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Event-related potentials elicited in mothers by their own and unfamiliar infants' faces with crying and smiling expression

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ABSTRACT

Crying by an infant signals an urgent desire for care and protection. Because of the special relationship between a mother and her infant and the signal value of her crying, it is plausible to suggest that the maternal brain efficiently processes crying by infants. In the present study, we examined this hypothesis by measuring event-related potentials in mothers while they observed crying or smiling by their own or unfamiliar infants embedded within a train of neutral expressions. We found that the amplitude of the face-specific N170 component was enlarged for crying regardless of familiarity. The P300 component, which reflects a later cognitive evaluation stage of stimulus processing, was decomposed into functionally distinct components by temporal principal component analysis. The amplitude of the third temporal factor, which corresponds to the earliest portion of the P300, was larger when a mother observed her own infant crying than for the other conditions. Moreover, onset latency of P300 was shortest when mothers observed their own infant crying. These results indicate that mothers process their own infant's crying more efficiently than smiling by their own infant or crying by an unfamiliar infant.

1. Introduction

Crying is one form of attachment behavior, and the auditory and visual signals accompanying crying elicit empathy and motivation to relieve the discomfort of the infant (Hendriks & Vingerhoets, 2006; Hendriks, Van Boxtel, & Vingerhoets, 2007; Spangler, Emlinger, Meinhardt, & Hamm, 2001). Crying plays a prominent role in the relationship between mothers and infants, especially at the non-verbal stage (Acebo & Thoman, 1995). An infant's crying signals an urgent need for care and protection, which makes it of primary importance for mothers to direct their attention efficiently toward their infant's crying cues. Attentiveness to infant crying together with the ensuing care-taking and protecting behaviors ultimately increases the odds of an off-spring's survival (Hahn-Holbrook, Holbrook, & Haselton, 2011). Therefore, throughout the evolutionary history of mankind, it has been quite advantageous for humans to be endowed with mechanisms that allow for efficient response to the crying of their infants.

In the sense that an infant's crying signals discomfort, a crying face can be regarded as one type of negative expressions. On this basis, it could be predicted that the processing of crying is partly subserved by neural mechanisms that are also recruited in the processing of negative expressions. The human visual system is quite efficient at detecting negative information (Cuthbert, Schupp, Bradley, Birbaumer, & Lang, 2000; Eimer & Holmes, 2002; Olofsson, Nordin, Sequeira, & Polich, 2008). This *negativity bias* (Ito, Larsen, Smith, & Cacioppo, 1998) extends to the domain of social cognition, with negative expressions inducing stronger and more efficient behavioral and neural responses than positive ones. At the same time, previous studies on crying indicate that a crying face, especially the crying face of an infant, is distinguishable from other negative expressions by the behavioral and neural responses to this stimulus (Noriuchi, Kikuchi, & Senoo, 2008; Strathearn, Fonagy, Amico, & Montague, 2009; Spangler et al., 2001). Therefore, simple extrapolations of findings based on negative facial expressions are not sufficient to unravel the neural mechanisms of processing crying. However, there is a paucity of studies that have examined the crying-related perceptual mechanisms.

In exploring the neural mechanism of the processing of attachment-related behavior such as crying, it is important to examine the influence of identity or familiarity. Because the attachment bond between mother and child is presumably one of the most intimate and personal of human relationships (Ainsworth, Blehar, Waters, & Wall, 1978; Bowlby, 1969), mothers often deem their own child irreplaceable. Considering the special status of her own infant for a mother (Bartels & Zeki, 2004; Grasso, Moser, Dozier, & Simons, 2009; Leibenluft, Gobbini, Harrison, & Haxby, 2004; Nitschke et al., 2004; Noriuchi et al., 2008), together with the fact that an infant's crying signals an urgent need for care and protection (Acebo & Thoman, 1995), we hypothesized that a mother's

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processing of her own infant's crying takes precedence over the processing of other types of facial expressions. However, few studies to date have empirically examined this hypothesis. Several previous studies using fMRI compared neural activations in mothers when viewing their own or an unfamiliar infant's expressions. However, most of these studies (Bartels & Zeki, 2004; Leibenluft et al., 2004; Nitschke et al., 2004; Ranote et al., 2004) focused on either neutral or smiling expressions.

As notable exceptions, some fMRI studies (Noriuchi et al., 2008; Strathearn et al., 2009) revealed that the presentation of expressions of social distress by a mother's own infant induces different neural activations from the presentation of similar expressions in unfamiliar infants. However, the low-temporal resolution of fMRI prevented the researchers from examining whether the processing of a mother's own infant's crying temporally precedes that of other types of infant emotional expressions. In contrast to fMRI, the event-related potential (ERP) technique is a useful tool for investigating the temporal course of neural activations in face processing because of its high temporal resolution. Nonetheless, to date there have been only a few sporadic attempts to apply ERP measurement to the study of processing crying faces (Hendriks et al., 2007; Proverbio, Brignone, Matarazzo, Del Zotto, & Zani, 2006; Rodrigo et al., 2011). Of particular relevance to the present study, Proverbio et al. (2006) compared the electrophysiological responses to infant's emotional expression across mothers, fathers, nulliparous women, and childless males. The results showed striking differences in the electrophysiological responses to infant's distress expressions between mothers and the other participant groups. However, they did not compare the electrophysiological responses to distress expressions of a mother's own and an unfamiliar infant.

The primary aim of the present study was to examine whether crying face of mother's own infant is processed more efficiently in mothers than other types of infant emotional expressions. To this end, we measured ERPs elicited by crying or smiling of a mother's own or an unfamiliar infant. To control for the stimulus attributes of the facial stimuli, a yoked design (Roye, Jacobsen, & Schröger, 2007; Roye, Schröger, Jacobsen, & Gruber, 2010) was adopted. Specifically, every participant was paired with another participant and presented a picture of her counterpart's infant as the unfamiliar infant, ensuring that exactly the same set of stimuli were presented in each condition. A similar stimulus presentation design was used in previous neuroimaging studies on neural activations in mothers in response to their own and an unfamiliar infant's emotional expressions (Nitschke et al., 2004; Ranote et al., 2004).

The crying and smiling expressions were presented in an oddball stimulus presentation format (Olofsson et al., 2008; Polich, 2007; Polich, Eischen, & Collins, 1994; Rozenkrants & Polich, 2008). Specifically, the infants crying and smiling expressions were presented as low-frequency targets embedded within a train of high-frequency neutral expressions. In such experimental paradigms, a series of early components (P1, N170) that reflect the perceptual processing of visual stimuli and a large positivity called P300 are elicited to target-stimuli. By examining the effects of facial expressions and familiarity on these components, we aimed to clarify whether these factors exert interacting influences at each stage of face processing.

The presentation of facial stimuli induces a series of components at the occipito-temporal electrode sites. After about an 80–120 ms stimulus onset, a prominent positivity (P1) is observed at occipital electrodes. P1 purportedly reflects the processing of low-level visual features such as luminance and contrast (Taylor, 2002). However, several studies have indicated that this component is also sensitive to face-specific information (Doi, Sawada, & Masataka, 2007; Doi, Ueda, & Shinohara, 2009; Herrmann, Ehlis, Ellgring, & Fallgatter, 2005; Linkenkaer-Hansen et al., 1998; Taylor, 2002). Following P1 component, a negativity called N170 is observed at the occipito-temporal region. N170 reflects the structural encoding of face processing (Bentin, Allison, Puce, Perez, & McCarthy, 1996; Eimer, 2000a, 2000b; Rossion et al., 1999), which is involved in the formation of representations of spatial relations among facial parts. Although whether N170 component is sensitive to information other than facial configurations (Eimer, 2000a) is still controversial, several recent studies have shown that both facial expression (Caharel, Courtay, Bernard, Lalonde, & Rebai, 2005; Doi, Amamoto, Okishige, Kato, & Shinohara, 2010) and familiarity information (Caharel et al., 2005; Caharel, Fiori, Bernard, Lalonde, & Rebai, 2006) modulate N170 component. Examining the effects of facial familiarity and expressions on these components should show whether the processing by mothers of their own infant's crying is different than the processing of the crying faces of other infants at the initial perceptual stages of face perception.

