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Electrophysiological evidence of facial inversion with rapid serial visual presentation

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ABSTRACT

Using measurements of event-related potentials (ERPs) during a facial recognition task, we aimed to investigate the facial inversion effect and the role of time-based attention in processing upright and inverted faces. We presented upright and inverted faces at the T2 (target 2) position using a rapid serial visual presentation paradigm. Our results indicate that the N170 component shows the usual face inversion effect (FIE), in which inverted faces elicit larger N170 amplitudes and a longer elicit N170 latency. We also found that upright faces elicit larger P1 amplitudes than inverted faces over the left hemisphere. This study indicates that the N170 and P3, but not the P1, components are modulated by time-based attention. In addition, we found that the N170 amplitude was modulated by an attentional blink (AB) based on behavioral data. These results suggest that the disruption of facial configuration processing caused by inverted faces is relatively independent of attentional resources.

1. Introduction

Previous studies have indicated that most objects are more difficult to recognize when inverted than upright, and this effect is much more pronounced for faces than for other objects (Yin, 1969). Many studies involving event-related potentials (ERPs) and magnetoencephalograms (MEGs) have indicated that the N170 (M170) component displays a longer latency and a larger amplitude in response to inverted compared to upright faces (Bentin et al., 1996; de Haan et al., 2002; Eimer, 2000; Itier and Taylor, 2002, 2004a,c; Jemel et al., 2009; Linkenkaer-Hansen et al., 1998; Rossion et al., 1999, 2000; Schweinberger et al., 2007; Taylor et al., 2001; Webb et al., 2012). This phenomenon is known as the face inversion effect (FIE) and is thought to reflect the disruption of facial configuration processing by the inversion. The spatial relationships among the different parts of the face, known collectively as configural information, play an important role in the processing of faces.

Prior ERP and MEG studies (Itier and Taylor, 2002; Krusemark and Li, 2011; Linkenkaer-Hansen et al., 1998; Liu et al., 2002; Pizzagalli et al., 2002) have also found that the P1 (M100) component is related to facial categorization, facial emotion processing, and facial inversion. However, some researchers have argued for the existence of an FIE in the P1 component. These investigators have suggested that facial inversion can modulate the P1 (M100) component because inverted faces elicit a larger P1 amplitude and a longer P1 latency than upright faces (Itier and Taylor, 2004a,c; Jacques et al., 2007; Linkenkaer-Hansen et al., 1998; Webb et al., 2012). However, other studies have not found a significant difference in the P1 component between inverted and upright faces (Honda et al., 2007; Itier and Taylor, 2002, 2004b; Itier et al., 2004; Jacques and Rossion, 2007a; Jemel et al., 2009; Rossion et al., 1999). One reason for this lack of P1 inversion effects in previous studies (Jacques and Rossion, 2007a; Jemel et al., 2009) may be the choice of electrodes analyzed.

The source of the N170 component remains controversial. Some studies have suggested that the superior temporal sulcus (STS) area produces this ERP component (Batty and Taylor, 2003; Henson et al., 2003; Itier et al., 2006; Itier and Taylor, 2004d), while others have indicated the fusiform gyrus (FG) is a more likely source (Deffke et al., 2007; Rossion et al., 2003; Shibata et al., 2002). In a 2009 review, Itier and Batty (2009) hypothesized that cells that are selective for the processing of faces and eyes reside in the FG and STS regions and that both regions contribute to the generation of the N170 (M170) component. Although previous studies

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have also found that the M170 recorded in response to the presentation of faces originates from the FG and inferior occipital gyri (IOG), which is also referred to as the occipital face area (OFA) (Itier et al., 2006), a transcranial magnetic stimulation (TMS) study that examined the latency with which the occipital face area contributes to facial processing found that TMS pulses administered to the OFA disrupt facial discrimination abilities 60–100 ms following the onset of the stimulus (Pitcher et al., 2007). This study suggests that facial selectivity in the OFA may be associated with earlier face-selective ERPs, such as the P1 component. Another recent study suggested that activity in the mid-fusiform gyrus (MFG), also known as the fusiform face area (FFA), and the STS is highly correlated with the face-selective N170 component and that activity in the OFA is highly correlated with the P1 component (Sadeh et al., 2010).

Several studies have investigated the relationship between attention and facial processing. For example, Mohamed et al. (2009) found that the N170 component was strongly dependent upon selective attention processes: it was shown that the face-elicited N170 is reduced under high perceptual load conditions, while the N170 elicited in response to pictures of houses is increased under high perceptual load conditions. It has also been suggested that the N170 component is sensitive to object-based selective attention. In addition, Jacques and Rossion (2007b) have indicated that the N170 may be sensitive to spatial attention. The rapid serial visual presentation (RSVP) paradigm has been used to examine the temporal characteristics of perceptual and attentional processes. In particular, researchers have used single-task versus dual-task RSVP paradigms to compare the demand on attentional resources under different conditions, as the dual version of the task requires more attention, and thus, when subjects are attentionally challenged, they show a poorer performance in the dual-task RSVP paradigm relative to the single-task RSVP paradigm. This performance dissociation has been attributed to a *limited attention capacity* or a *bottleneck effect*. An important demonstrable example of a limited attention capacity affecting behavioral performance is the so-called attentional blink (AB) effect described by Raymond et al. (1992). In the dual-task RSVP paradigm, when there was a stimulus onset asynchrony (SOA) between the first (T1) and second (T2) stimulus presentations of 200–500 ms, Raymond et al. (1992) showed that correct detection of T1 impaired the subsequent detection of T2. The AB effect has been observed for letters, digits, artificial symbols, scenes, and other naturalistic stimuli (Evans and Treisman, 2005; Raymond et al., 1992). Previous studies (Einhäuser et al., 2007; Jackson and Raymond, 2006) have also detected the AB effect when the T2 stimuli consisted of faces. Some researchers (Awh et al., 2004; Landau and Bentin, 2008) have reported an absence of an AB effect when the T2 stimuli were faces, but the T1 stimuli were non-face objects. However, there is controversy regarding whether one can still refer to an AB effect for faces when the T1 stimuli are non-face objects.

