Brain Research 1642 (2016) 287–297

Contents lists available at ScienceDirect

Brain Research

journal homepage: www.elsevier.com/locate/brainres

Research Report

Processing of self-related kinematic information embedded in static handwritten characters

Reiko Sawada [a,*,1], Hirokazu Doi [b], Nobuo Masataka [a]

[a] Primate Research Institute, Kyoto University, 41-2 Kanrin, Inuyama, Aichi 484-8506, Japan
[b] Graduate School of Biomedical Sciences, Nagasaki University, 1-12-4 Sakamoto-cho, Nagasaki 852-8523, Japan

ARTICLE INFO

Article history:
Received 2 August 2015
Received in revised form
15 February 2016
Accepted 24 March 2016
Available online 28 March 2016

Keywords:
Event-related potential
Handwritten character
Bodily self-processing
Self-referential processing

ABSTRACT

Handwritten characters are generated by our own motor actions, and previous studies have shown that the manner in which such characters are perceived and generated is related. However, the temporal course of the neural activation involved in the processing of self-related kinematic information embedded in static handwritten characters remains to be identified. We applied event-related potential (ERP) recording while participants judged whether handwritten characters were self- or non-self-generated. To test the effects of the self-related kinematic characteristics of static handwritten characters, we conducted two experiments in which the styles or familiarity of characters were manipulated. The ERP results indicated differences in brain activation between self- and non-self-written characters for the P250 component (250–350 ms after stimulus onset) in right posterior regions and for the late positive component (LPC; 350–500 ms after stimulus onset) in anterior midline regions; this was the case even when the handwritten characters were not generated in their usual form or were written for the first time. Therefore, our data indicate that self-information embedded in handwritten characters involves both right-lateralized brain activation associated with bodily self-processing and anterior midline brain activation related to self-referential processing.

1. Introduction

Handwritten characters are generated by human motor actions (i.e., writing), and even the same character may differ among individuals in terms of kinematic characteristics, such as the shape of trajectories, stroke order, speed, and pressure. Moreover, individualized self-related kinematic information embedded in static handwritten characters enables us to easily discriminate our own handwriting from that of others.

Previous studies have indicated that such kinematic information contributes to the perception of handwritten characters. Behavioral studies have found a qualitative difference between the recognition of handwritten versus printed characters (Williams, 1984) and have demonstrated that individuals can extract kinematic information from static handwritten characters (Babcock and Freyd, 1988). Neuroimaging studies have also shown differences in the visual processing of handwritten and printed characters; the processing of handwritten characters is associated with the primary motor cortex (Longcamp et al., 2011) and right ventral occipito-temporal cortex (Barton et al., 2010; Qiao et al., 2010). These studies have indicated that the manner in which static characters are produced modulates their subsequent visual processing.

An increasing number of studies have demonstrated that visual processing of the bodily self, including the face and body, preferentially involves the right hemisphere. Behavioral studies have shown a left-hand advantage in response to the self-face (Keenan et al., 1999; Keenan et al., 2000; Platek et al., 2004). These results support the notion of right hemispheric dominance during self-face processing, which is in accordance with contralateral motor control. Furthermore, neuroimaging studies have shown that the major regions involved in self-face processing (Kaplan et al., 2008; Ma and Han, 2012; Uddin et al., 2005; however, see Sugiura, 2015) and self-body processing (Hodzic et al., 2009; Myers and Sowden, 2008) are the right frontal and parietal areas. Moreover, in addition to the self-body, the products of self-generated motor actions may also induce right-lateralized brain activation. For example, behavioral and neuroimaging studies indicate preferential involvement of the right hemisphere during the processing of one's own voice (Kaplan et al., 2008; Nakamura et al., 2001; Rosa et al., 2008).

* Corresponding author.
E-mail address: sawada.reiko.3z@kyoto-u.ac.jp (R. Sawada).
[1] Present address: Reiko Sawada is now at Graduate School of Medicine, Kyoto University, 53 Shogoin-Kawaharacho, Sakyo, Kyoto 606-8507, Japan, and Organization for Promoting Neurodevelopmental Disorder Research, 40 Shogoin-Sannoucho, Sakyo, Kyoto, 606-8392, Japan.

http://dx.doi.org/10.1016/j.brainres.2016.03.039
0006-8993/

Electrophysiological studies, which allow for high time-resolution measurements, have provided information on the temporal features involved in bodily self-processing. Several event-related potential (ERP) components exhibit differences with respect to the processing of self- versus non-self bodily stimuli. First, for the N170 component, a study found that negative deflections occurring around 170 ms after stimulus onset at posterior regions, reflecting structural encoding processing (Bentin and Deouell, 2000), were greater for self-face than for non-self-faces (Keyes et al., 2010). However, several studies did not find differences in N170 amplitude between self- and non-self-faces (Caharel et al., 2002; Caharel et al., 2005), rendering the sensitivity of the N170 component to self-processing ambiguous. Second, for the P250 component, positive deflections occurring around 250–350 ms post-stimulus at posterior sites, which are associated with the activation of stored structural representations in memory, were found to be smaller for self-face compared with non-self-faces (Caharel et al., 2002). The results were interpreted as demonstrating that self-faces demand a smaller perceptual load than non-self-faces with respect to retrieval from and access to stored structural representations, whereas non-self faces require a more extensive memory search (Caharel et al., 2002; Caharel et al., 2005), which is consistent with the hypotheses that long-term experience of faces enhances their representation in memory and that their visual processing demands fewer attentional resources (Tong and Nakayama, 1999). Third, the late positive potential after 350–500 ms (late positive component; LPC) in anterior midline regions is greater for self- versus non-self-related stimuli. A previous study reported a greater LPC for one's own hands than those of others (Su et al., 2010). Similarly, several studies have shown that psychological self-processing modulates LPC amplitude (e.g., self-appraisal: Luo et al., 2010). Therefore, the LPC in anterior midline regions appears not only to relate to bodily self-processing but also to reflect the self-referential processing involved in the judgment of whether stimuli are self- or non-self-relevant (i.e., authorship judgment).

