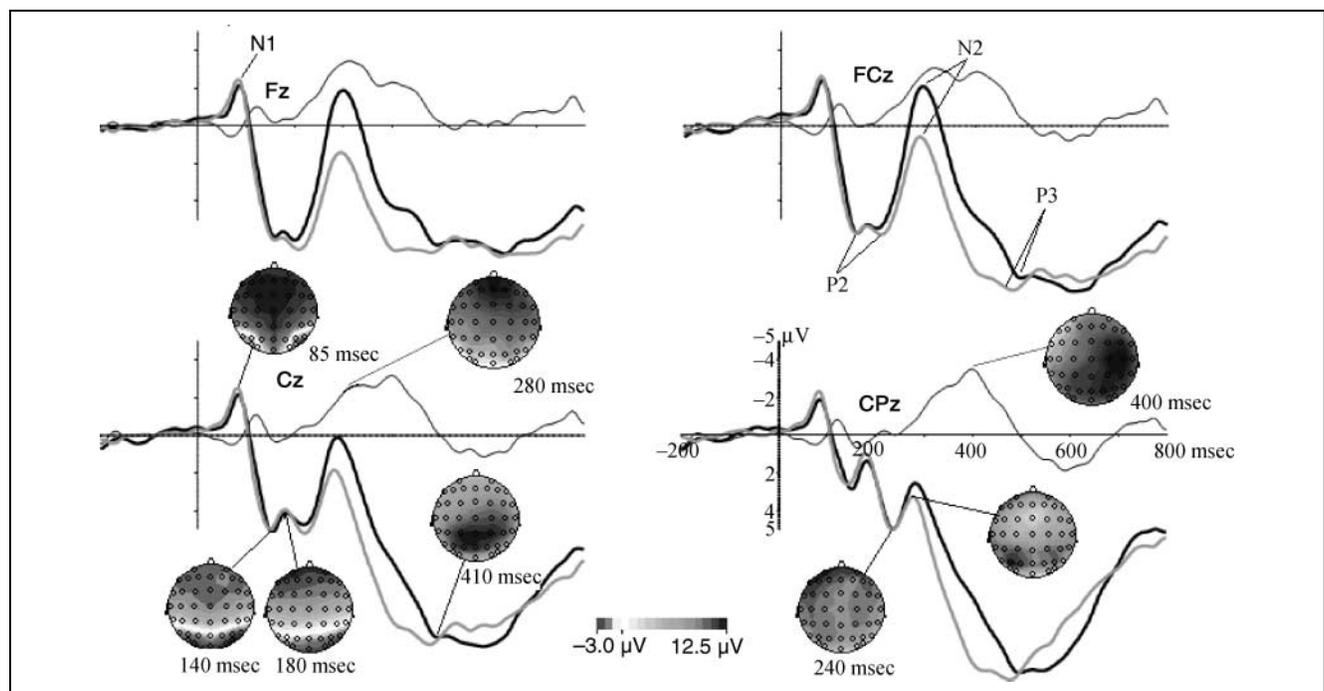


interelectrode impedance was maintained below 5 k $\Omega$ . Averaging of ERPs was computed off-line; the analysis epoch began 200 msec before onset of each verse pair, and continued until 800 msec after stimulus onset. Trials with EOG artifacts (mean EOG voltage exceeding  $\pm 80$   $\mu$ V) and those contaminated with artifacts due to amplifier clipping with peak-to-peak deflection exceeding  $\pm 80$   $\mu$ V were excluded from averaging.

#### ERP Data Analysis and Statistics

The ERP waves for both conditions were overlapped and averaged. As seen in the grand-averaged waveforms and

topographical maps, the ERPs elicited by the *own* and *other* conditions showed prominent differences from each other in Experiment 1 and these differences were largest at frontal and central regions (see Figure 3). Similarly, the grand-average ERPs of Experiment 2 displayed prominent differences at central and frontal regions along the midline (Figure 6). Thus, the following 18 electrode sites were selected for statistical analysis: F3, F4, C3, C4, P3, P4, Fz, Cz, Pz, FC3, FC4, CP3, CP4, FCz, CPz, PO4, POz, and PO3. The major aims were to measure and analyze the amplitudes and latencies of N1 (70–100 msec), P2 (P150, 140–180 msec; N180, 160–200 msec; and P220, 200–240 msec), and N2 (270–310 msec). As can be seen in Figure 3,



**Figure 3.** Grand-average ( $n = 13$ ) ERPs to *own* and *other* handwriting samples at four electrode sites (Fz, FCz, Cz, and CPz). Time = 0 msec corresponds to onset of handwriting presentation. Thick gray lines represent *own* handwriting, thick dark lines represent *other* handwriting, and thin dark lines represent the other minus *own* difference wave. N1, P2, N2, and P3 are indicated on the waveform plots. Topographical voltage maps of the difference wave at 280 and 400 msec (dash line) and the original waves at 85, 140, 180, 240, and 410 msec (solid line) are presented; increasing grayness in the topographics of the difference waves represents increased negativity, and increasing grayness in those of the original waves represents increased positivity.

despite the lack of prominent ERP components in the 360–440 msec intervals, there were ERP differences during the interval. Therefore, mean amplitudes for the two conditions in this interval were also measured. Analysis of variance (ANOVA) was conducted on the amplitudes (from baseline to peak) and peak latencies of N1, P2, N2, and the mean amplitudes in the 360–440 msec interval, with factors of condition (own writing and other writing) and electrode sites (18 electrode sites). The *p* values of all main and interaction effects were corrected using the Greenhouse–Geisser method for repeated-measures effects.

### Dipole Source Analysis

The Brain Electrical Source Analysis program (BESA 5, 2003, MEGIS Software GmbH, Munich, Germany) was used to perform dipole source localization analysis on the basis of the four-shell ellipsoidal head model. The difference wave was obtained by subtracting the averaged ERPs of own handwriting from that of other handwriting trials. Principal component analysis (PCA) was employed for the ERP difference wave in order to estimate the minimal number of dipoles. After the minimal dipole numbers were determined, the software automatically determined the dipole locations according to the related residual variance criterion.