P300 is a long-latency positive component elicited at posterior-medial electrodes by low-frequency target stimuli (Olofsson et al., 2008; Polich, 2007; Polich et al., 1994; Rozenkrants & Polich, 2008). P300 is generally considered to reflect cognitive evaluation stages of face processing that take place after initial perceptual stages of face processing reflected in P1 and N170. Previous studies have shown that P300 reflects diverse array of cognitive functions, including attentional control (Langeslag, Jansma, Franken, & Van Strien, 2007; Langeslag, Franken, & Van Strien, 2008), memory (Olofsson et al., 2008; Polich, 2007; Polich et al., 1994; Rozenkrants & Polich, 2008), emotional arousal (Cuthbert et al., 2000; Delplanque, Silvert, Hot, & Sequeira, 2005), and stimulus evaluation (Bobes, Quiñonez, Perez, Leon, & Valdés-Sosa, 2007; Kutas, McCarthy, & Donchin, 1977; Picton, 1992; Polich, 2007; Woodman, 2010). On the basis of these, we hypothesized that analyzing the modulation of P300 should determine whether own infant's crying expression is processed more efficiently than other facial expressions at these later cognitive evaluation stages of face processing.

Some studies indicate that the neural responses to infants' faces are supposed to be instinctive, whereas other studies show individual differences in these responses. With regard to the former notion, it is well accepted that "baby shema", a collection of babyish characteristics such as big eyes and round contours, instinctively triggers protective and care-taking behaviors (Glocker et al., 2009a, 2009b). In support of the latter notion, a recent study by Rodrigo et al. (2011) showed that personality traits modulate the amplitudes of long-latency potentials that are elicited when viewing infants' emotional expressions. Specifically, they showed that the amplitudes of the long-latency positivity elicited by the neutral, crying, and laughing faces of unfamiliar infants were smaller in neglectful mothers than in healthy controls. If the neural responses to crying are influenced by individual characteristics (Rodrigo et al., 2011) as well as being instinctive responses (Glocker et al., 2009a, 2009b), ERP components should be sensitive to a participants' personality traits. To examine this possibility, we measured the participant's attachment attitudes towards their infants using a self-administered questionnaire and analyzed the relationship between these measures and ERP amplitudes.

2. Materials and methods

2.1. Participants

Sixteen mothers ($M = 31.7 \pm 0.5$ yrs) with infants approximately 12 months old (four girls; $M = 12.3 \pm 0.7$ months) participated in the study. They provided an informed consent for the experimental procedure that was approved by the institutional ethics committee of Nagasaki University. All mothers were right-handed and had normal or corrected-to-normal visual acuity. They had no history of mental illness and were not on any medication at the point of participation.

2.2. Material preparation

At least two weeks before the EEG recordings, the neutral, smiling, and crying faces of the participant's infants were video-recorded to prepare the stimulus material. Smiling expressions were elicited by letting the infants freely interact with their mothers. Mothers were permitted to do anything they thought would amuse their infant during the mother–infant interaction. The procedure for inducing crying by the infants was partly derived from Ainsworth's strange situation procedure (Ainsworth et al., 1978). After smiling expressions were successfully video-recorded, the experimenter cued the mother to stop interacting with her infant and to leave the room. Just after the infant was separated from the mother, an adult male stranger entered the room. The stranger stood silently about 1 m away from the infant and kept gazing straight toward the infant expressionlessly. After the infant started crying, the crying face was video-recorded for about 1 min. The mother then re-entered the room to soothe the infant.

After video recording sessions were completed, three pictures each of faces with neutral, smiling, and crying faces were extracted from the video sequence under the constraint that the head and gaze of the infant were directed roughly straight towards the camera. The background of these frames was replaced by a black background.

To ascertain whether there were any differences in the low-level perceptual features of the images, the luminance, contrast and perceptual complexity of stimulus faces were compared among the conditions. Luminance and contrast (RMS contrast; Peli, 1990) were quantified as the mean and the standard deviation of the pixel intensity, respectively. Perceptual complexity was determined from the compression rate of the image by a gif compression algorithm because Forsythe, Nadal, Sheehy, Cela-Conde, and Sawey (2011) have shown using a large set of images that gif compression rates predict the perceived complexity of images, which validated it as a good, objective measure of perceptual image complexity. The luminance, contrast, and perceptual complexity data were entered into an one-way analysis of variance (ANOVA) with the factor of expression (neutral–crying–smiling). Because the ANOVAs did not reveal any significant effects, $Fs < 0.5$, $ps > .10$, $power = 0.06$–0.17, data provide no evidence that the low-level perceptual features were systematically different across conditions.

2.3. Stimulus

Every participant was paired with another participant pseudo-randomly under the constraint that her age and her own infant's gender matched those of her counterpart. The experiment consisted of four blocks, and a short break was taken between each block. In half of the blocks (hereinafter referred to as own block), images of the face of the participant's own infant were presented, whereas those of the paired participant's infant were presented in the remaining blocks (hereinafter referred to as unfamiliar block). The order of the blocks was either own–unfamiliar–own–unfamiliar or unfamiliar–own–unfamiliar–own, and this alternative ordering was counterbalanced across participants, with the constraint that the reverse block order was applied to paired participants. In each block, neutral, smiling, and crying trials were delivered 144, 18, and 18 times, respectively. Therefore, 288 neutral trials and 36 smiling or crying trials were administered in each familiarity (own–unfamiliar) condition throughout the experiment.

2.4. Procedure

2.4.1. EEG recording

All of the visual stimuli were presented on a 17-in. computer display. During the recordings, the participants were seated 110 cm from the screen in a dimly lit room. Each trial began with a 500 ms presentation of a fixation cross at the center of the screen, followed by the presentation of the stimulus face for 1000 ms. The picture subtended roughly 4.5° in height and 4.5° in width of the visual field in this experimental setting.

To avoid confounding oculomotor artifacts, each participant was asked to maintain fixation on the center of the screen during the trials and blink during the inter-trial intervals. They were instructed to press a hand-held button as soon as possible when they observed either smiling or crying infants. The hand used to press the response button was counterbalanced across participants under the constraint that the paired participants used the same hand.

Electroencephalogram (EEG) signals were recorded from 19 scalp sites (Fp1/Fp2, F3/F4, F7/F8, C3/C4, T7/T8, P3/P4, P7/P8, O1/O2, Fz, Cz, Pz) localized according to the extended international 10/20 reference system. The recordings were conducted using Ag–AgCl electrodes mounted in an elastic cap. To monitor horizontal and vertical oculomotor artifacts, electro-oculogram (EOG) signals were recorded from the electrodes positioned above and lateral to the right eye. Impedance was kept below 10 kΩ. The electrodes placed over the left and right earlobes served as reference electrodes. The EEG signal was sampled at 500 Hz, and the data were stored on a hard disk.

