

**Differential prefrontal response to infant facial emotions in mothers compared with non-mothers**

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Total number of pages: 26

Total number of figures: 2

Total number of tables: 1

## **Abstract**

A considerable body of research has focused on neural responses evoked by emotional facial expressions, but little is known about mother-specific brain responses to infant facial emotions. We used near-infrared spectroscopy to investigate prefrontal activity during discriminating facial expressions of happy, angry, sad, fearful, surprised and neutral of unfamiliar infants and unfamiliar adults by 14 mothers and 14 age-matched females who have never been pregnant (non-mothers). Our results revealed that discriminating infant facial emotions increased the relative oxyHb concentration in mothers' right prefrontal cortex but not in their left prefrontal cortex, compared with each side of the prefrontal cortices of non-mothers. However, there was no difference between mothers and non-mothers in right or left prefrontal cortex activation while viewing adult facial expressions. These results suggest that the right prefrontal cortex is involved in human maternal behavior concerning infant facial emotion discrimination.

Key words: Maternal behavior, prefrontal cortex, near-infrared spectroscopy, emotions, facial expression, reproduction, neuroendocrinology, imaging

## **Introduction**

Evidence suggests that females in all mammalian species, from rats to humans, undergo fundamental behavioral changes during pregnancy and motherhood (Kinsley and Lambert, 2006). Taking care of an infant requires the mother to be sensitive to the signals coming from her own infants, including visual (Kaitz et al., 1988) auditory (Purhonen et al., 2001) and olfactory cues (Kaitz et al., 1987; Porter et al., 1983), increasing their ability to respond appropriately to their infant's needs. These behavioral changes in pregnancy and motherhood can be explained by changes in the female brain caused by drastic hormonal fluctuation during pregnancy, birth and lactation (Kinsley et al., 2008; Wartella et al., 2003). In humans, however, little is known about the functional and structural changes that occur in the brain during pregnancy and motherhood.

In rodent species, several brain areas have been implicated in maternal behavior, such as the medial preoptic area, the ventral bed nucleus of the stria terminalis, amygdala, lateral septum, periaqueductal gray, nucleus accumbens and ventral tegmental area (Brunton and Russell, 2008). It has been reported that the prefrontal cortex (PFC) is related to maternal behaviors, and medial PFC lesions have been shown to impair maternal behavior in rats and hamsters (Afonso et al., 2007). Enhanced *c-fos*

expression has been found in the PFC in animals that are maternally active for the first time (Fleming et al., 1994; Fleming and Walsh, 1994). Changes in prefrontal activity have been reported in dams after exposure to pup suckling as well as oxytocin injection, which helps strengthen the mother-infant relationship (Febo et al., 2005). Macbeth et al. (2008) proposed that decreased levels and activity of DA, NE and 5-HT in the PFC may account for the increase in spatial working memory performance observed in pregnant females rats (Macbeth et al., 2008). Taken together, these findings support the notion that human maternal behaviors are associated with reproductive-hormone-induced functional and/or structural modulation of the PFC.

Several research groups have recently investigated how human mothers' brains respond to their own child's visual cues using functional magnetic resonance imaging (fMRI) to examine the neural correlates of maternal behaviors (Bartels and Zeki, 2004; Leibenluft et al., 2004; Minagawa-Kawai et al., 2008; Nitschke et al., 2004; Noriuchi et al., 2008; Ranote et al., 2004; Strathearn et al., 2008). This research has shown that mothers viewing their own infant's faces exhibit a distinctive pattern of brain activation in several areas including the PFC. Few studies, however, have compared brain activity during the discrimination of other infant faces between mothers and non-mothers, although maternal behavior could be triggered and/or maintained by

hormone-induced-functional and/or structural changes in the brain during pregnancy and motherhood in experimental animals.

Adult humans use both verbal and non-verbal expressions of emotion to respond appropriately during social interaction. For mothers, however, non-verbal facial expression may play a key role to identify their infant's emotions, since they are unable to express their emotions in words although they express their pleasant or disgust feeling by vocalization. As such, it is plausible that the maternal brain responds differently to infant emotional facial expressions compared to the expressions of adults.