## Results

### Behavioral Results

The mean reaction time (RT) for own handwriting was  $715 \pm 26.6$  msec (mean  $\pm$  SE), whereas the mean RT for other handwriting was  $809 \pm 38.1$  msec. The result of a paired-sample *t* test showed a significant difference in RT between the two handwriting conditions [ $t(12) = 3.043$ ,  $p = .003$ ]. The error rate of judging one's own handwriting was  $2.3 \pm 0.2$  (%  $\pm$  SE), whereas the error rate of judging others' handwriting was  $6.1 \pm 0.5$ . The result of a paired-sample *t* test showed a significant difference between the two error rates [ $t(12) = 2.865$ ,  $p = .008$ ].

### ERP Components

Figure 3 shows that the experimental conditions produced remarkable N1, P2, N2, and P3 components. It is noted that the waveform of P2 here is more complex than the general P2, as a small negative deflection appears during the interval of the present P2, especially at posterior electrodes. Therefore, the P2 was divided into three subcomponents (P150, N180, and P220) for statistical analysis in order to more accurately compare the P2s of two waves. In addition, whereas the two waves overlapped in the P3 component, the difference wave showed a prominent ERP difference between the two handwriting conditions prior to the peak of the P3 component, and this difference reached its maximal magnitude at about 400 msec after stimulus onset. Thus, a two-way ANOVA was conducted on the amplitudes (from the baseline to the peaks) and peak latencies of N1, P2s (P150, N180, and P200), and N2, as well as on the mean amplitudes from 360 to 440 msec. The results are shown in Table 1.

The results of the ANOVA on mean amplitudes in the 360–440 msec interval showed that other handwriting ( $5.8 \pm 0.638$   $\mu$ V) elicited a significantly greater negativity than own handwriting ( $7.9 \pm 1.1$   $\mu$ V) [ $F(1, 12) = 6.931$ ,  $p = .022$ ]. In summary, neither amplitude nor latency effects were observed at N1 and P2, but both N2 amplitude and latency were significantly different between the two conditions, as was mean amplitude in the 360–440 msec interval.

### Results of Dipole Source Analysis

The ERP wave elicited by own handwriting was subtracted from that elicited by other writing to obtain a difference wave. Because the two conditions differed only in writing characteristics, the difference wave should reflect the brain's activities underlying the processing of the characteristics of the writing. Figure 3 shows that the difference wave displays a remarkable negative component in the 200–500 msec interval; thus, PCA was conducted on the difference wave in this interval. The result showed that

**Table 1.** The Results of ANOVA on Amplitudes and Latencies of Each Component

	Amplitudes ( <i>M</i> $\pm$ SE) and Significance Tests				Latencies ( <i>M</i> $\pm$ SE) and Significance Tests			
	Other ( $\mu$ V)	Own ( $\mu$ V)	<i>F</i> (1, 12)	<i>p</i>	Other (msec)	Own (msec)	<i>F</i> (1, 12)	<i>p</i>
N1	$-2.1 \pm 0.35$	$-2.3 \pm 0.34$	1.179	.299	$86 \pm 1.9$	$84 \pm 1.8$	2.998	.109
P150	$3.0 \pm 0.9$	$3.1 \pm 0.89$	0.026	.847	$165 \pm 2.1$	$163 \pm 2.5$	0.761	.400
N180	$0.25 \pm 0.76$	$0.23 \pm 0.7$	0.004	.948	$172 \pm 2.4$	$170 \pm 2.1$	0.584	.460
P220	$5.7 \pm 0.79$	$6 \pm 0.89$	0.953	.348	$223 \pm 2.7$	$223 \pm 2.5$	0.085	.776
N2	$0.78 \pm 1.1$	$2 \pm 1.1$	6.080	.030*	$288 \pm 1.9$	$282 \pm 1.7$	10.150	.008**

\**p* < .05.

\*\**p* < .01.

two principal components accounted for 93% of the variance, with principal component 1 accounting for 31.5%, principal component 2 accounting for 61.8%, and the remaining components accounting for no more than 5%. Thus, only two dipoles fit the data (Figure 4).

When the dipole's orientation and place were not limited, the dipole for principal component 1 was localized in the medial-temporal lobe (MTL) (Talairach coordinates:  $x = -5.9$ ,  $y = -6.8$ , and  $z = 14.7$ ), and the maximal dipole moment strength was at about 286 msec. The dipole for principal component 2 was localized in the ACC (Talairach coordinates:  $x = 19.7$ ,  $y = -10.6$ , and  $z = 40.1$ ), and the maximal dipole moment strength was at about 400 msec. At the moment of the dipoles' peak activation, this model can best account for the data in the interval, and accounts for the most variance, with a residual value of 9.074%.

## Discussion

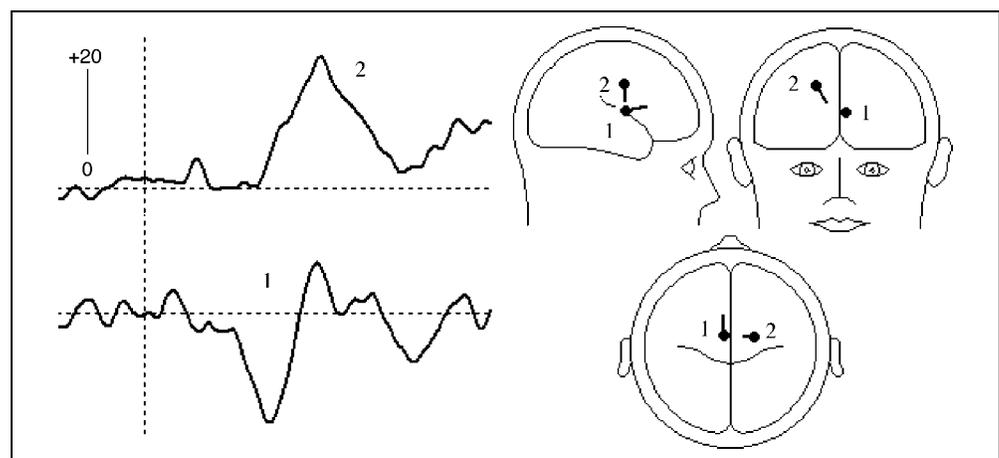
The behavioral statistical results showed that the response to own handwriting was significantly faster than the response to other handwriting, and the error rate was significantly lower, which demonstrated a memorial advantage for own handwriting that is consistent with the *self-reference effect* in self-referential processing (Rogers et al., 1977). However, the ERP results showed that the waves elicited by the two kinds of stimuli were not significantly different in either the latencies or amplitudes of N1 and P2, but they appeared significantly different in the N2 (280 msec) component and the interval of 360–440 msec. These results suggest that the early processing of the two kinds of stimuli was similar, and that self-referential processing may have taken place during the late ERP components. It should be noted that although the P2 waveform was more complex in the present study, none of the statistical results for its three subcomponents were significant. Considering that the P2 is related to perception analysis (e.g., Karayanidis &