2.4.2. Stimulus evaluation

After the EEG recordings were completed, the participants evaluated how aroused they felt and how pleasant they felt when viewing the presented stimuli using a 7-point Likert scale. In the stimulus display, each facial stimulus was presented on the upper half of the screen. Below the facial stimulus, track bars for the arousal rating and the pleasantness rating were presented. The left edge of the arousal track bar was labeled "not at all aroused", and the right edge was labeled "highly aroused". Similarly, the left edge of the pleasantness track bar was labeled "highly unpleasant", and the right edge was labeled "highly pleasant".

The participants were instructed to move the track bars so that the ratings reflected their feeling towards each presented stimulus, and to click the register button at the bottom of the screen to submit their final evaluation. Clicking the register button triggered the next trial. Each facial stimulus was presented only once in the stimulus evaluation, and the order of presentation was determined pseudo-randomly.

2.4.3. Self-administered questionnaire

After the stimulus evaluation was completed, the participants completed a Japanese version of the Maternal Attachment Inventory (MAI-J). The original inventory was developed by Muller (1994) to measure the attachment relationship between mother and infant. The MAI-J is a 26-item self-administered questionnaire reported to have an acceptable level of internal consistency and test–retest reliability (Nakajima, 2001; Cronbach's alpha coefficient = 0.92, test–retest reliability coefficient = 0.84).

2.5. EEG data analysis

2.5.1. Pre-processing

The EEG data were analyzed off-line. The raw data were digitally filtered with a 0.1-Hz high-pass filter and a 30-Hz low-pass filter, and re-referenced to the averaged potential across all of the scalp sites. The average reference was chosen for the following reasons. First, the application of an average reference theoretically minimizes the possibility that the waveform topography is distorted by waveforms from a few electrode sites. Despite the relatively small number of electrodes, they were evenly distributed across scalp surface in the present study. Thus, the use of average reference presumably reduces the risk of topography distortions. Second, some of the components of interest in the present study are recorded more prominently by using the average reference than other reference methods (Joyce & Rossion, 2005). Third, relevant studies have successfully applied average references to a comparable number of electrode sites as that in the present study (Caharel et al., 2005; Doi et al., 2009; Herrmann et al., 2005; Wieser, Pauli, Reicherts, & Mühlberger, 2010).

All EEG data were then segmented into epochs ranging from 100 ms before to 800 ms after the stimulus onset. The pre-stimulus window served as the baseline. Artifact rejection was automatically performed with a threshold of ±100 μV and visually checked afterwards. Thereafter, grand-averaged waveforms were calculated on the basis of correct trials.

2.5.2. Peak amplitude and latency analysis

The P1 and N170 components were measured at the O1/O2 and P7/P8 electrode sites, respectively. These electrodes were chosen because they are located in the same scalp region as the electrodes used in previous studies (Bötzel, Schulze, & Stodieck, 1995; Eimer, 2000a, 2000b; Jemel, Pisani, Calabria, Crommelinck, & Bruyer, 2003; Rossion et al., 1999). The prominent deflections were ascertained by visual inspection. The peaks of the P1 and N170 components were defined as the largest deflections at the following latency ranges: 80–130 ms for the P1 component and 140–220 ms for the N170 component. The peak latency of each component was defined as the latency until the component reached its peak activity.

The P300 was measured at Fz, Cz and Pz electrode sites. The peaks of the P300 component were defined as the largest deflections between 250–800 ms after the stimulus onset. The peak latency was defined as described above.

2.5.3. Principal component analysis

P300 is not supposed to be a unitary electrophysiological response, but is comprised of several overlapping yet functionally distinct sub-components (Delplanque et al., 2005; Johnston, Miller, & Burleson, 1986; Pourtois, Delplanque, Michel, & Vuilleumier, 2008), each of which shows differential sensitivities to experimental manipulations. To delineate the effects of facial expression and familiarity on each of these overlapping sub-components, P300 component was decomposed into functionally distinct sub-components by temporal principle component analysis (PCA; Chapman & Mccrary, 1995; Van Boxtel, 1998). PCA is a technique that is used to represent complex relationships among a large number of observable variables by small number of latent variables, which provides a more parsimonious representation of original data (Van Boxtel, 1998). PCA of ERP is analogous to representing the observed ERP waveform as a superposition of a set of independent sub-components (Delplanque et al., 2005; Johnston et al., 1986; Pourtois et al., 2008). By examining the influences of familiarity and facial expression on each of the sub-components, the modulation of each dissociable stage of face processing by these factors can be clarified.

When applied to the analysis of the ERP data, PCA treats voltage at each time-point as an observable variable, and extracts a set of latent variables called temporal factors (TFs). These TFs correspond to independent sub-components that constitute the original ERP waveform. Importantly, the TFs are extracted so that they can explain as large a proportion of the variance in the original ERP data as possible under the constraint that TFs are orthogonal. Each TF is a weighted linear

combination of time-insensitive variables. The weights are called factor loadings, and they represent the contribution of each TF to the voltage at each time-point. The PCA technique has been used in studies on ERP responses to emotional stimuli to disentangle functionally distinct components comprising long-latency positivity (Delplanque et al., 2005; Johnston et al., 1986).

In order to decompose P300 into TFs, a PCA based on a covariance matrix was conducted on the averaged waveforms from the medial electrodes (Fz–Cz–Pz). Six averaged waveforms (2 familiarity × 3 expression) were recorded from three electrode sites (Fz–Cz–Pz) from sixteen participants, which resulted in a set of 288 waveforms for the PCA.

TFs that correspond to the P1 and N170 were also extracted by the PCA so that the influences of adjacent components on the peak amplitudes of these components minimized by the PCA. The TFs corresponding to the P1 component were extracted by entering the averaged waveforms at the O1/O2 electrode sites to the PCA. A set of 192 averaged waveforms recorded in 12 conditions (2 hemisphere × 2 familiarity × 3 expression) from sixteen participants served as the database for the PCA for the P1 component. In a similar vein, the TFs corresponding to the N170 component were extracted by entering the averaged waveforms at the P7/P8 electrode sites to the PCA. A set of 192 averaged waveforms served as the database for the PCA.

We computed the amplitude of each TF as mean amplitude in the temporal window during which the contribution of each TF to the voltage exceeded 0.80 criterion (for a similar analysis, see Delplanque et al., 2005).

2.5.4. P300 onset latency analysis

Onset of ERP component rather than peak latency often serves as critical measure of cognitive process (Bobes et al., 2007; Woodman, 2010). In contrast to ERP components with sharp peaks such as the P1 and N170 components, the peak latency of the P300 does not necessarily reflect its onset latency, because P300 lasts several hundred milliseconds. Thus, P300 onset latency was quantified by determining the temporal point at which the waveforms elicited by the target stimuli diverged from those elicit by standard stimuli, using a novel permutation test method. In this way, the onset latency of the P300 can be determined independently from the peak latency on statistical basis. This method has previously been used to examine the temporal course of differences in waveforms elicited by facial stimuli (Bobes et al., 2007; González et al., 2011; Kuefner, Jacques, Prieto, & Rossion, 2010).

ERP waveforms for crying and smiling expressions in each familiarity condition were compared with the ERP waveforms elicited during viewing of neutral expression by the same infant in a point-by-point manner by a permutation test (Blair & Karniski, 1993). Permutation tests were performed on ERP data at the Pz electrode because the P300 component was most prominent at this electrode site. We did not apply onset latency detection using permutation tests to the P1 and N170 components because these components were elicited in both the target (crying–smiling) and standard (neutral) trials, which makes it hard to detect the P1 or N170 onset latencies by comparing the waveforms elicited by the target and standard stimuli.