The present study aims to determine whether activation of the PFC during the discrimination of infant emotional facial expressions is mother-specific. That is, we investigated whether this brain area undergoes functional changes when a woman becomes a mother. To this end, we studied distinctive maternal brain activity using near-infrared spectroscopy (NIRS). We compared maternal frontal cortex activity between mothers and non-mothers while discriminating pictures of six emotional facial expressions (happy angry, sad, fearful, surprised and neutral). Furthermore, we determined whether mothers' PFC responses to infant facial expressions differed from those elicited by adult facial expressions.

## **Materials and Methods**

### *Participants*

Fourteen non-mothers (mean age 28.4 years, ranging from 20 to 39 years; SD = 7.4) and 14 mothers (mean age = 31.2 years, ranged from 22 to 42 years; SD = 5.2) participated in this study. All participants were right-handed and none reported psychiatric or neurological abnormalities. All the mothers were the biological parents of the infants. The average age of the mothers' youngest child was 21.3 months (ranging from 9 to 36 months; SD = 9.5). There were no significant differences in age between non-mothers and mothers. All participants gave written informed consent after the purpose of the experiment was explained. The experimental protocol was in accord with the tenets of the Helsinki Declaration and was approved by the Ethics Committee of the Nagasaki University Graduate School of Biomedical Sciences.

### *Procedures*

Participants were seated in a dimly lit quiet room, and a 17-inch monitor was placed at a viewing distance of 50 cm. In facial discrimination tasks of infant and adult, color pictures of infant and adult faces were sequentially presented in a randomized order on the monitor, respectively (see Fig. 1), for 60 s (task period). Participants were

required to judge each facial expression as happy, angry, sad, fearful, surprised or neutral, and press an upper left, center, right, lower left, center, right button with the thumb of her right hand, respectively. These buttons were labeled with happy, angry, sad, fearful, surprised or neutral in one Chinese character. Participants were required to respond as accurately and quickly as possible within each 60-s task period so that they proceed to the next stimulus when the subject pressed a button, that is, the stimulus was presented until the subjects pressed a button. During the tasks, accuracy, reaction time (RT) and the number of answers were recorded.

Before each task, participants are asked to relax and view monitor displaying ‘please discriminate facial expressions’ for 10 s, during which the baseline NIRS recordings were made (pre-task baseline).

The infant facial expression pictures used in the present study were obtained as follows. We recruited four unfamiliar infant-mother couples, of which mother would not participate in the facial discrimination experiments. Infant’s emotional facial expressions were recorded by video camera (DCR-TRV18K, Sony) in five situations as follows. We recorded facial expressions of happiness when infants were playing with their mothers using a variety of age-appropriate toys, expressions of sadness when mothers left infants alone in the room (although mothers were watching their child from

behind a 1-way mirror), expressions of anger when mothers took away infant's favorite toys while they were playing with them, expressions of fear when an unfamiliar male entered the room and stared at the infant for 30 sec, expressions of surprise when a loud noise was made by a digital alarm (80 dB), and expressions of a neutral emotion when infants were at rest.

Still images of each infant's face while expressing the most intense emotion in each condition was captured from the video clips. All images were standardized for size, orientation, and background using Adobe Photoshop (Adobe Systems, San Jose, CA); the view was frontal or rotated by no more than 45° and vertically inclined by no more than 45°. We used the standard classification and labeling of emotional expressions typically used in studies involving adult faces. We produced a final set of 24 photos which included six facial expressions × 4 infants (two boys and two girls, mean age = 9.6 months, ranged from 8.1 to 10.6 years; SD = 1.2) based on the independent evaluations of a panel of other enrolled mothers. These mothers observed one photograph at a time and rated the intensity (1 [extremely low] to 7 [extremely high]) of the emotion expressed by the infant.

The adult facial expression pictures used in the present study were obtained from the DB99 (ATR, Kyoto, Japan).