Several recent electrophysiological studies regarding the self-processing of static handwritten characters have revealed the temporal features of brain activation. Wamain et al. (2012) demonstrated differences between self- and non-self-written characters in the ERPs in right posterior regions that peak approximately 300 ms after stimulus onset. This suggests that the processing of self-generated handwritten characters is related to right-lateralized bodily self-processing. Moreover, Chen et al. (2008) reported differences in positive deflections in anterior midline regions at a time window of 360–440 ms in response to the recognition of self- versus non-self-written characters, suggesting that this component reflects self-referential processing during authorship judgments. Taken together, these data indicate that visual processing of the self-related information embedded in static handwritten characters may modulate the P250 component in right posterior regions in addition to the LPC in anterior midline regions.

People generally have more opportunities to observe their own handwritten characters than those of others, suggesting that extensive experience of observing one's own handwritten characters results in the representation of self-related information associated with handwritten characters. On the other hand, in the domain of dynamic handwriting perception, previous studies have shown that people can distinguish their own handwriting from the handwriting of others when the shapes are both familiar and unfamiliar (Knoblich and Prinz, 2001). This suggests that it is the experience of the action of self-generated writing, and not the specific shape of the trajectories, that is involved in the construction of self-kinematic representations in memory. Thus, it remains unclear whether the ERP responses to self-generated handwritten characters found in previous studies (Chen et al., 2008; Wamain et al., 2012) depended on stored representations developed through the experience of observing the particular shapes of self-handwritten characters, or whether the ERP responses were induced by stored representations developed through self-related kinematic characteristics (i.e., the writing action itself).

In the present study, we conducted ERP experiments in which participants judged whether a presented character was self-generated or non-self-generated, with the aim of investigating the temporal features of the neural correlates underlying the processing of self-generated visual patterns. Two approaches were adopted to delineate the effects of visual experience and self-kinematic information on ERP responses to handwritten characters. In the first approach (experiment 1), the degree of stylization of characters was manipulated. There were two conditions: the freestyle condition, in which participants wrote characters in their habitual style, and the stylized condition, in which they wrote characters in strict adherence to a specific model. Under the freestyle condition, responses to self- and non-self-generated handwritten characters differed with respect to both the degree of experience in observing the handwritten characters and the availability of self-related kinematic information. In contrast, under the stylized condition, participants had had little opportunity to observe their own handwritten characters, and the shapes of the trajectories of the self- and non-self-written characters were almost the same. Thus, the stylized condition equalized (at least to an approximate degree) the experience of observing self- and non-self-written characters, while maintaining a contrast in the availability of kinematic information between self- and non-self-written characters. If the differences in ERP responses shown in previous studies (Chen et al., 2008; Wamain et al., 2012) originated from self-related kinematic information *per se*, rather than from greater experience with observing self-specific character shapes relative to non-self-written characters, then self-related ERP modulations for stylized characters as well as for freely-written ones should be evident.

In the second approach (experiment 2), the familiarity of characters was manipulated across two conditions, the familiar and unfamiliar conditions. Under the familiar condition, stimuli were chosen from among characters that participants used frequently in their daily lives. In contrast, under the unfamiliar condition, stimuli were characters that they had never used before. Thus, with respect to the unknown characters, participants had virtually equal amounts of experience (i.e., none) in observing their own handwritten characters and those generated by someone else. If self-related kinematic representations are developed through the writing action itself, rather than through experience of observing the characters, ERP differences between self-written characters and those generated by someone else should be found under both the familiar and unfamiliar conditions.

In accordance with the aforementioned ERP studies (e.g., Caharel et al., 2002; Chen et al., 2008; Wamain et al., 2012), we analyzed ERPs between 140–210 ms (N170) and 250–350 ms (P250) in posterior regions and those after 350–500 ms (LPC) in anterior midline regions to clarify the self-related processing of static handwritten characters. Additionally, ERPs of 100–140 ms (P100) at occipital sites were also analyzed to assess the effect of the perceptual aspects of stimuli, such as their size, brightness, and contrast (Allison et al., 1999); we expected that self-related processing would not be associated with these basic visual features. We predicted that (1) self-processing of static handwritten characters would enhance the right-lateral posterior activity of the P250 component related to bodily self-processing; (2) correct judgments for self- versus non-self-stimuli would enhance the anterior midline activities of the LPC related to self-referential