The general principles for permutation test are summarized below (see also Bobes et al., 2007; González et al., 2011; Kuefner et al., 2010). When comparing two ERP waveforms by a permutation test, the assignment of amplitudes to conditions was shuffled randomly within each participant. Thereafter, t-values are computed at each time point. By repeating this procedure many times, the distribution of the t-statistic is obtained for each time point under the null hypothesis that there is no difference between the waveforms at this time-point. By comparing the observed differences between the ERP waveforms to the distributions obtained by permutation test, the p-value at each time point can be estimated.

In judging the significance of waveform difference at each time point, the significance level must be adjusted so that making multiple comparisons does not inflate the overall risk of making a Type 1 error. Of several variants of permutation test proposed by Blair and Karniski (1993), we adapted the t_{max} method to judge the significance of waveform differences at each time-point. As is the case with Bonferroni's adjustment procedure, the t_{max} method controls the family-wise Type 1 error rate of a set of multiple comparisons. The advantage of the t_{max} method over the conventional Bonferroni's procedure is that the t_{max} method gives an exact critical value to maintain the desired level of family-wise Type 1 error rate.

3. Results

3.1. Behavioral results

3.1.1. Reaction times (RTs)

The RTs in the correct trials were averaged over each condition and are summarized in Table 1 together with the accuracy rates. The averaged RTs were entered into a two-way ANOVA with within-participant factors of familiarity (own–unfamiliar) and expression (smiling–crying). The ANOVA revealed a significant main effect of expression, $F(1, 15) = 36.22$, $p < .01$, $\eta_p^2 = 0.71$, with RTs to images depicting crying being shorter than those to images depicting smiling. No other significant results were obtained, Fs < 2.0, ps > .10, *power* = 0.09–0.27. The accuracy rates were entered into an ANOVA with the same factorial design described above. The ANOVA revealed no significant effects, Fs < 1.0, ps > .10, *power* = 0.08–0.15.

3.1.2. Stimulus ratings

The stimulus evaluation results are summarized in Table 2 together with the standard deviations. The arousal and pleasantness ratings for the stimuli in each condition were entered into a two-way within-participant ANOVA with the factors of familiarity (own–unfamiliar) and expression (neutral–crying–smiling).

For the arousal ratings, the ANOVA revealed a significant main effect of familiarity, $F(1, 15) = 6.0$, $p < .05$, $\eta_p^2 = 0.28$. The main effect of expression did not reach significance, $F(2, 30) = 3.28$, $p < .06$, *power* = 0.28. However, there was a significant interaction between familiarity and expression, $F(2, 30) = 3.48$, $p < .05$, $\eta_p^2 = 0.19$. A simple main effect analysis revealed a significant simple main effect of familiarity in the smiling condition with arousal being higher in mothers when they viewed smiling by their own rather than unfamiliar infants, $F(1, 45) = 12.84$, $p < .01$, $\eta_p^2 = 0.22$. No such effect was obtained either for neutral, $F(1, 45) = 1.05$, $p > .10$, *power* = 0.09, or for crying, $F(1, 45) = 0.73$, $p > .10$, *power* = 0.08, faces. The simple main effect of expression yielded significance in the own, $F(2, 60) = 5.17$, $p < .01$, $\eta_p^2 = 0.15$, but not in the unfamiliar condition, $F(2, 60) = 1.43$, $p > .10$, *power* = 0.14. Multiple comparisons showed that mothers rated their arousal during viewing of their own infant smiling significantly higher than during viewing of their own infant with a neutral expression, $t(60) = 3.14$, $p < .01$, $d = 0.87$. No other pair-wise comparisons yielded significant results, ps > .10, *power* = 0.10–0.63.

For the valence ratings, the pictures of their own infants elicited more positive emotions in mothers than those of unfamiliar infants, $F(1, 15) = 5.28$, $p < .05$, $\eta_p^2 = 0.28$. There was also a significant main effect of expression, $F(2, 30) = 9.77$, $p < .01$, $\eta_p^2 = 0.39$. The interaction between familiarity and expression did not reach significance, $F(2, 30) = 1.87$, $p > .10$, *power* = 0.21. Multiple comparisons revealed that crying was evaluated significantly more negatively than neutral, $t(30) = 2.36$, $p < .05$, $d = 0.54$, or smiling expressions, $t(30) = 4.42$, $p < .01$, $d = 0.80$. There was no significant difference between the evaluations of smiling and neutral expressions, $t(30) = 2.06$, $p > .10$, *power* = 0.39.

3.2. ERP results

3.2.1. P1

The recorded waveforms in each condition at O1/O2 electrodes are shown in Fig. 1.

3.2.1.1. Peak amplitude and latency analysis. The latencies and amplitudes of the peaks of the P1 component were entered into a repeated-measures ANOVA with the within-participant factors of hemisphere (left–right), familiarity (own–unfamiliar), and expression (smiling–crying–neutral). The ANOVA did not reveal any

Table 1
Averaged RT and accuracy rate in each condition. Standard deviations are in parentheses.

	Own crying	Smiling	Unfamiliar crying	Smiling
RT (ms)	588.5 (87.1)	624.9 (86.4)	598.1 (83.9)	644.2 (99.5)
Accuracy rate (%)	99.7 (0.9)	94.6 (8.7)	97.7 (5.1)	96.2 (7.5)

Table 2
Averaged ratings of arousal and valence elicited by the stimuli in each condition. Standard deviations are in parentheses.

	Own neutral	Cry	Smile	Unfamiliar neutral	Cry	Smile
Arousal	4.0 (0.4)	4.2 (0.7)	4.7 (0.9)	3.9 (0.4)	4.1 (0.7)	4.2 (0.7)
Valence	4.2 (1.1)	3.5 (1.1)	4.9 (1.1)	3.9 (1.4)	3.4 (1.3)	4.4 (1.7)

Larger rating values for valence indicate more positive feelings.

significant effects either for the P1 amplitude or the P1 latency, $Fs < 2.3$, $ps > .10$, *power* = 0.06–0.12.

3.2.1.2. PCA. After varimax rotation, PCA revealed five distinct components accounting for 89.95% of the total variance. Of these, only one TF was extracted within the latency range of the P1 component. The 0.8 criterion resulted in the latency range of 108–128 ms for this TF. Averaged amplitudes of the TFs corresponding to P1 component were entered into an ANOVA with the same factorial design described above. The ANOVA did not reveal any significant effects, $Fs < 2.0$, $ps > .10$, *power* = 0.05–0.48.

3.2.2. N170

The recorded waveforms in each condition at P7/P8 electrodes are shown in Fig. 2.

3.2.2.1. Peak amplitude and latency analysis. The peak amplitudes of the N170 component were entered into an ANOVA with the same factorial design described above. The averaged amplitudes of the N170 component in each condition are shown in Fig. 3 together with the standard errors.

The ANOVA revealed a significant main effect of expression, $F(2, 30) = 48.14$, $p < .01$, $\eta_p^2 = 0.71$. Multiple comparisons by Ryan's method revealed a significant difference in every pairwise comparison. Specifically, the N170 component for crying infants was significantly larger than that for the neutral, $t(30) = 9.42$, $p < .01$, $d = 0.77$, or smiling infants, $t(30) = 2.31$, $p < .05$, $d = 0.18$. The N170 component for smiling infants was significantly larger than that for neutral infants, $t(30) = 7.10$, $p < .01$, $d = 0.64$. The interaction between Hemisphere and familiarity approached, but did not reach significance, $F(1, 15) = 3.34$, $p < .08$, *power* = 0.42. No other effects approached or yielded significance, $Fs < 2.5$, $ps > .10$, *power* = 0.06–0.32.

The N170 latencies were entered into an ANOVA with the same factorial design described above. The ANOVA revealed no significant effects, $Fs < 1.5$, $ps > .10$, *power* = 0.08–0.83.