Michie, 1996), and the font style and strokes of handwriting were rather complex, the result may be related to the complexity of handwriting perception. Therefore, the difference waves of the N2 component and the 360–440 msec interval were the focus of subsequent analyses.

To better understand N2/P3 modulation in the present study, a dipole analysis was conducted on the difference wave in the 250–500 msec time window. Two dipoles were fitted to the data in this time window, with one dipole located in the MTL and the other in the ACC, with maximal dipole moment strength of the MTL taking place earlier than that of the ACC. The MTL is involved in integration of extraneous and intraneous information with respect to their self-relatedness (Northoff et al., 2006; D'Argembeau et al., 2005). In the present study, this integration may be related to the interaction between extraneous and self-referential information, such as the encoding of input information (Macrae, Moran, Heatherton, Banfield, & Kelley, 2004; Fossati et al., 2003) and the retrieval of self-related information (Fossati et al., 2004; Lou et al., 2004).

To evaluate the ownership of a presented stimulus, the subject must retrieve own handwriting and compare it with the stimulus. When the presented stimulus is other handwriting, the strangeness would elicit more effort to determine whether the stimulus is *other*, and more retrieval of own handwriting features would be elicited. Accordingly, encoding/retrieval would be stronger in the *other* condition, which is consistent with greater MTL activity in the *other* condition. However, it is noted that some studies have found the reverse activation pattern: greater MTL activity during encoding of self-referential trait adjectives relative to conditions that were not self-related (Fossati et al., 2003, 2004; Macrae et al., 2004). The difference may be related to differences in the stimuli and task. Trait adjectives evoke semantic processing and episodic memories, especially when they are evaluated regarding reference to the self (Symons & Johnson, 1997). Moreover, the positive relationship between episodic memory and the MTL has been well

**Figure 4.** Dipole models of the *other* – *own* difference waveforms over the 200–500 msec interval. The dipole source waveforms at the left show the interaction components that were modeled and the two dipoles indicated at the right were located in the MTL (Dipole 1) and the ACC (Dipole 2).



established (e.g., Dolan & Flecher, 1997). In contrast, self-identification of handwriting is unlikely to be based on episodic memories of its production (Knoblich & Flach, 2003; Knoblich, Seigerschmidt, Flach, & Prinz, 2002), and may also not involve semantic processing because the identification of handwriting features is a visual task. Recognizing ownership of stimuli is different from judging whether an adjective describes oneself. Obviously, the judgment of self-relevance is more complex because the trait of a person cannot be answered with a simple yes or no, but may evoke various self-related memories. However, the recognition of ownership is simpler, and handwriting features corresponding to presented stimuli are relevant for retrieval.

According to the results of source localization, the ACC, activated immediately after the MTL, may be associated with both the anterior feature comparison and the posterior behavioral response. During the comparison between input handwriting features and retrieved ones, if the difference exceeds a threshold, the evident conflict will disturb information processing. Several previous studies have claimed that the ACC is associated with conflict detection (Botvinick, Cohen, & Carter, 2004; Kerns et al., 2004). Similar to MTL activation during the *other* condition, the difference between input handwriting features and retrieved ones would be higher, resulting in greater ACC activation in this condition. In addition, greater ACC activity in the *other* condition is associated with higher error rates and slower responses, which imply that the activity is also related to task difficulty (e.g., Johnston, Levin, Koval, & Everling, 2007).

## EXPERIMENT 2

In Experiment 1, an overt response was required and the RT to recognition of handwriting was obtained. Accordingly, the ERP time window of recognition could be determined. However, because the stimulus disappeared immediately after the recognition response and the mean RTs in the two conditions were about 800 msec, the stimuli were only presented for about 800 msec. Although the time interval was sufficient to elicit self-related processing, this type of self-related processing may be associated with cognitive operations such as perception, recognition, conflict detection, and categorization. Considering the complexity of self-referential processing (Klein, Rozendal, & Cosmides, 2002), we believe that more self-related processing, such as an emotional response related to the self, may be elicited if the stimuli are presented for a longer time. In fact, the presentation times of stimuli in neuroimaging studies are no less than 2000 msec (e.g., Kelley et al., 2002) and sufficient self-related processing is elicited in these studies. In contrast, because of short stimulus presentation times in ERP studies, the processing elicited may be limited to the cognitive level, such as judgment of self-relevance of the stimuli

(e.g., Ninomiya et al., 1998; Berlad & Pratt, 1995), and more complete self-referential processing, including both cognitive and emotional elements, may not have been thoroughly evoked.

Accordingly, in Experiment 2, the stimulus presentation time was extended to 3000 msec and no overt response was required during the time interval. Through this manipulation it was expected that more self-related processing would be elicited.

## Methods

### Participants

Fourteen undergraduate students were paid participants. There were eight men and six women, with ages ranging from 18 to 20 and averaging 19.2 ( $SE = 0.4$ ). All subjects were physically and mentally healthy, right-handed, and had normal or corrected-to-normal vision. All subjects signed an informed consent form for the experiment.

### Stimuli

The stimuli in the experiment were the same as those in Experiment 1.