## *NIRS*

Relative oxyhemoglobin (oxyHb) and deoxyhemoglobin (deoxyHb) were measured with two-channel NIRS (OM-220, Shimadzu Corp., Tokyo, Japan). Two NIRS probes were placed over the prefrontal regions, so that the emitters were positioned at Fp1 and Fp2, with detectors positioned 4 cm to the lateral side, placed along the T3-T4 line according to the international 10/20 system. The NIRS set-up records hemoglobin changes approximately 2-3 cm beneath the scalp, i.e., the cortical surface area (Hock et al., 1997; Toronov et al., 2001). The rate of data sampling was 1 s. The baseline was determined as the mean level over a 10-s period just before the 60-s task period. Simultaneous NIRS and fMRI studies have correlated cerebral blood flow more strongly to oxyHb than to deoxyHb (Strangman et al., 2002). Therefore, oxyHb changes were adopted as a measure of cerebral activation in this analysis.

## *Data analysis and statistics*

Mean accuracy rates, reaction times (RT) and the number of answers were compared using a two-way repeated measures ANOVA, separately for each parameter. Group and task were considered independent variables.

Obtained oxyHb data were averaged for each participant during the baseline

period (10 s) and each task period (60 s). The oxyHb changes (task minus baseline) were analyzed using a two-way repeated measures ANOVA, separately for each task. Group and hemisphere were considered independent variables. When significant interactions were detected, subsequent analyses of simple main effects were conducted. Where overall effects were reported, these were followed by Tukey's post hoc tests, comparing pairs of groups. In addition, the oxyHb changes with task performances as covariates were also analyzed by using ANCOVAs.

## Results

### *Behavioral data*

There was no significant main effect on accuracy rates in ‘group’ [ $F(1, 26) = 1.36, p = 0.25$ ]. There was a significant main effect of ‘task’ [ $F(1, 26) = 343.49, p = 0.000$ ]. No significant interaction was observed [ $F(1, 26) = 1.38, p = 0.25$ ].

There was no significant main effect on RT in ‘group’ [ $F(1, 26) = 2.37, p = 0.14$ ] or ‘task’ [ $F(1, 26) = 3.85, p = 0.06$ ]. No significant interaction was observed [ $F(1, 26) = 1.7, p = 0.27$ ]. There was no significant main effect on the number of answers in ‘group’ [ $F(1, 26) = 2.30, p = 0.14$ ] or ‘task’ [ $F(1, 26) = 2.00, p = 0.17$ ]. No significant interaction was observed [ $F(1, 26) = 0.11, p = 0.74$ ]. These results may exclude a possibility that mothers spent more time than non-mothers and viewing infant faces than adult faces.

### *NIRS data*

In the emotion discrimination task of the infant facial expressions, two-way repeated measures ANOVA showed no significant main effect of ‘group’ [ $F(1, 26) = 1.63, p = 0.21$ ] and ‘hemisphere’ [ $F(1, 26) = 1.49, p = 0.23$ ] in oxyHb changes. However, the results revealed a significant interaction between ‘group’ and

‘hemisphere’ [ $F(1, 26) = 4.70, p < 0.05$ ]. Subsequent analyses showed a significant difference between the groups for right hemisphere activation [ $F(1, 52) = 4.71, p < 0.05$ ], demonstrating that oxyHb changes in the right PFC during the emotion discrimination for infant facial expressions were significantly greater in mothers than non-mothers (Fig. 2a). In addition, oxyHb increases in the right hemisphere were significantly larger than those in the left hemisphere in mothers [ $F(1, 26) = 5.74, p < 0.05$ ]. No other pair-wise comparisons were significant.

In the emotion discrimination task for images of adults, two-way repeated measures ANOVA showed no significant main effect on oxyHb changes in ‘group’ [ $F(1, 26) = 0.46, p = 0.50$ ] or ‘hemisphere’ [ $F(1, 26) = 0.39, p = 0.54$ ]. There was no significant interaction between ‘group’ and ‘hemisphere’ [ $F(1, 26) = 0.51, p = 0.48$ ] (Fig. 2b).