3.2.2.2. PCA. After varimax rotation, PCA revealed five distinct components accounting for 90.08% of the total variance. Of these, only one TF was extracted within the latency range of the N170 component. The 0.8 criterion resulted in the latency range of 140–166 ms for this TF.

Averaged amplitudes of TFs corresponding to the N170 component were entered into an ANOVA with the same factorial design described above. The ANOVA yielded essentially the same results as the conventional peak amplitude analysis. Specifically, the main effect of expression reached significance, $F(2, 30) = 25.77$, $p < .05$, $\eta_p^2 = 0.63$. Multiple comparisons analysis by Ryan's method revealed that the TF for crying was significantly larger than that for neutral, $t(30) = 7.14$, $p < .01$, $d = 0.36$, or smiling infants, $t(30) = 2.98$, $p < .05$, $d = 0.22$. The TF for smiling infants was significantly larger than that for neutral infants, $t(30) = 4.16$, $p < .01$, $d = 0.14$. No other main effect or interaction reached significance, $Fs < 2.0$, $ps > .05$, *power* = 0.09–0.52.

3.2.3. P300

The waveforms recorded at the medial electrode sites (Fz–Cz–Pz) are shown in Fig. 4. At the latency range from 250 to 800 ms after stimulus onset, a large positive deflection was observed for target stimuli. From its scalp distribution, latency range, and response to experimental manipulation, we determined this deflection as P300.

3.2.3.1. Peak amplitude and latency analysis. The peak amplitudes of the P300 component were entered into a three-way within-participant ANOVA with the factors of electrode (Fz–Pz–Cz), familiarity (own–unfamiliar), and expression (neutral–crying–smiling). The ANOVA revealed a significant main effect of electrode, $F(2, 30) = 27.49$, $p < .01$, $\eta_p^2 = 0.65$, and expression, $F(2, 30) = 81.59$, $p < .01$, $\eta_p^2 = 0.84$. There was also a significant interaction between electrode and expression, $F(4, 60) = 23.64$, $p < .01$, $\eta_p^2 = 0.61$.

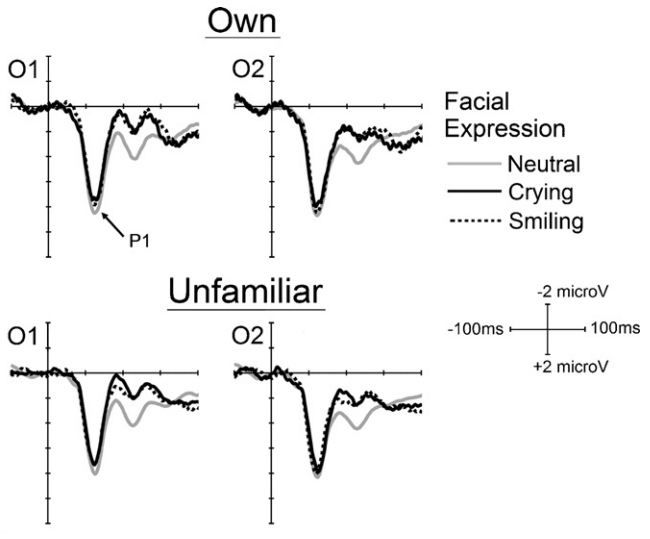

Fig. 1. Grand averaged waveforms at O1/O2 electrode sites in each condition.

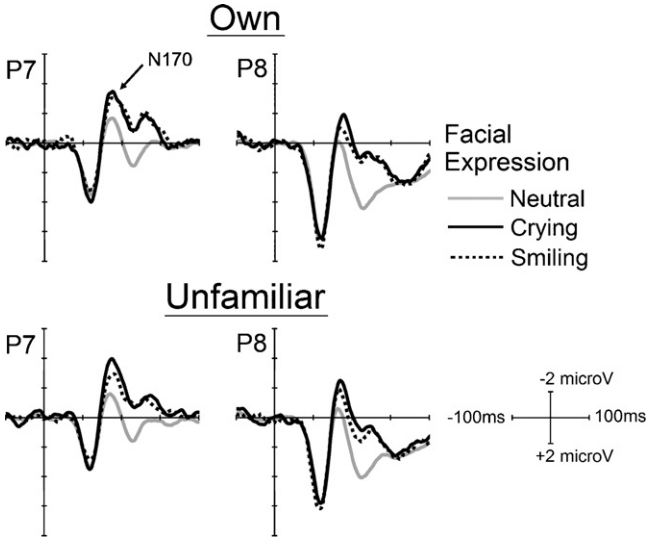

Fig. 2. Grand averaged waveforms at P7/P8 electrode sites in each condition.

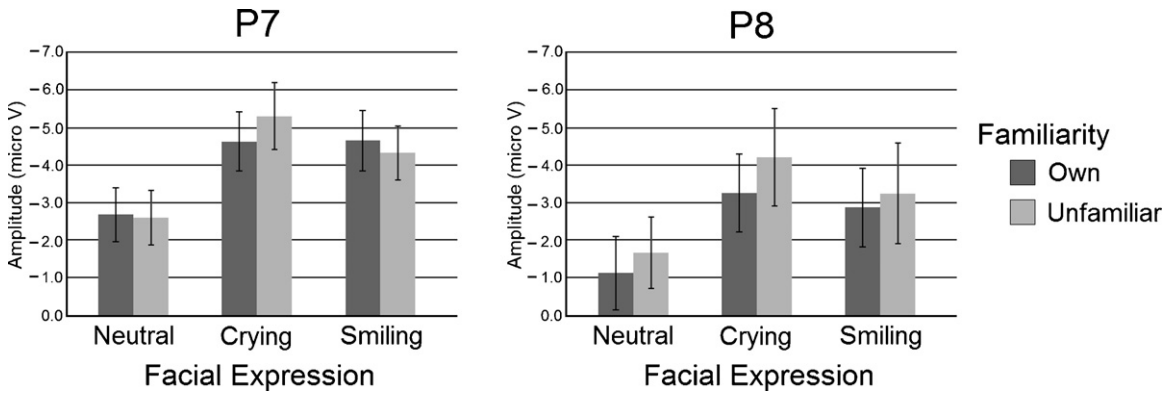

Fig. 3. Averaged amplitudes of N170 in each condition at P7/P8 electrodes. The error bars indicate standard errors.

The simple main effect of electrode reached significance for crying, $F(2, 90) = 48.69$, $p < .01$, $\eta_p^2 = 0.51$, and smiling infants, $F(2, 90) = 28.38$, $p < .01$, $\eta_p^2 = 0.38$, but not for neutral expression, $F(2, 90) = 1.18$, $p > .10$, *power* = 0.08. The simple main effect of expression reached significance at every electrode site, $Fs > 5.05$, $ps < .01$, $\eta_p^2 = 0.15$. Multiple comparisons revealed that the amplitudes of the responses to both smiling and crying infants differed significantly from those to infants with neutral expressions at every electrode, $ts > 2.5$, $ps < .05$, $ds > 0.6$. At the same time, the differences between the P300 amplitudes for the crying and smiling infants did not reach significance at any of the three electrode sites, $ts < 2.1$, $ps > .10$, *power* = 0.07–0.27.

The P300 peak latencies were entered into an ANOVA with the same factorial design described above. The main effect of electrode approached but did not reach significance, $F(2, 30) = 2.98$, $p < .07$, *power* = 0.31. No other effects either approached or yielded significance, $Fs < .1.9$, $ps > .10$, *power* = 0.06–0.16.

3.2.3.2. PCA. After varimax rotation, PCA revealed five distinct components as shown in Fig. 5, accounting for 91.83% of the variance in total.