### Experiment Design

Participants were asked to categorize stimuli as quickly as they could, but they did not respond immediately after the judgment. Instead, they continued to gaze at each stimulus for 3000 msec until an index of response appeared. The participants then pressed a key corresponding to their judgment.

### Procedure and Task

Participants were asked to judge whether presented handwriting was their own or belonged to someone else (*other*) after stimulus onset, but did not press any key until the stimulus disappeared (Figure 5). All other aspects were the same as in Experiment 1.

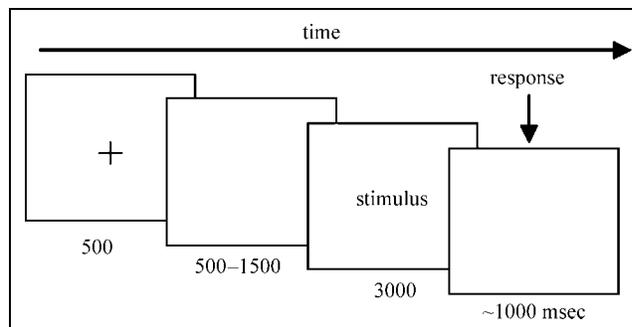


Figure 5. Illustration of handwriting categorization in Experiment 2.

## Electroencephalogram Recording

The configuration of EEG recording was the same as that in Experiment 1.

### ERP Data Analysis and Statistics

Because the psychological response following judgment of the stimulus category was the focus of the experiment, only the ERPs following correct judgment were analyzed. According to the results of Experiment 1, the participants could make correct judgments about 500 msec after stimulus onset. Therefore, the wave difference after 500 msec was analyzed. The selected electrodes were the same as in Experiment 1. Because no obvious peaks appeared after 500 msec (Figure 6), the mean amplitude was measured and compared between two waves. Specifically, the mean amplitudes in the 500–700, 700–1000, 1000–1500, 1500–2000, 2000–2500, and 2500–3000 msec intervals were compared between the two conditions.

### Dipole Source Analysis

Using the same methods as in Experiment 1, dipole analysis was conducted in the 1000–1500 and 1500–2000 msec intervals.

## Results

### ERP Components

Although the waveforms of both kinds of stimuli began to separate after 700 msec and lasted for the entire presentation, the statistical results showed that the mean amplitudes differed significantly only in the intervals of 1000–1500 and 1500–2000 msec (Table 2). These results

**Table 2.** ANOVA Results of Mean Amplitudes from 500 to 3000 msec

Interval (msec)	Mean Amplitudes ( $M \pm SE$ )		Significance Tests	
	Other ( $\mu V$ )	Own ( $\mu V$ )	$F(1, 13)$	$p$
500–700	$6.4 \pm 0.77$	$6.6 \pm 0.78$	0.182	.677
700–1000	$5.2 \pm 0.73$	$6 \pm 0.57$	2.6	.133
1000–1500	$4.6 \pm 0.63$	$5.8 \pm 0.48$	7.755	.017*
1500–2000	$4 \pm 0.6$	$5.2 \pm 0.54$	12.383	.004**
2000–2500	$4 \pm 0.68$	$4.6 \pm 0.54$	1.529	.24
2500–3000	$3.5 \pm 0.55$	$3.8 \pm 0.58$	0.299	.595

\* $p < .05$ .

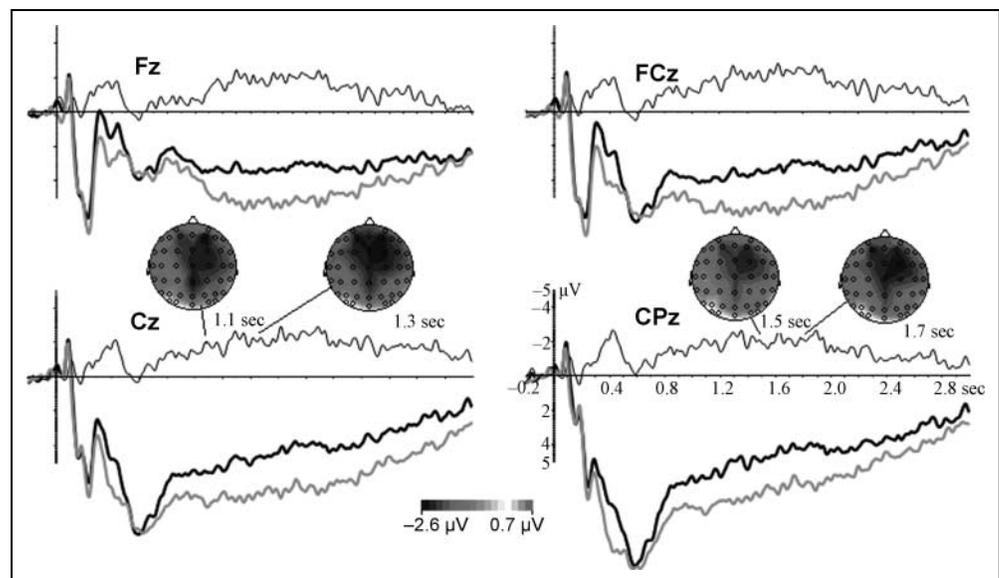
\*\* $p < .01$ .

suggest that brain activity in response to own handwriting was significantly different from other handwriting during these two intervals and that the brain was experiencing new self-referential processing. In order to gain more information about self-referential processing, a dipole analysis was conducted on the difference wave in these two intervals.

### Results of Dipole Source Analysis

The dipole procedure was similar to that conducted in Experiment 1. A PCA was conducted on the difference wave in the 1000–1500 msec interval. The results showed that only one principal component accounted for 93.6% of the variance, and other components accounted for less than 5%. Therefore, only one dipole fit the data. When the dipole's orientation and place were not fixed, the dipole was localized in the PCC (Talairach coordinates:  $x =$

**Figure 6.** Grand-average ( $n = 14$ ) ERPs to *own* and *other* handwriting at four electrode sites (Fz, FCz, Cz, and CPz). Time = 0 msec corresponds to the onset of the handwriting stimulus. Thick gray lines are *own*, thick dark lines are *other*, and thin dark lines are difference waves of *other* minus *own*. Topographical voltage maps of the difference wave at 280 and 400 msec and the original waves at 1.1, 1.3, 1.5 and 1.7 sec are presented. Increasing grayness on the color scale represents increased negativity.