## **Discussion**

The results of the present study demonstrated that discriminating infant facial emotions, which may be required for maternal behavior, caused a significant increase in right prefrontal activity in mothers compared with non-mothers. This finding indicates that right prefrontal activation in response to infant facial discrimination may be related to parental status. On the other hand, mothers did not display an increase in PFC activation (compared with non-mothers) in either hemisphere when discriminating adult facial expressions, which may not be required for maternal behavior. This finding indicates that PFC responses to adult facial discrimination are independent of parental status. Taken together, these results suggest that the right PFC is involved in maternal behaviors and that maternal behaviors recruit different brain areas to other social behaviors.

However, it can be postulated that viewing infant faces itself activated prefrontal cortex in mothers. When mother discriminated gender of infant faces, it could not increase right frontal activity (data not shown). We can, therefore, conclude that right maternal prefrontal cortex is activated during discriminating facial emotions but not during passive viewing facial emotions.

The main aim of the present study was to determine whether brain activity is

modulated when a person becomes a mother. During pregnancy and motherhood, mammals (including humans) (Kinsley and Lambert, 2006) experience dramatic changes in a variety of hormones, which have been shown to induce changes in the brain in other mammalian species (Brunton and Russell, 2008). In humans, mothers have an enhanced attractiveness of infant odors, ability to identify own infant odor, and ability to discriminate between infant pain and hunger cry (Fleming et al., 1997). The results of the current study revealed an enhanced PFC response to infant facial emotions in mothers compared with non-mothers, in accord with the notion that reproductive hormones affect the human brain during the pregnancy and motherhood in a way that increases maternal behavior. This speculation is supported by a previous neuroimaging study, which found that PFC activation in response to infant vocalizations was dependent on parental status (Seifritz et al., 2003).

It is also plausible that the maternal experience itself modulates brain function without any changes in reproductive hormones. One study in rats reported that repeated exposure to foster pups led virgin females to acquire and eventually express a full spectrum of maternal caretaking behaviors directed toward pups (Seip and Morrell, 2008). However, it should be noted that it is difficult to determine the effect of parenting experience and reproductive hormones on brain function separately, because exposure

to foster pups could modulate their reproductive hormone levels. Current research could be extended by investigating PFC activity in nurses working in nurseries, who take care of infants as a job.

In addition, previous studies have investigated the neural correlates of maternal behaviors using different tasks. In several studies in humans, the brain activity of mothers while viewing pictures or videos of their own infants was compared with activity while they were viewing other unfamiliar infants. Findings from this research have suggested PFC involvement in maternal behaviors (Bartels and Zeki, 2004; Leibenluft et al., 2004; Minagawa-Kawai et al., 2008; Noriuchi et al., 2008; Ranote et al., 2004; Strathearn et al., 2008), which is consistent with the findings of the present study. The findings of these previous studies are likely to reflect the activity of the brain areas underlying maternal bonding, which occurs exclusively between mothers and their infants. In contrast, the findings of the present study are more likely to have reflected the brain activity underlying maternal empathy for infants more generally.

The current findings raise the question of how enhanced PFC activity during the discrimination task of infant facial expressions might functionally benefit mothers. It is possible that mothers become more skillful at discriminating facial expressions due to increased PFC activation. The current results do not support this possibility, however,

because there were no significant differences in response accuracy, RT or the number of answers in the infant facial discrimination task between non-mothers and mothers. Furthermore, ANCOVAs revealed that differential prefrontal responses between mothers and non-mothers were not confounded with differential task performances during the discrimination task of infant facial expressions ( $p < 0.05$ ).

We tentatively propose that maternal PFC activations reflect their empathy for infants. Empathy is defined as the ability to take the psychological and emotional perspective of another, so that the other person's thoughts, feelings and actions can be understood. Empathizing ability would thus be particularly critical in the case of a mother rearing her infant. Indeed, Brodmann areas 11 and 10, over which we placed detector probes, were found to be necessary for cognitive empathy (Shamay-Tsoory et al., 2009). Furthermore, previous neuroimaging studies have implicated the medial frontal lobes as a part of neural circuit underlying 'mentalizing' or 'theory of mind' (ToM), which enables us to understand the mental states - beliefs, desires and intentions - of others (Gallagher and Frith, 2003).