Within the latency window of P300, three temporal factors (TFs), i.e., TF1, TF2 and TF3, were extracted. TF2 was discarded from the further analysis due to the auto-regressive nature of the data (Van Boxtel, 1998; Wastell, 1981). Therefore, in the analysis, we focused on TF1 and TF3. We analyzed the mean amplitude in the following latency range for each TF: 404–612 ms for TF1 and 272–328 ms for TF3. The mean amplitudes of TF3 and TF1 in each condition were entered into a three-way within-participant ANOVA with the same factorial design described above.

3.2.3.2.1. TF3 amplitude (272–328 ms after stimulus onset). The ANOVA revealed a significant main effect of Electrode, $F(2, 30) = 6.67$, $p < .01$, $\eta_p^2 = 0.31$, confirming the parieto-central distribution of this TF. The main effects of familiarity, $F(1, 15) = 2.48$, $p > .10$, *power* = 0.33, and expression, $F(2, 30) = 0.65$, $p > .10$, *power* = 0.10, did not reach significance. There was a significant interaction between Electrode and expression, $F(4, 60) = 3.91$, $p < .01$, $\eta_p^2 = 0.21$. There was also a significant three-way interaction between Electrode, familiarity, and expression, $F(4, 60) = 3.96$, $p < .01$, $\eta_p^2 = 0.20$.

To clarify the source of the three-way interaction, two-way ANOVAs with the within-participant factors of familiarity and expression were separately conducted for the data recorded at each electrode. At the Fz and Cz electrodes, no significant effects were obtained, $Fs < 2.2$, $ps > .10$, *power* = 0.05–0.32. At the Pz electrode, the ANOVA revealed significant main effects of familiarity, $F(1, 15) = 5.26$, $p < .05$, $\eta_p^2 = 0.26$, and expression, $F(2, 30) = 5.88$, $p < .01$, $\eta_p^2 = 0.28$. There was also a significant interaction between

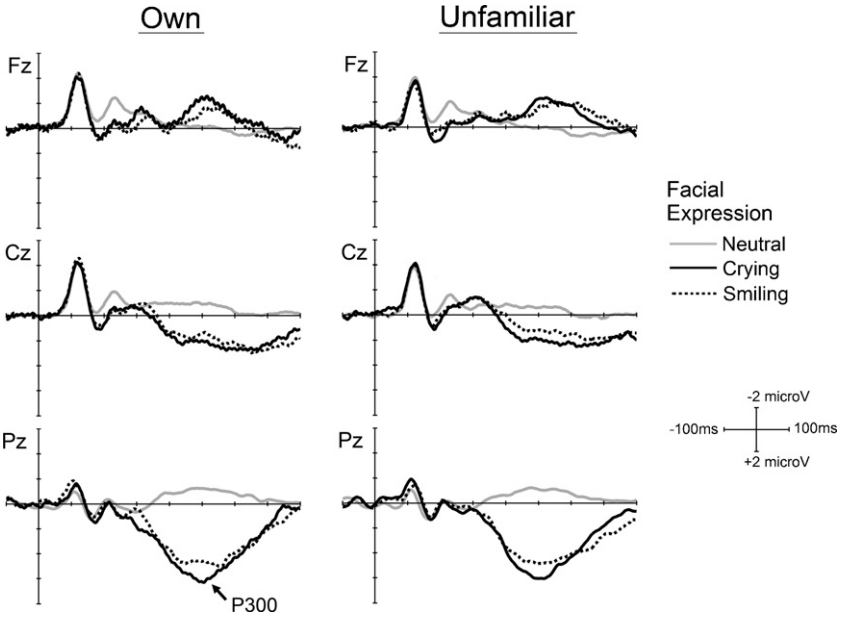

Fig. 4. Grand averaged waveforms at medial electrode sites (Fz–Cz–Pz) in each condition.

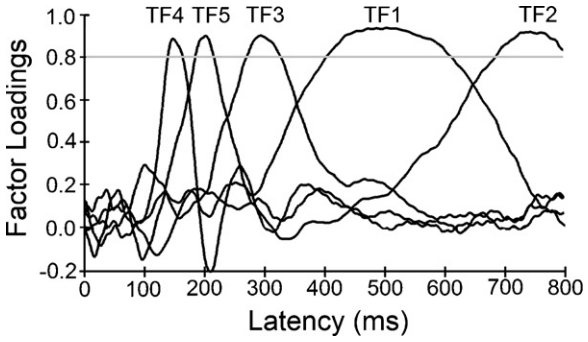

Fig. 5. Temporal course of factor loadings of each temporal factor extracted by PCA on the basis of the averaged waveforms recorded at medial electrode sites (Fz–Cz–Pz) The gray horizontal line indicates the contribution criterion of 0.8.

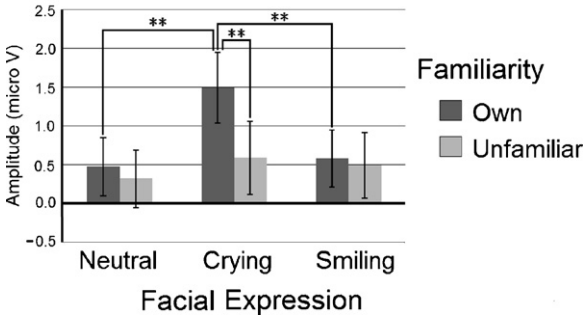

Fig. 6. Averaged amplitudes of TF3 in each condition at the Pz electrode. The error bars indicate standard errors. $^{**}p < .01$.

familiarity and expression, $F(2, 30) = 3.91$, $p < .05$, $\eta_p^2 = 0.21$. The averaged amplitudes of TF3 at the Pz electrode in each condition are shown in Fig. 6.

A simple main effect analysis revealed that the TF3 amplitude in response to the crying of a mother's own infant was significantly larger than that for the response to the crying of an unfamiliar infant, $F(1, 45) = 12.81$, $p < .01$, $\eta_p^2 = 0.22$. The simple main effect of familiarity did not reach significance either in the neutral, $F(1, 45) = 0.37$, $p > .10$, *power* = 0.06, or smiling expression condition, $F(1, 45) = 0.13$, $p > .10$, *power* = 0.06. The simple main effect of expression reached significance in the own, $F(2, 60) = 9.49$, $p < .01$, $\eta_p^2 = 0.24$, but not in the unfamiliar condition, $F(2, 60) = 0.56$, $p > .10$, *power* = 0.07. Multiple comparison analysis by Ryan's method revealed that the TF3 amplitude was significantly larger in response to the crying of a mother's own infant than for the same infant exhibiting a neutral expression, $t(60) = 3.97$, $p < .01$, $d = 0.53$, or smiling, $t(60) = 3.55$, $p < .01$, $d = 0.54$. The TF3 amplitude in response to the smiling of a mother's own infant did not differ from that in response to the infant exhibiting a neutral expression, $t(60) = 0.42$, $p > .10$, *power* = 0.06.

3.2.3.2.2. TF1 amplitude (404–612 ms after stimulus onset). The ANOVA revealed a significant main effect of Electrode, $F(2, 30) = 43.46$, $p < .01$, $\eta_p^2 = 0.74$, confirming the parieto-central distribution of this TF. There was also a significant main effect of expression, $F(2, 30) = 45.36$, $p < .01$, $\eta_p^2 = 0.75$. The main effect of familiarity did not reach significance, $F(1, 15) = 0.63$, $p > .10$, *power* = 0.11. There was also a significant interaction between Electrode and expression, $F(4, 60) = 37.69$, $p < .01$, $\eta_p^2 = 0.71$. No other effects reached significance, $Fs < 2.5$, $ps > .10$, *power* = 0.06–026.