2.2,  $y = -41.1$ , and  $z = 7$ ; Figure 7). This model can best account for the data in the interval, and accounts for the most variance, with a residual value of 13.109%.

With the same dipole procedure, a PCA was conducted on the difference wave in the 1500–2000 msec interval. The PCA results showed that only one principal component accounted for 96.8% of the variance, and other components accounted for less than 1%; therefore, only one dipole fit the data. When the dipole's orientation and place were not fixed, the dipole was localized in the PCC (Talairach coordinates:  $x = -0.3$ ,  $y = -45.7$ , and  $z = 6.8$ ; Figure 7). This model can best account for the data in the interval, and accounts for the most variance, with a residual value of 12.211%.

The dipole results suggest that the encephalic source of the difference wave was in the PCC in the 1000–2000 msec interval, which provides some support to the idea that self-referential processing takes place in the PCC (Northoff et al., 2006; Northoff & Bermpohl, 2004). The topographical maps of the difference wave (Figure 6) provide further support; activity at 1.1, 1.3, 1.5, and 1.7 sec was greater on the midline scalp.

## Discussion

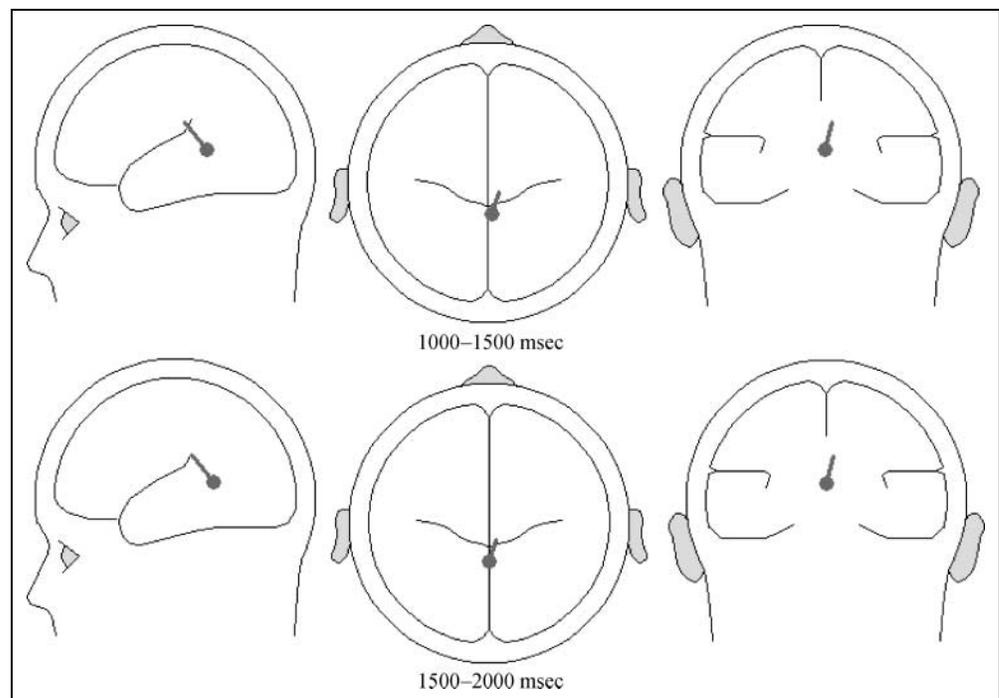
In this experiment, handwriting stimuli were presented for a longer time interval of 3000 msec, and the response took place after presentation. In terms of behavioral data, the response time was about 400 msec in both conditions, and the error rate was close to zero. These data suggest that the behavioral response was not directly related to self-referential processing and were not analyzed. The ERP

results, in contrast, replicated the results of Experiment 1. The waves elicited by both kinds of stimuli did not differ in the early N1 and P2 components, but differed from 200 to 500 msec and the *other* wave was more negative; however, the waves began to overlap at 500 msec. In addition, the two waves differed significantly from 1000 to 2000 msec, and the dipole analysis of the difference wave in this interval suggested a source in the PCC.

Neuroimaging research has shown that the PCC plays a role in integrating self-referential stimuli in the context of one's own person (Northoff et al., 2006; Northoff & Bermpohl, 2004). In terms of the results of Experiment 1, handwriting recognition would have been completed at about 500 msec; therefore, the waveforms in the 1000–2000 msec interval reflected processing after recognition of handwriting. While gazing silently at the handwriting, *own* handwriting evoked a more positive ERP wave. In general, the processing evoked by other handwriting would be more objective, such as evaluation of some stroke features. In addition to objective processing, *own* handwriting would evoke subjective processing. Therefore, the difference wave would reflect this subjective processing, and the dipole analysis for the difference wave showed that the PCC was activated in the 1000–2000 msec interval. These results suggest that this subjective processing may have involved the integration of various self-related information (Northoff & Bermpohl, 2004).

Previous research has shown that many kinds of self-referential tasks activate the PCC (Northoff & Bermpohl, 2004) and a common feature in these tasks is some integration in the context of personal traits (Fossati et al., 2003; Johnson et al., 2002). While gazing at the handwriting

**Figure 7.** Dipole models of the *other* – *own* difference waveforms over the intervals of 1000–1500 msec (top row) and 1500–2000 msec (bottom row). Both dipoles in these intervals were located in the PCC.



samples, some self-referential information may be activated by own handwriting; for example, how did I write these words, why do I always write in this way, why can I not change a bad writing style, and is my handwriting good. Although the information can be a bit chaotic, it is related to the self, and *own* handwriting is evaluated in the process. The integration of this information may involve the retrieval of self-referential data embedded in a rich context of personal information (Fink et al., 1996), such as the stroke features of own handwriting in this study. This may elicit retrieval of when and where own handwriting used to appear, how these words were written when the subject was in primary school, and other thoughts. Finally, a stronger emotional response may be evoked by own handwriting (Maddock, Garrett, & Buonocore, 2003; Greene & Haidt, 2002); for example, satisfaction or dissatisfaction with own handwriting and subsequent positive or negative emotion. This implicates the posterior CMS in putting self-referential stimuli within a temporal context by linking them to past self-referential stimuli.