In contrast to cognitive empathy, the emotional empathy system is thought to primarily involve Brodmann area 44 (Kramer et al., 2010). Moreover, developmental studies have reported that infants show emotional empathy, but it is only later during



childhood and adolescence that individuals become increasingly capable of cognitive empathy (Decety and Jackson, 2004; Gallese, 2003; Hoffman, 1977; Preston and de Waal, 2002). These findings suggest the possibility that human females acquire an increased ability for cognitive empathy for infants once they become mothers.

In our study, maternal prefrontal activation during the discrimination of infant facial emotions was predominantly right-sided. Several previous studies implicated an important role of the right PFC in human maternal behaviors using NIRS (Minagawa-Kawai et al., 2008) and fMRI (Bartels and Zeki, 2004), producing findings consistent with our current results. Furthermore, Lorberbaum and colleagues (1999, 2002) reported that infant crying and laughing, compared with control stimuli, produced neural activation in the temporal cortex, which was stronger on the right side. It was found that the anterior cingulate and right medial PFC were the only brain regions exhibiting significantly increased activity in response to infant cries compared with white noise control sounds (Lorberbaum et al., 1999; Lorberbaum et al., 2002). Furthermore, a large body of literature, primarily from human lesion studies, has implicated the right hemisphere in the processing of emotional and social information (Adolphs et al., 2001). Our finding of increased activation on the right suggests that the right hemisphere might be preferentially involved in maternal behavior.

In conclusion, the results of the current study demonstrated that right PFC activity increased during the discrimination task of infant facial expressions in mothers, but not in non-mothers. This PFC activation increase was not observed during the discrimination task of adult faces, suggesting that the involvement of the right PFC is specific to maternal behaviors. This finding leads us to propose that maternal PFC activation results from dynamic hormonal changes during pregnancy and motherhood. Further studies are required to verify this hypothesis.

## **Acknowledgments**

This research was supported financially by the Research Institute of Science and Technology for Society, Japan Science and Technology Agency, and by KAKENHI, Grant-in-Aid for Young Scientists (B), (19790180) and Grant-in-Aid for Scientific Research (C), (21590259). The use of the ATR DB99 database was permitted from ATR Promotions. We are also grateful to Sumihisa Honda for providing statistical processing help.