A simple main effect analysis revealed a significant simple main effect of expression at the Fz, $F(2, 90) = 5.65$, $p < .01$, $\eta_p^2 = 0.11$, Cz, $F(2, 90) = 17.59$, $p < .01$, $\eta_p^2 = 0.28$, and Pz, $F(2, 90) = 97.53$, $p < .01$, $\eta_p^2 = 0.78$, electrode sites. Multiple comparisons by Ryan's method revealed that the TF1 amplitudes in response to crying and smiling expressions differed significantly from those in response to neutral expression at every electrode site, $ts > 2.5$, $ps < .01$, $ds > 0.60$. However, the TF1 amplitudes did not differ between smiling and crying infants in any electrode sites, $ts < 1.7$, $ps > .10$, *power* = 0.18–0.38. The simple main effect of Electrode reached significance for crying, $F(2, 90) = 71.75$, $p < .01$, $\eta_p^2 = 0.61$, and smiling infants, $F(2, 90) = 48.53$, $p < .01$, $\eta_p^2 = 0.52$, but not for neutral expression, $F(2, 90) = 1.66$, $p > .10$, *power* = 0.09.

3.2.3.3. Onset latency analysis by the permutation test. The ERP waveforms for the crying and smiling infants were compared with the ERP waveforms for the infants with neutral expressions in a point-by-point manner within each familiarity condition. We performed 10,000 permutations to generate the *t*-statistic distributions. The onset latency of the P300 component was determined as the time point at which the *t*-value first becomes smaller than the critical value during the period 250–800 ms after stimulus onset. Because the permutation tests were performed on four pairs of waveforms, the significance level was adjusted by Bonferroni's procedure to 0.05/4 or 0.0125. To avoid making a Type I error, only differences that persisted at this significance level for at least 10 consecutive samples were considered significant. This analysis revealed P300 onset latencies of 302 ms in the own-crying condition, 344 ms in the own-smiling condition, 390 ms in the unfamiliar-crying condition, and 374 ms in the unfamiliar-smiling condition.

3.3. Correlation between behavioral measures and ERP amplitudes

To understand the nature of the processing reflected by each ERP component, a series of correlation analyses were performed for the TF1 and TF3 of the P300 component and the amplitudes of the TFs corresponding to P1 and N170 components. Correlation coefficients between these TFs and the behavioral measures, including the MAI-J score and the rating scores for faces in each condition were computed. Because there was no significant effect of Hemisphere for the amplitudes of the TFs corresponding to either the P1 or N170, the data were collapsed across Hemisphere for these TFs. For the correlation analysis of TF1 and TF3, the amplitudes of these TFs at Pz electrode were entered because the amplitudes of the TFs were maximal at this electrode site.

3.3.1. Correlation with rating results

Correlations between TF amplitudes in each condition and the arousal and valence ratings for the stimuli in the corresponding condition were calculated. For example, correlation coefficients between TF1 amplitude in own-crying condition and the arousal and valence ratings in the own-crying condition were computed. The results revealed no significant correlations, $r^2 < .09$, $ps > .10$, *power* = 0.05–0.21.

3.3.2. Correlation with questionnaire result

Correlations between the ERP amplitudes in each condition and MAI-J scores were calculated. The significance level was adjusted by Bonferroni's procedure to 0.0083 (=0.05/6) because six correlation coefficients were computed for each TF. The positive correlation between MAI-J and TF1 amplitudes to the smiling of the mother's own infant reached significance, $r = 0.64$, $p < .05$, indicating that mothers with larger MAI-J scores showed larger TF1 amplitude in response to smiling by their own infant. No other significant correlation was obtained, $r^2 < .31$, $ps > .10$, *power* = 0.06–0.69.

4. Discussion

The present study measured ERPs elicited in mothers while they observed crying and smiling by their own or unfamiliar infants. N170, which is supposed to reflect perceptual stage of face processing, was enlarged by presentation of crying faces regardless of kinship of infant. In contrast, the early portion of the P300 component, TF3, was modulated by both facial expression and familiarity. That is, TF3 was larger in response to a mother's own infant's crying than to the other three types of facial stimuli. Interestingly, similar interactions between facial familiarity and facial expression were not observed at later portion of the P300 component. Recent neuroimaging studies (Noriuchi et al., 2008; Strathearn et al., 2009) have indentified neural regions sensitive to both infants' emotional expressions and their familiarity. The present study extended these findings by clarifying for the first time the temporal course with which emotional expression and familiarity exert interactive influences on neural processing of infant's faces in mothers. Furthermore, to the best of our knowledge, this is the first study to show that facial expression and familiarity information influence early portions of the parieto-centrally distributed P300 component in a different manner from later portions of this component.

Our analyses revealed that the amplitude of the N170 component was enlarged in response to crying compared to smiling and neutral expression. This finding concurs with previous research (Hendriks et al., 2007; Proverbio et al., 2006) showing that crying elicits larger N170 components. Taken together, these results indicate that the visual cue of crying is detected as early as the structural encoding stage of face processing (Bentin et al., 1996; Eimer, 2000a, 2000b; Rossion et al., 1999). Interestingly, the N170 amplitudes to crying and smiling expressions did not differ according to familiarity of infant face. Although null findings should be treated cautiously, this finding might indicate that infant faces are processed in a similar manner regardless of familiarity at initial perceptual stages of face processing, which are supposed to be subserved by fusiform gyrus (FG), superior temporal sulcus (STS), and occipital face area (OFA) (for a review, see Minnebusch & Daum, 2009). This further indicates the possibility that N170 reflects instinctive responsiveness in mothers to infant stimuli, which is triggered regardless of kinship of infant. Such mechanism of parental instinct must be quite beneficial for the purpose of species-preservation. An ERP study by Purhonen et al. (2001) has demonstrated that mothers show enhanced neural responses to unfamiliar infant's crying compared to females with no child at perceptual stages. Furthermore, Proverbio et al. (2006) revealed that mothers show different N170 response to distressed expressions of unfamiliar infants from fathers. Taking these into consideration, it seems possible that N170 responses to infant stimuli in females are altered through the experiences of delivery and care-taking.

Presentation of infant faces activates neural regions linked to parental and care-giving behaviors such as orbitofrontal cortex, anterior cingulate cortex, and insula (Bartels & Zeki, 2004; Lorberbaum et al., 2002; Nitschke et al., 2004; Swain, Lorberbaum, Kose, & Strathearn, 2007). Furthermore, the amygdala is sensitive to both "baby-schema" (Glocker et al., 2009a, 2009b; Zebrowitz, Luevano, Bronstad, & Aharon, 2009) and crying of unfamiliar infants (Sander, Frome, & Scheich, 2007; Seifritz et al., 2003). It is suggested that these regions influence visual processing in cortical regions via pulvinar nuclei in thalamus (for a review, see Pessoa & Adolphs, 2010). On the basis of these, activation of candidate regions for N170 generation such as FG and STS (Itier & Taylor, 2004; Rossion, Joyce, Cottrell, & Tarr, 2003) might be augmented by influences from neural regions linked to parental instinct or care-taking behaviors.

