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Possible neural correlate of young child attachment to mother in 4 to 5 year olds

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Attachment between mothers and infants is the most primitive and primary form of human social relationship. Recently, it has been reported that the anterior prefrontal cortex (APFC) of infants younger than 3 years old may play an important function in forming attachments to their mothers. However, little is known about how the neural correlates of attachment develop after 3 years of age. Bowlby argued that there is a critical period, between birth and 2.5 years (0–30 months), for attachments to form and if it does not form in this time then it is not possible to develop thereafter. The current study investigated the role of the APFC in the attachment of 5 year olds to their mothers. Subjects included 18 young children (5.0 ± 0.4 years), whose mothers' smiles were video recorded. By means of near-infrared spectroscopy (NIRS), we measured APFC activation in the children while viewing their mother smiling, and compared the activation with that resulting from an unfamiliar mother smiling. We found significant increases in right APFC activation in these 5 year olds in response to their mother's smile. Furthermore, the APFC response to mothers' smiles did not change as a function of age between 4 and 5 years old. These results suggest that the right APFC is still involved in young childrens' attachment to their mothers until at least 5 years of age.

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1. Introduction

The mother is usually the first person with whom the human infant meets and socially interacts. Immediately after birth, reciprocal social interactions begin between mother and child to establish an attachment. This attachment serves as a motivational and behavioral system for infants to approach or maintain close proximity to the attachment figure in both physical and mental ways when they are alarmed, with the expectation that they will receive protection and emotional support. John Bowlby was the first researcher to propose the importance of understanding early attachment to the mother using clinical studies in the 1950s.[1] Later, Moriceau and Sullivan demonstrated that children should form a secure attachment with their mother in infancy and childhood.[2] This process has been proven to be highly important since the attachment formed underlies subsequent inter-personal relationships throughout his or her lifetime.[3]

The establishment of infant-mother attachment is largely based on their experience of mutual interaction. Adult humans fluently use both verbal and non-verbal means to express and understand emotion, to enable appropriate responses during social interactions. Infants, however, find it difficult to recognize their mother's emotions and express their own emotions accurately in words. On the other hand, infants do show the characteristic ability of recognizing their mother's face within a few months after birth, or even shortly after birth under certain conditions.[4, 5] Infants thus learn to recognize the emotional state of the mother via facial expressions, so that non-verbal facial expression may play a key role in communicating with their mother. As such, interaction via emotional facial expressions may be

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crucial for attachment formation between infant and mother.

Recent studies have focused on the neural bases for forming an attachment to the mother during early infancy.[6] All of these studies[7-10] compared children's brain activity while viewing their mother's smile with that during viewing of another mother's smile because in infancy emotional facial expressions may be essential for attachment formation as mentioned above. As a result, children viewing their mother's smile exhibit distinctive patterns of brain activation in several neural areas [7-9, 11, 12] such as the neural networks for attention,[13, 14] facial processing,[15-17] and emotion recognition.[18, 19] In addition, it has also been suggested that the neural network underlying attachment involves reward networks,[20] especially the anterior part of the prefrontal cortex (APFC) containing the orbitofrontal cortex (OFC), which is the front end of the mesolimbic reward circuit.[16, 21-25] It is worth noting that the OFC plays a role in coding positive affect information mediated by different sensory modalities[26-28] and in the "Social Brain Network".[29]

Although a number of researchers (investigating 9–10 month,[8] 9–13 month,[9] and 7–8 month[11] olds) have elucidated the neural correlates of attachment between mothers and infants younger than 30 months, there is no developmental study on the neural correlates in infants older than 30 months. It is important to study this because Bowlby argued that there is a critical period between the ages of birth and 2.5 years (0–30 months) in which conditions must be right for an attachment to form, and if it does not form in this time then it is not possible to develop thereafter.[30] Therefore, to understand how attachment between infant and mother changes after 30 months, we investigated the neural correlates of attachment in young children around 60 months (5 years old). To this end, we studied APFC activity in young children using near-infrared spectroscopy (NIRS), comparing activity during viewing of a video of their mother smiling with that of an unfamiliar woman smiling.

Although NIRS can monitor only surficial activations with relatively low spatial resolution,[31] this non-invasive and relatively concise neuroimaging technique has advantages over functional MRI (fMRI) when used in subjects of various ages, particularly infants and young children.