The first goal of the present study was to examine the relationship between attention resources and facial configural processing. Because facial inversion appears to disrupt facial configuration processing, as discussed above, we will examine whether facial inversion affects the relationship between facial configural processing and attention resources. Mohamed et al. (2011) found that the FIE on the N170 persists under both high and low perceptual load conditions, suggesting that the disruption of facial configural processing due to inversion should be independent of attentional resources. Thus, we expect to see an usual N170 inversion effect, irrespective of attention resources.

The second goal of this study was to determine which stage(s) of facial processing – i.e., encoding and/or recognition – is sensitive to shifts in attention resources under the RSVP paradigm. The N170 component is usually a good index of facial encoding (Itier and Taylor, 2004b), and previous work (Mohamed et al., 2009) has suggested that the face-elicited N170 is dampened under high perceptual load conditions. The later components (e.g., P3) may reflect the recognition stage of facial processing. Indeed, the P3 component elicited by facial expression processing can be modulated by attention (Luo et al., 2010), and the amplitude of P3 appears to be sensitive to the allocation of processing resources (Kok, 2001). Both the dual-task and short-lag conditions of the RSVP paradigm are thought to reveal deficiencies in attentional resources. Therefore, we predict that we will find evidence supporting the notion that both the encoding and recognition stages are modulated by attention resources.

The third goal of this study was to determine whether there is an AB effect when the T2 stimuli consist of images of faces, while the T1 stimuli are images of non-face objects. If the AB effect emerges for both upright and inverted faces, it will suggest that facial processing is not a completely automatic process and that there is not a complete face immunity effect. Given that the AB effect is considered to be a reflection of perceptual bottlenecking (Raymond et al., 1992) and because the N170 component is an index of facial perceptual encoding (Rossion et al., 2004), we expect to find evidence of an AB effect in the N170 component, fitting the behavioral effect.

2. Materials and methods

2.1. Subjects

Fifteen undergraduates (eight women, seven men, aged 18–23 years, with a mean age of 19.1 years) from the Southwest University in China participated as paid subjects in the current study. All participants were healthy, right-handed, and had normal or corrected-to-normal vision. The participants gave written informed consent to participate in the study, and the experiment was conducted in accordance with the Declaration of Helsinki.

2.2. Stimuli

Pictures of faces from the native Chinese Facial Affective Picture System (CFAPS), consisting of four different neutral female facial images (two upright and two inverted), were used. Fourteen upright pictures of birds were also employed: 12 of the images were black and white, while the other two were red. All of the pictures were similar in terms of their size, spatial frequency, contrast grade, and brightness. All of the female faces retained interior characteristics. Every picture was cropped into the shape of an ellipse using Adobe Photoshop 8.0 software. The viewing angle was $5.7^{\circ} \times 4.6^{\circ}$, and the screen resolution was 72 pixels per in. The subjects were seated in a sound-proof room with their eyes positioned approximately 100 cm from a 17-in. screen. All stimuli were displayed in the center of the screen.

2.3. Procedure

The experimental procedure was programmed using the E-Prime 1.2 software package (Psychology Software Tools Inc., Pittsburgh, PA, USA). At the beginning of the experiment, a white fixation point and a blue fixation point appeared successively in the center of the screen and remained for 500 ms and 300 ms, respectively. Shortly thereafter, 14 pictures of distracting and target stimuli were displayed, each of which was visible for 100 ms. The distractive stimuli consisted of 12 black and white pictures of birds. The T1 stimulus was one of the two pictures of a red bird, each of which had an equal probability of occurrence. The T2 stimulus was one of the four pictures of either an upright or an inverted face, each of which again had an equal probability of the occurrence. The T1 stimulus appeared randomly, with an equal probability of appearing in the third, fourth, or fifth position of the picture series. The T2 stimulus also appeared randomly, and occurred with equal probability in the third (lag 3) or sixth (lag 6) picture position following the T1 stimulus. After this RSVP sequence, the subjects were asked a single two-alternative-forced-choice (2-AFC) question regarding T1, in which they had to select one bird from two choices. They were also presented with a five-alternative-forced-choice (5-AFC) question for T2 (Fig. 1), in which they were asked to indicate which upright or inverted face they had seen, or whether they had seen nothing in the preceding RSVP sequence.

In the single task, the subjects were presented with a question regarding T2. In the dual task, they were presented with a question about T1 and a question about T2. The subjects were asked to make the most accurate judgment possible. There was no time limit for the subjects to indicate their responses. The pictures disappeared when the subject indicated his or her response by pressing a button. The next picture series began after a 500 ms period during which the screen was black (Fig. 1).