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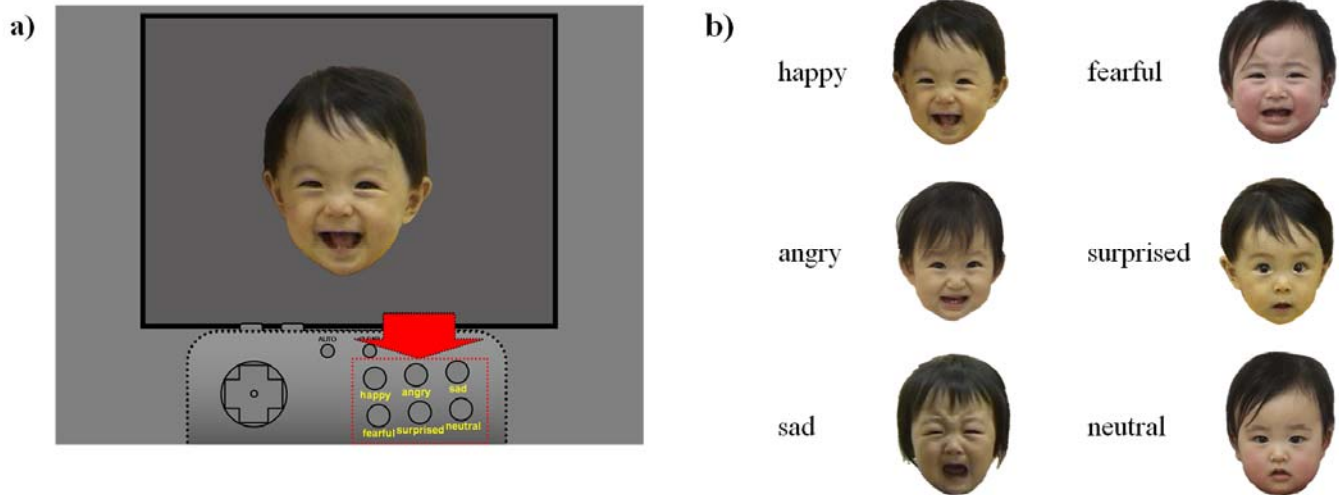
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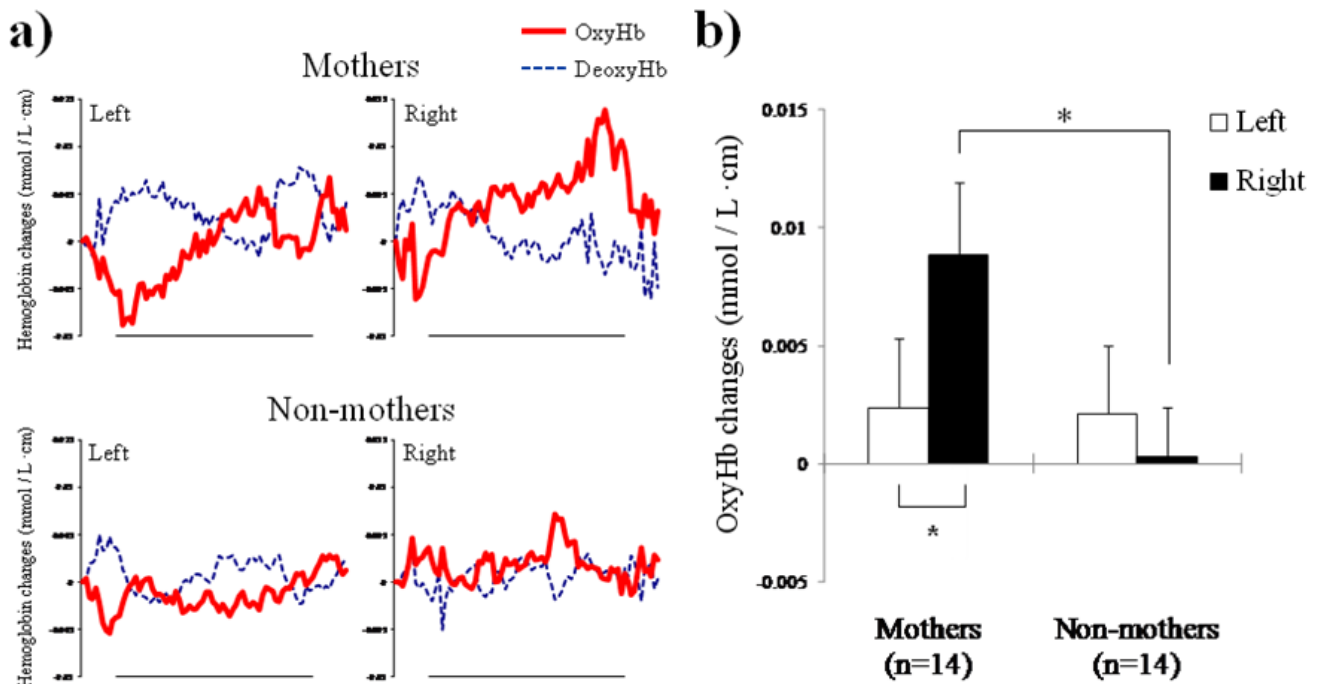
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## Figure legend



