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Electrophysiological responses in mothers to their own and unfamiliar child's gaze information

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ABSTRACT

An attachment bond between a mother and her child is one of the most intimate human relationships. It is important for a mother to be sensitive to her child's gaze direction because exchanging gaze information plays a vital role in their relationship. Furthermore, recent studies have revealed differential neural activation patterns in mothers when presented the faces of their own children or the unfamiliar child of other people. Based on these findings, in the present study, we investigated whether mothers show differential neural responses to gaze information of their own child compared to that of an unfamiliar child. To this end, event-related-potentials elicited by the faces of one's own or an unfamiliar child with straight or averted gaze directions were measured using an oddball-paradigm. The results showed that peak amplitudes of the N170 component were enlarged by viewing the straight gazes compared to the averted gazes of one's own child, but not of an unfamiliar child. When the gaze was directed straight, the P3 amplitude elicited by one's own child's face is smaller than that elicited by an unfamiliar child's face. P3s elicited in viewing one's own child's face with averted gaze and in viewing an unfamiliar child's face with straight gaze were positively correlated with state-anxiety. These results bolster the hypothesis that processing the gaze information of one's own child elicits differential neural activation compared to the gaze information of an other person's unfamiliar child at both perceptual and evaluative stages of face processing.

1. Introduction

The mother-child relationship is one of the most intimate types of human relationship (Fisher, Aron, Mashek, Li, & Brown, 2002; Leibenluft, Gobbini, Harrison, & Haxby, 2004; Strathearn, Fonagy, Amico, & Montague, 2009), as evidenced by the huge investment mothers expend in child-rearing activities (Mayes, Swain, & Leckman, 2005). There is good reason for mothers to be attentive to their child's gaze direction information throughout development, because developmental studies indicate that the establishment of mutual gaze and a mother's attentiveness to their child's attentional focus play critical roles in each stage of development (Hains & Muir, 1996; Hunnius & Geuze, 2004). During the neonatal period, mother and infant pairs frequently show episodes of temporally-synchronized behavioral patterns (Tronick & Cohn, 1989), the emergence and maintenance of which is considered to serve as an important scaffolding for the development of affective attachment (Feldman, 2007a, 2007b). Interestingly, such behavioral synchrony scarcely occurs when either the mother or her infant is not paying attention to each other. Some authors have interpreted this finding as indicating that mutual gaze is a prerequisite for the development of affective attachment (de Graag, Cox, Hasselman, Jansen, & de Weerth, 2012; Feldman, 2007a). During toddlerhood, children learn the instrumental value of gaze direction as communicative signals and gain the ability to use their own gaze as way of engaging others in cooperative behavior (Warneken, Chen, & Tomasello, 2006). Therefore, it becomes all the more important for mothers to monitor their children's gaze as they develop. Likewise, mothers use various strategies to regulate the focus of their child's attention, and establish joint attention in a triadic context (Laakso, Poikkeus, Eklund, & Lyytinen, 1999; Landry, Garner, Swank, & Baldwin, 1996), which consequently facilitates the development of child's play skills and language comprehension (Ereky-Stevens, 2008; Laakso et al., 1999; Sung & Hsu, 2009). On the basis of these, it can fairly be said that the exchange of mutual gaze remains one of the main channels of social communication throughout childhood.

Another line of research indicates that the neural activation elicited in mothers by their own children's affective expressions differ from those elicited by unfamiliar children's expressions (for a review, see Swain, Lorberbaum, Kose, & Strathearn, 2007). Several functional magnetic resonance imaging (fMRI) studies have revealed that increased neural activation is elicited when mothers view their own child's face (compared with other infant's faces) in

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subcortical regions linked to reward-processing (striatum, nucleus accumbens, putamen, periaguaductal-gray; Bartels & Zeki, 2004; Noriuchi, Kikuchi, & Senoo, 2008; Ranote et al., 2004) and parental behavior (midbrain, pituitary gland; Bartels & Zeki, 2004; Strathearn et al., 2009). These findings indicate that a mother's own child's face effectively triggers parental instinct (Glocker et al., 2009a, 2009b). Likewise, the face of a mother's own child has been found to induce strong emotion in mothers, compared with the faces of unfamiliar children, with several studies reporting increased activation in emotion-related brain regions such as the orbitofrontal cortex, insula, and anterior cingulate cortex (Bartels & Zeki, 2004; Nitschke, Nelson, Rusch, Fox, Oakes & Davidson, 2004; Leibenluft et al., 2004). Some studies have also indicated that mothers process their own child's face more efficiently than the other types of facial stimuli. Support for this claim comes from fMRI studies showing increased neural activation in mothers in response to their own child's face in brain areas related to visual processing, such as occipital visual areas, fusiform gyrus, and superior temporal sulcus (Bartels & Zeki, 2004; Leibenluft et al., 2004; Ranote et al., 2004). Additionally, a recent electrophysiological study by Grasso, Moser, Dozier, and Simons (2009) revealed that a mother's own child's face elicited differential event-related potential (ERP) responses compared with other children's faces, or familiar adult's faces, as early as 250–350 ms after stimulus onset. This finding indicates that prioritized processing of a mother's own child's face begins at the initial stages of visual processing.