## GENERAL DISCUSSION

### Comparison between Handwriting and Other Stimuli

Handwriting is a personal product that incorporates some personal information. One's own handwriting may be similar to one's own voice because the voice is also produced by the individual. Self voice has been used to explore the neural correlates of self-processing (Perrin et al., 2005; McGuire, Silbersweig, & Frith, 1996). However, hearing our own voice played back does not account for bone conductance, and therefore, a recording of our voice rarely sounds like our own voice heard from inside (Devue et al., 2007). Therefore, the self-information conveyed by voice is somewhat distorted. On the contrary, handwriting can convey more evident self-information, for the handwriting seen in everyday life is the same as that presented in the experiment. In addition, the information in voice is mainly physiologically related, such as frequency, amplitude, and tone quality. However, handwriting often consists of complex information, such as writing style, personality information, mental state, and so forth.

Handwriting is also comparable to facial stimuli. During the recognition of facial stimuli for social assessment, for example, a beautiful face would be likely to elicit positive emotions, but an ugly face would elicit negative emotions. According to the self-positivity bias of attributing outcomes to one's own characteristics (Pahl & Eiser, 2005; Mezulis, Abramson, Hyde, & Hankin, 2004; Heine, Lehman, Markus, & Kitayama, 1999), facial stimuli would elicit a complex self-related emotional response. Although some emotional response, such as that elicited in Experiment 2, can be evoked by handwriting, its intensity would be weaker with regard to social assessment.

Finally, handwriting can be compared with personality trait adjectives and autobiographical stimuli. When a trait adjective is associated with the self, an obvious self-reference effect would appear (Rogers et al., 1977), and autobiographical memory is thought to be central to the self (McAdams, 2001; Wheeler, Stuss, & Tulving, 1997). However, semantic elaboration and self-related processing are typically confounded in trait adjective tasks (Symons & Johnson, 1997). Also, autobiographical memory can be considered equivalent to episodic memory in that the remembered information is embedded in some spatio-temporal context in which it was originally experienced (Gillihan & Farah, 2005). On the contrary, the contributions of both semantic processing and episodic memory in handwriting recognition are weak (Knoblich & Flach, 2003; Knoblich et al., 2002). In the present study, recognition of handwriting was mainly based on its visual features. Thus, handwriting mainly evokes processing of the core self, including implicit self-processing.

### The Timing of Self-related Processing

In the present study, handwriting was used to explore the timing of self-referential processing for the first time. Because handwriting is most likely a mixture of culture and an individual's body and personality, the idea of Yang Xiong reminded also us that *own* handwriting may evoke processing of the so-called psychological or core self. Using novel stimuli and the high temporal resolution of ERPs, the temporal course of self-related processing has been explored. Dipole analysis of the difference wave was also conducted, and the results supplement the temporal data.

According to the present results, the self-referential processing evoked by handwriting may consist of the following stages or levels: encoding/retrieving self-related information, categorizing stimuli, and integrating self-related information. The first two stages involve cognitive processing, whereas the third stage involves an interaction of cognitive and emotional processing. Of course, this hypothesis requires more data, and future studies of ERPs (temporal information) plus fMRI (spatial information) may provide more details.

Through silently gazing at the stimuli for a longer time, more complex cognitive and emotional processing may be evoked by the self-referential stimuli following basic cognitive processing. This assumption was supported by the significant difference between two waves in the 1000–2000 msec interval and the corresponding dipole in the PCC. For shorting of the graphology analysis, subjects cannot explicitly read the personality information incorporated in their handwriting. The experimental results show that their responses to *own* handwriting are different from their response to the *other* condition, which implies that implicit self-related processing can be elicited by handwriting stimuli.

Since Freud, the implicit or unconscious aspects of the self have been widely recognized in psychology and philosophy (Northoff et al., 2006; Legrand, 2005; Knoblich & Flach, 2003); the results of the present study show that handwriting is a new stimulus for the investigation of implicit aspects of the self. The dipole for the difference wave in the interval of 1000–2000 msec poststimulus in Experiment 2 was located in the PCC, which is closely connected to the hippocampus (Northoff et al., 2006), and the hippocampus is associated with implicit processing (e.g., Degonda et al., 2005). Accordingly, the activation of the PCC implies that handwriting would elicit implicit self-related processing.

### Is Self-referential Processing Specific?

Whether the processing of the self is specific in the brain is a major question that Northoff et al. (2006), Gillihan and Farah (2005), and Northoff and Bermpohl (2004) have tried to address. Gillihan and Farah concluded that processing of some aspects of the physical self is specific, but for most aspects of the self, both physical and psychological, there is no good evidence that the self is specific. However, Northoff et al., as well as Northoff and Bermpohl, proposed that processing of the self is specific because self-referential processing is mediated by specific structures, the CMS.

In the present study, different brain structures correspond to different ERP time windows: the MTL in 250–300 msec, the ACC in 340–380 msec, and the PCC in 1000–2000 msec. Although these structures are dissociated, they are parts of the CMS as proposed by Northoff et al. (2006) and Northoff and Bermpohl (2004). In addition, sequential activation of these structures suggests that a different brain structure is involved in each stage of self-related processing. Accordingly, the results of the present study support that self-referential processing is specific. However, no specific brain structure, but a relatively interconnected network, including the MTL, ACC, and PCC, is involved in the processing of the self.

### Conclusion

In sum, the present ERP study showed the temporal course of self-referential processing. The results suggest that self-referential processing consists of several successive and distinct stages, with corresponding neural activity in the MTL, ACC, and PCC. These areas are part of the CMS, and thus these results are consistent with the assumption that the CMS form the anatomical basis of self-referential processing (Northoff et al., 2006; Northoff & Bermpohl, 2004). The differences between handwriting and other self-related stimuli allow the exploration of different aspects of self-referential processing, which will be valuable in future studies using other techniques such as fMRI.