At medial electrode sites, the predicted interaction between familiarity and facial expression was observed in TF3. Specifically, the amplitude of TF3 was increased by own infant's crying expression compared to the other three types of target faces. The independence of processing streams dedicated to stable aspects of face information, such as familiarity, and changeable facial expression information has been the focus of controversy since the introduction of the influential model of face processing by Bruce and Young (1986, see also Young, McWeeny, Hay, & Ellis, 1986). Although the independence between these processing streams has been confirmed by neuroimaging (Andrews & Ewbank, 2004; Haxby, Hoffman, & Gobbini, 2000) and clinical studies on brain-damaged patients (Tranel, Damasio, & Damasio, 1988), recent behavioral studies (Campbell & Burke, 2009; Ellamil, Susskind, & Anderson, 2008; Schweinberger, Burton, & Kelly, 1999; Why & Huang, 2010) have demonstrated the interaction between familiarity and emotional expression information of faces. The results of the present study add further evidence that these two types of facial information, i.e. facial expression and facial familiarity information, do interact at long-latency cognitive evaluation stage of face processing (see also, Martens, Leuthold, & Schweinberger, 2010; Wild-Wall, Dimigen, & Sommer, 2008).

In the three-stimuli oddball paradigm, to-be-ignored low-frequency stimuli induce early positive deflection called P3a (Delplanque et al., 2005; Pourtois et al., 2008) within a similar latency range as TF3 in the present study. However, P3a amplitude reaches its maximum at fronto-central electrode sites contrarily to TF3. Moreover, both crying and smiling expressions were to-be-attended stimuli in the present study. Therefore, TF3 does not seem to be the homolog of P3a in standard oddball-paradigm as used in the present study. Judging from the latency range and the occipito-parietal centered distribution of TF3, it seems likely that TF3 corresponds to the early ascending portion of the P300 component. On the basis of this, the present finding seems to indicate that own infant's crying expression elicits P300 more efficiently than other types of facial stimuli. This interpretation is further corroborated by the results of the permutation test that the onset latency of the P300 to own infant's crying expression was shorter than those to the other three types of target faces.

Efficiency of P300 elicitation has been linked to speed of evaluation of target stimulus (Bobes et al., 2007; Kutas et al., 1977; Woodman, 2010; for a review see, Polich, 2007). The logic behind this assumption is that P300 cannot arise before differences between target and standard stimuli are detected. From this perspective, the present finding may indicate that the evaluation of deviance from neutral expression is completed more efficiently for a mother's own infant's crying than for the other three types of stimuli. If this hypothesis is correct, it would be interesting to determine which characteristics of a mother's own infant's crying allow for the accelerated evaluation of it. Although speculative at this point, a potential candidate is the socio-emotional significance the crying of a mother's own infant bears. Her own infant is the primary target of the affective attachment of mothers (Bartels & Zeki, 2004; Grasso et al., 2009; Leibenluft et al., 2004; Nitschke et al., 2004; Noriuchi et al., 2008; Strathearn et al., 2009). Moreover, infant's crying expression signals urgent need of care and protection (Abramowitz, Schwartz, & Moore, 2003; Acebo & Thoman, 1995; Hahn-Holbrook et al., 2011). These characteristics of own infant's crying face presumably makes them especially salient for mothers, which might accelerate the evaluation of it.

There are several alternative interpretations to the modulation pattern of the TF3 besides the accelerated evaluation of a mother's own infant's crying proposed above. First, the present results might reflect memory functions associated with recognition of familiar own infant's faces. A number of studies have linked P300 (Polich et al., 1994; Polich, 2007; Soltani & Knight, 2000) and P300-like enlarged positivity (Dolcos & Cabeza, 2002; Righi et al., 2012; Wilding, 2000; Yovel & Paller, 2004) to memory encoding and

recognition of memorized familiar items. Moreover, some studies (Halgren et al., 1995a, 1995b; Smith et al., 1990) have localized the generator of P300 to temporal memory-related regions. Considering these findings together with the fact that own infant's faces were more familiar for participants than those of stranger's infant, it is quite conceivable that neural activations accompanying memory recognition of own infant face have contributed to the observed pattern of TF3 modulation.

Second alternative explanation is that the observed pattern of TF3 modulation is attributable to emotional responses induced by stimulus faces. Own infant's crying expression is potentially the most negative stimuli for mothers (Abramowitz et al., 2003; Hahn-Holbrook et al., 2011) among the four types of target stimuli. Considering this together with the *negativity-bias* (Ito et al., 1998) of human emotional reaction, it is not surprising that own infant's crying face was most efficient inducer of emotional response. This explanation is partly refuted by the results of stimulus rating, which showed no signs that own infant's crying face was rated especially negative or arousing. However, given the limited reliability of subjective rating (Greenwald, McGhee, & Schwartz, 1998), it is still possible that TF3 modulation reflects differences in emotional responses induced by presented facial stimuli. To compensate for the methodological weakness of subjective rating, simultaneous recordings of EEG and physiological measurements of peripheral reactions (Herzmann, Schweinberger, Sommer, & Jentzsch, 2004; Tranel et al., 1988; Vico, Guerra, Robles, Vila, & Anllo-Vento, 2010), such as skin-conductance responses and heart rate should be quite helpful. Although correlation analyses did not reveal any correlation between emotional ratings and TF3 amplitudes, more objective measures of peripheral responses may show correlation with TF3 amplitude, which would be of great help in clarifying the functional significance of the processing stage reflected by this temporal factor.

Following the TF3, a large positive deflection of the TF1 was observed to crying and smiling expressions. The TF1 possibly corresponds to the pinnacle of the P300 as judged from their cortical distributions and latency ranges. This contention is supported by the finding that modulation pattern of TF1 is paralleled by that of P300 peak amplitude. Correlation analyses indicated that there was a positive correlation between TF1 amplitudes elicited by a mother's own infant's smiling expression and MAI-J score. This indicates that the mothers with more positive-feelings toward their infants showed increased neural response to smiling by their own infant. The rewarding value of own infant's smile is evidenced by several recent studies (Nitschke et al., 2004; Noriuchi et al., 2008). It is also known that individual differences in reactivity to rewarding stimuli is influenced by genetics (Camara et al., 2010; Filbey, Schacht, Myers, Chavez, & Hutchison, 2010) and hormonal status (Dreher et al., 2007; Frank, Kim, Krzemien, & Van Vugt, 2010). On the basis of these, we tentatively think that relation between TF1 amplitude and attachment attitude as found in the present study might be mediated by individual differences in response to rewarding stimuli, which is partly determined by genetic or hormonal predispositions. Examination of this hypothesis is surely an interesting topics for the future research.

The interpretation of the results of the present study are limited by the following methodological weaknesses. First, a relatively small number of electrodes were used, which prevented us from providing detailed analysis of scalp potential distributions or applying source reconstruction methods such as dipole source modeling. To further clarify the precise nature of the present findings, the use of high-density electrodes should be quite informative. Second, we did not include faces of infants that were not kin, but familiar to the mothers as a control condition, which prevented us from determining whether the effects of infant's identity are attributable to kinship or perceptual familiarity (Caharel et al., 2005, 2006; Furl, Van Rijsbergen, Treves, Friston, & Dolan, 2007). It is possible that perceptually familiarity of infant's face modulated neural processing of face, which might have led to differential neural responses to crying faces of own and unfamiliar infant.

As for the second limitation, we believe that personal attachment or kinship rather than mere familiarity have played at least some roles in modulating ERP responses on the following grounds. First, if the present results were explainable solely by perceptual familiarity, similar effect of face identity would have been observed for all the expressions, which was apparently not the case. Second, efficient processing of own infant's crying expression squares firmly with the indications of previous studies that mothers are particularly sensitive to own infant's attachment behaviors (Acebo & Thoman, 1995; Hahn-Holbrook et al., 2011; Kim et al., 2011; Noriuchi et al., 2008). However, considering the purpose of the present study, it is of primary importance in future studies to delineate the effects of perceptual familiarity and personal relationships by including different kinds of familiar faces.

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