**Figure 1**

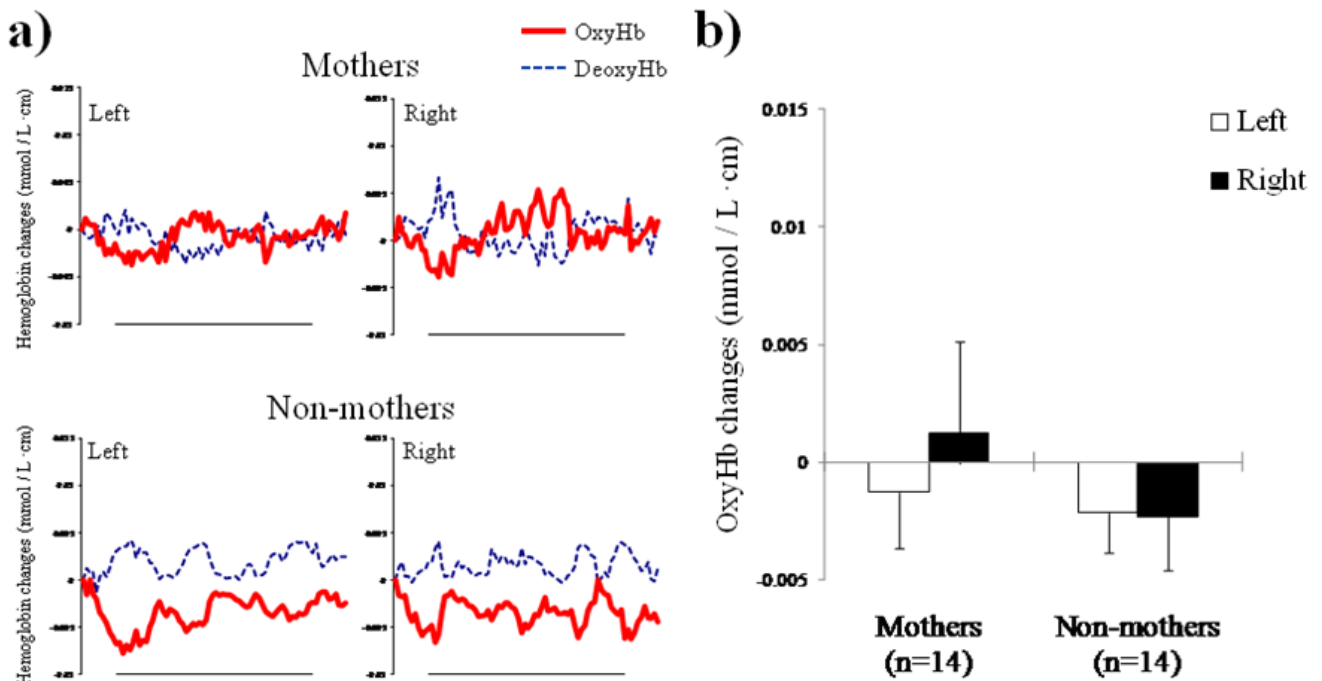
a) Example of the screenshot in the experiment. b) Examples of photographs used in the emotion discrimination task of the infant facial expressions.



**Figure 2**

a) Hemodynamic responses to the emotion discrimination tasks of the infant facial expressions. Top: Mothers, Bottom: Non-mothers. Right: Right PFC, Left: Left PFC. Line: red, oxyHb, blue, deoxyHb. Horizontal bars indicate periods of the task. b)

Comparisons of oxyHb changes between mothers and non-mothers in response to the emotion discrimination task of the infant facial expressions. Data are expressed as the mean  $\pm$  se. The number of subject in each group is given in parentheses. \*:  $p < 0.05$  (mothers vs non-mothers in the right hemisphere), \*:  $p < 0.05$  (left vs right hemisphere in mothers)



**Figure 3**

a) Hemodynamic responses to the emotion discrimination tasks of the images of adults.

Top: Mothers, Bottom: Non-mothers. Right: Right PFC, Left: Left PFC. Line: red,

oxyHb, blue, deoxyHb. Horizontal bars indicate periods of the task. b) Comparisons of

oxyHb changes between mothers and non-mothers in response to the emotion

discrimination task of the adult facial expressions. Data are expressed as the mean  $\pm$  se.

The number of subject in each group is given in parentheses.

**Table 1** Behavioral data

	Accuracy (%)		RT (msec)		Number	
	Mothers	Non-mothers	Mothers	Non-mothers	Mothers	Non-mothers
Infant	59.2 ±		2710 ±		24.7 ±	
emotion	2.6	54.5 ± 2.1	296	2148 ± 181	2.5	30.6 ± 3.7
Adult	87.1 ±		2129 ±		28.1 ±	
emotion	1.4	86.2 ± 1.9	127	1990 ± 195	1.8	32.7 ± 2.9