### Acknowledgments

This work was supported by the National Natural Science Foundation of China (NSFC) #30700226, #30770727, #30525030, #60736029, and the 973 Project 2003CB716106.

Reprint requests should be sent to Hong Li, Key Laboratory of Cognition and Personality of Ministry of Education, Southwest University, Chongqing, China, 400715, or via e-mail: lihong@swu.edu.cn. Or to Dezhong Yao, School of Life Science and Technology, University of Electronic Science and Technology of China, Chengdu, China, 610054, or via e-mail: dyao@uestc.edu.cn.

### REFERENCES

- Berlad, I., & Pratt, H. (1995). P300 in response to the subject's own name. *Electroencephalography and Clinical Neurophysiology*, *96*, 472–474.
- Blakemore, S. J., & Frith, C. (2003). Self-awareness and action. *Current Opinion in Neurobiology*, *13*, 219–224.
- Botvinick, M., Cohen, J. D., & Carter, C. S. (2004). Conflict monitoring and anterior cingulate cortex: An update. *Trends in Cognitive Sciences*, *8*, 539–546.
- Bower, G. H., & Gilligan, S. G. (1979). Remembering information related to one's self. *Journal of Research in Personality*, *13*, 420–432.
- Craik, F. I. M., Moroz, T. M., Moscovitch, M., Stuss, D. T., Winocur, G., Tulving, E., et al. (1999). In search of the self: A positron emission tomography study. *Psychological Science*, *10*, 26–34.
- D'Argembeau, A., Collette, F., Van der Linden, M., Laureys, S., Del Fiore, G., Degueldre, C., et al. (2005). Self-referential reflective activity and its relationship with rest: A PET study. *Neuroimage*, *25*, 616–624.
- D'Argembeau, A., Ruby, P., Collette, F., Degueldre, C., Baetee, E., Luxen, A., et al. (2007). Distinct regions of the medial prefrontal cortex are associated with self-referential processing and perspective taking. *Journal of Cognitive Neuroscience*, *19*, 935–944.
- Degonda, N., Mondadori, C. R., Bosshardt, S., Schmidt, C. F., Boesiger, P., Nitsch, R. M., et al. (2005). Implicit associative learning engages the hippocampus and interacts with explicit associative learning. *Neuron*, *46*, 505–520.
- Devue, C., Collette, F., Baetee, E., Degueldre, C., Luxen, A., Maquet, P., et al. (2007). Here I am: The cortical correlates of visual self-recognition. *Brain Research*, *1143*, 169–182.
- Dolan, R. J., & Flecher, P. C. (1997). Dissociating prefrontal and hippocampal function in episodic memory encoding. *Nature*, *388*, 582–585.
- Farrer, C., & Frith, C. D. (2002). Experiencing oneself vs. another person as being the cause of an action: The neural correlates of the experience of agency. *Neuroimage*, *15*, 596–603.
- Ferguson, T. J., Rule, G. R., & Carlson, D. (1983). Memory for personally relevant information. *Journal of Personality and Social Psychology*, *44*, 251–261.
- Fink, G. R., Markowitsch, H. J., Reinkemeier, M., Bruckbauer, T., Kessler, J., & Heiss, W. D. (1996). Cerebral representation of one's own past: Neural networks involved in autobiographical memory. *Journal of Neuroscience*, *16*, 4275–4282.
- Fossati, P., Hevenor, S. J., Graham, S. J., Grady, C., Keightley, M. L., Craik, F., et al. (2003). In search of the emotional self: An fMRI study using positive and negative emotional words. *American Journal of Psychiatry*, *160*, 1938–1945.
- Fossati, P., Hevenor, S. J., Lepage, M., Grahama, S. J., Grady, C., Keightley, M. L., et al. (2004). Distributed self in episodic memory: Neural correlates of successful