Developmental studies have consistently indicated the importance of mothers monitoring and regulating their child's gaze direction. Furthermore, recent fMRI and electrophysiological studies have revealed that mothers process their own child's face differently from those of an unfamiliar child's. These findings suggest the possibility that mothers process the gaze direction information of their own child differently from that of unfamiliar children. However, to the best of our knowledge, no systematic research has been undertaken to test this hypothesis. The primary aim of the present study is to investigate whether mothers show differential neural responses to gaze information from their own child compared with that from an unfamiliar child. To this end, we measured neural activation elicited in mothers by the faces of their own and unfamiliar children exhibiting straight or averted gazes. Specifically, we used an oddball paradigm, and measured ERPs elicited by low-frequency target faces of their own and unfamiliar children exhibiting straight and averted gazes, embedded within a train of distractor faces with their eyes closed. To control for the stimulus attributes of the facial stimuli, we adopted a yoked design (Roye, Jacobsen, & Schröger, 2007; Roye, Schröger, Jacobsen, & Gruber, 2010) in which every participant was paired with another and presented with a picture of her counterpart's child, which served as the picture of an unfamiliar child. The strength of this design is that it ensures that the same set of facial stimuli is presented across the comparison conditions. A similar stimulus-presentation design was previously used successfully to compare the neural activation elicited by emotional expressions of a mother's own child and an unfamiliar child (Nitschke et al., 2004; Strathearn et al., 2009).

It is difficult to disentangle the effects of familiarity and personal relationship just by comparing ERPs elicited by a mother's own child's face and an unfamiliar child's faces. One potential way to resolve this issue is to include faces of familiar but non-kin children as a control. However, as Grasso et al. (2009) have correctly pointed out, it is quite difficult to find an acquaintance with whom the participant has spent roughly the same length of time as she did with her own child. Typical mother/child pairs spend an extremely long time in close proximity with each other (Doi, Kato, Nishitani, & Shinohara, 2011). Taking "mere exposure effect" (Zajonc, 1968) into consideration, the resultant high familiarity itself may constitute an important aspect of the strong affection of mothers towards their child, which further indicates that the special status of own child's face and its high familiarity for his/her mother are inherently inseparable. On the basis of these considerations, we did not include a control condition for facial familiarity in the present study. Comparison between ERPs to mother's own and an unfamiliar child's faces without control for facial familiarity makes it harder to identify the emotional or social responses of a mother specific to her own child's face, but, still can give us valuable information regarding the nature of maternal responses to her own child's communicative signals.

We chose to use ERP measurement in the present study, because its high temporal resolution allows for the examination of the effects of facial identity at each processing stage of gaze direction discrimination. Majority of existing studies on neural responses in mothers to their own and other's unfamiliar child's facial information has utilized fMRI technique, which suffers from low-temporal resolution. Thus, little is known about the temporal course of the processing of their own child's face in mothers. Because it bears great importance for mothers to rapidly detect their children's communicative signals in order to take appropriate caregiving behaviors (Grasso et al., 2009), it seems indispensable to elucidate the temporal course of mother's neural responses to her own child's gaze information in clarifying the specialization of maternal brain.

Electrophysiological studies on face processing have succeeded in dissecting facial processing into several dissociable stages. The presentation of face stimuli has been found to induce a prominent positivity, referred to as the P1, recorded at occipital electrodes approximately 80–120 ms after stimulus onset. The P1 is widely believed to reflect visual cortex processing of low-level visual features such as luminance and contrast. However, several studies indicate that the P1 may also be sensitive to face-specific information (Doi, Sawada, & Masataka, 2007; Doi, Ueda, & Shinohara, 2009a, 2009b; Herrmann, Ehlis, Ellgring, & Fallgatter, 2005; Linkenkaer-Hansen et al., 1998; Taylor, 2002). For example, Herrmann et al. (2005) reported that faces elicit a larger P1 than non-face control stimuli. With regard to gaze direction perception, Doi et al. (2007) measured ERPs while participants performed a left/right discrimination of averted gaze. The results revealed that P1 latency was delayed by inverting the eyes of the face stimulus, indicating that the P1 partially reflects the face-specific processing responsible for the face inversion effect.

Following the P1 component, a negativity referred to as the N170 is typically observed over occipito-temporal sites. It is widely accepted that the N170 reflects structural encoding processes related to face processing (Bentin, Allison, Puce, Perez, & McCarthy, 1996; Eimer, 2000a, 2000b; Rossion et al., 1999), in which the spatial relationships among facial parts are analyzed in a holistic manner (Maurer, Le Grand, & Mondloch, 2002). The neural generator of the N170 component is located in the ventral occipito-temporal cortex (Bötzel, Schulze, & Stodieck, 1995, but see Itier & Taylor, 2004). Although there is some controversy regarding the sensitivity of the N170 to facial information other than face configuration (Eimer, 2000a, 2000b; Jemel, Pisani, Calabria, Crommelinck, & Bruyer, 2003), previous studies have reported that the N170 can be modulated by facial familiarity information (Caharel, Courtay, Bernard, Lalonde, & Rebai, 2005; Caharel, Fiori, Bernard, Lalonde, & Rebai, 2006). For example, Caharel et al. (2005) have revealed larger N170 to faces of personally familiar persons than to unfamiliar ones. Furthermore, a number of previous studies have shown that N170 amplitude is increased for emotional faces, particularly those with threatening qualities, such as fearful and angry expressions (Batty & Taylor, 2003; Leppänen, Moulson, Vogel-Farley & Nelson, 2007; Williams, Palmer, Liddell, Song, & Gordon, 2006). Taken together, these findings indicate that the N170 reflects processing