- retrieval of self-encoded positive and negative personality traits. *Neuroimage*, *22*, 1596–1604.
- Gillihan, S. J., & Farah, M. J. (2005). Is self special? A critical review of evidence from experimental psychology and cognitive neuroscience. *Psychological Bulletin*, *131*, 76–97.
- Gray, H. M., Ambady, N., Lowenthal, W. T., & Deldin, P. (2004). P300 as an index of attention to self-relevant stimuli. *Journal of Experimental Social Psychology*, *40*, 216–224.
- Greene, J., & Haidt, J. (2002). How (and where) does moral judgment work? *Trends in Cognitive Sciences*, *6*, 517–523.
- Heatherton, T. F., Macrae, C. N., & Kelley, W. M. (2004). What the social brain sciences can tell us about the self. *Current Directions in Psychological Science*, *13*, 190–193.
- Heine, S. J., Lehman, D. R., Markus, H. R., & Kitayama, S. (1999). Is there a universal need for positive self-regard? *Psychological Review*, *106*, 766–794.
- Johnson, S. C., Baxter, L. C., Wilder, L. S., Pipe, J. G., Heiserman, J. E., & Prigatano, G. P. (2002). Neural correlates of self-reflection. *Brain*, *125*, 1808–1814.
- Johnston, K., Levin, H. M., Koval, M. J., & Everling, S. (2007). Top-down control-signal dynamics in anterior cingulate and prefrontal cortex neurons following task switching. *Neuron*, *53*, 453–462.
- Karayanidis, F., & Michie, P. T. (1996). Frontal processing negativity in a visual selective attention task. *Electroencephalography and Clinical Neurophysiology*, *99*, 38–56.
- Keenan, J. P., McCutcheon, B., Freund, S., Gallup, G. G., Sanders, G., & Pascual-Leone, A. (1999). Left hand advantage in a self-face recognition task. *Neuropsychologia*, *37*, 1421–1425.
- Keenan, J. P., Nelson, A., O'Connor, M., & Pascual-Leone, A. (2001). Self-recognition and the right hemisphere. *Nature*, *409*, 305.
- Kelley, W. M., Macrae, C. N., Wyland, C. L., Caglar, S., Inati, S., & Heatherton, T. F. (2002). Finding the self? An event-related fMRI study. *Journal of Cognitive Neuroscience*, *14*, 785–794.
- Kerns, J. G., Cohen, J. D., MacDonald, A. W., III, Cho, R. Y., Stenger, V. A., & Carter, C. S. (2004). Anterior cingulate conflict monitoring and adjustments in control. *Science*, *303*, 1023–1026.
- Klein, S. B., & Loftus, J. (1988). The nature of self-referent encoding: The contributions of elaborative and organizational processes. *Journal of Personality and Social Psychology*, *55*, 5–11.
- Klein, S. B., Rozendal, K., & Cosmides, L. (2002). A social-cognitive neuroscience analysis of the self. *Social Cognition*, *20*, 105–135.
- Knoblich, G., & Flach, R. (2003). Action identity: Evidence from self-recognition, prediction, and coordination. *Consciousness and Cognition*, *12*, 620–632.
- Knoblich, G., Seigerschmidt, E., Flach, R., & Prinz, W. (2002). Authorship effects in the prediction of handwriting strokes: Evidence for action simulation during action perception. *Quarterly Journal of Experimental Psychology*, *55*, 1027–1046.
- Legrand, D. (2005). Being a body. *Trends in Cognitive Sciences*, *9*, 413–414.
- Levine, B., Black, S. E., Cabeza, R., Sinden, M., McIntosh, A. R., Toth, J. P., et al. (1998). Episodic memory and the self in a case of isolated retrograde amnesia. *Brain*, *121*, 1951–1973.
- Lou, H. C., Luber, B., Crupain, M., Keenan, J. P., Nowak, M., Kjaer, T. W., et al. (2004). Parietal cortex and representation of the mental self. *Proceedings of the National Academy of Sciences, U.S.A.*, *101*, 6827–6832.
- Lewis, M. J., & Mooney, S. (2001). Examination performance and graphological analysis of students' handwriting. *Perceptual and Motor Skills*, *93*, 367–381.
- Macrae, C. N., Moran, J. M., Heatherton, T. F., Banfield, J. F., & Kelley, W. M. (2004). Medial prefrontal activity predicts memory for self. *Cerebral Cortex*, *14*, 647–654.
- Maddock, R. J., Garrett, A. S., & Buonocore, M. H. (2003). Posterior cingulate cortex activation by emotional words: fMRI evidence from a valence decision task. *Human Brain Mapping*, *18*, 30–41.
- McAdams, D. P. (2001). The psychology of life stories. *Review of General Psychology*, *5*, 100–122.
- McGuire, P. K., Silbersweig, D. A., & Frith, C. D. (1996). Functional neuroanatomy of verbal self-monitoring. *Brain*, *119*, 907–917.
- Mezulis, A. H., Abramson, L. Y., Hyde, J. S., & Hankin, B. L. (2004). Is there a universal positivity bias in attributions? A meta-analytic review of individual, developmental, and cultural differences in the self-serving attributional bias. *Psychological Bulletin*, *5*, 711–747.
- Michel, G. C. A., Trevor, D. P., & Kenneth, C. B. (2002). Event-related potentials reveal the effects of altering personal identity. *NeuroReport*, *13*, 1595–1598.
- Ninomiya, H., Onitsuka, T., Chen, C. H., Sato, E., & Tashiro, N. (1998). P300 in response to the subject's own face. *Psychiatry and Clinical Neurosciences*, *52*, 519–522.
- Northoff, G., & Bermpohl, F. (2004). Cortical midline structures and the self. *Trends in Cognitive Sciences*, *8*, 102–107.
- Northoff, G., Heinzel, A., Greck, M., Bermpohl, F., Dobrowolny, H., & Panksepp, J. (2006). Self-referential processing in our brain—A meta-analysis of imaging studies on the self. *Neuroimage*, *31*, 440–457.
- Pahl, S., & Eiser, J. R. (2005). Valence, comparison focus and self-positivity biases. Does it matter whether people judge positive or negative traits? *Experimental Psychology*, *52*, 303–310.
- Perrin, F., Maquet, P., Peigneux, P., Ruby, P., Degueldre, C., Baiteau, E., et al. (2005). Neural mechanisms involved in the detection of our first name: A combined ERPs and PET study. *Neuropsychologia*, *43*, 12–19.
- Ren, J., & Feng, X. (2001). Handwriting differentiation: A new interdisciplinary (in Chinese). *China Anti Counterfeiting*, *6*, 55–56.
- Rogers, T. B., Kuiper, N. A., & Kirker, W. S. (1977). Self-reference and the encoding of personal information. *Journal of Personality and Social Psychology*, *35*, 677–688.
- Symons, C. S., & Johnson, B. T. (1997). The self-reference effect in memory: A meta-analysis. *Psychological Bulletin*, *121*, 371–394.
- Turk, D. J., Heatherton, T. F., Kelley, W. M., Funnell, M. G., Gazzaniga, M. S., & Macrae, C. N. (2002). Mike or me? Self-recognition in a split-brain patient. *Nature Neuroscience*, *5*, 841–842.
- Uddin, L. Q., Iacoboni, M., Lange, C., & Keenan, J. P. (2007). The self and social cognition: The role of cortical midline structures and mirror neurons. *Trends in Cognitive Sciences*, *11*, 153–157.
- van Rooij, J. J. F., & Hazelzet, A. M. (1997). Graphologists' assessment of extraversion compared with assessment by means of a psychological test. *Perceptual and Motor Skills*, *85*, 919–928.
- Watson, L. A., Dritschel, B., Obonsawin, M. C., & Jentszsch, I. (2007). Seeing yourself in a positive light: Brain correlates of the self-positivity bias. *Brain Research*, doi:10.1016/j.brainres.2007.03.049.
- Wheeler, M. A., Stuss, D. T., & Tulving, E. (1997). Toward a theory of episodic memory: The frontal lobes and autoecic consciousness. *Psychological Bulletin*, *121*, 331–354.
- Zhou, D. W., & Tao, E. (2004). The effect of calligraphy theory and practice in the Chinese character development (in Chinese). *Journal of Changchun Teachers College*, *23*, 54–56.