2. Material and method

2.1. Participants

The participants were eighteen 4 and 5 year old healthy and experimentally naïve young children (seven boys and 11 girls, mean age 5.0 years, age range from 4.5–5.6 years). We recruited the children through several kindergartens in Nagasaki, Japan. All participants were screened by a child psychiatrist with assessments including a psychological assessment and a neurological examination. None of the children had a past or current developmental, medical, or psychiatric diagnosis. All participants were right-handed on the basis of the Edinburgh Handedness Inventory.[32] The parents of all participants gave written informed consent on behalf of the participants after being given a full explanation of the purpose of the experiment. 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.

2.2. Stimuli

Initially, we digitally video recorded (GZ-MG40; Victor) neutral and smiling facial expressions from the participants' mothers to be used as the stimuli. The video camera was positioned approximately 135 cm in front of the mother in a quiet experimental room and a recording made for approximately 3 min. For recording the smiling expression, we asked each mother to smile as if talking to her child, raise the corners of her mouth so that her face was most expressive, and look straight at the camera to provide stimuli with eye contact.[33] When the experimenter recorded the mothers' faces, she conversed to help them smile. For recording of the neutral faces, each mother was asked not to show any facial expression. Each video image was edited using Canopus Edius J (Thomson Canopus Co., Ltd., Japan) to obtain 20 s of video stimuli of the mothers with neutral and smiling expressions. When editing each video image, the following criteria were employed for controlling physical characteristics among the mothers: 1) the gaze was fixed straight, 2) the upper part of the body was visible, and 3) the image was recorded against a white background. The video stimuli were presented with no sound because of their high variance in auditory information.

2.3. Procedure

2.3.1. Visual presentation task

After placement of the NIRS probes, each participant performed the visual presentation task during NIRS recording as follows. First, a white hairline cross in the black background was presented for 20 s, then the video stimulus

of their mother's neutral face was presented for 20 s, and finally the video stimulus of their mother's smiling face was presented for 20 s. After this, a white hairline cross was again presented for 20 s, another video stimulus of an unfamiliar mother's neutral face was presented for 20 s, followed by the same mother's smiling face. Finally, after 20 s, the unfamiliar mother's smiling face disappeared, and 20 s of a white hairline cross was presented. The task was repeated three times. For half of the participants, the unfamiliar mother's faces were presented prior to their own mother's faces to control for the potential effects of presentation order. Participants had no task to perform and were asked to just watch the video stimuli on the screen. None of the participants could identify the person who was presented as the unfamiliar mother.

2.3.2. NIRS recording

The NIRS probes were attached on the forehead according to the international 10–20 electrode system employed in electroencephalography (EEG), such that a horizontal line through FP1-FPZ-FP2 matches the lowest two detectors in our NIRS system. Two emitters and two detectors were aligned as previously reported,[34] resulting in two recording sites (channels) as these positions enable assessment of the PFC including the APFC area. Right and left recording sites were referred to channels (CH) 1 and 2, respectively. During the visual presentation task, hemoglobin concentrations were measured at a sampling rate of 6 Hz using the 2-channel NIRS system (NIRO-200; Hamamatsu Photonics, Japan; wavelengths 775, 810, and 850 nm, path length 18 cm). A modified Lambert-Beer law was used for calculation of the oxyhemoglobin (oxyHb) and deoxyhemoglobin (deoxyHb) concentration changes.

2.4. Statistical analysis

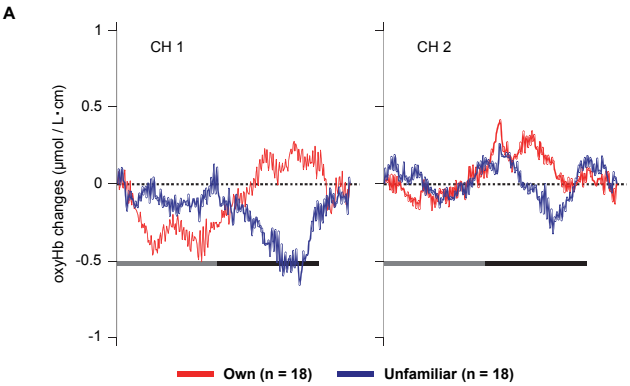
Among the 27 young boys and girls, nine participants were excluded from the analysis for the following reasons: less than two trials for either the mother or unfamiliar woman conditions (three participants), equipment failure (two participants), or the point-to-point concentration change was larger than 2 μM/L・m (four participants).

Thus, the data from a total of 18 participants were used for successive analyses. We report the results based on the changes in oxyHb concentrations, which we consider the most sensitive parameter of hemodynamic responses.[35-38] First, the changes in oxyHb concentrations were averaged for each participant by using data in the last 13.3 s of the neutral and smiling conditions. Then, we calculated the differences between the means of the neutral and smiling conditions. We conducted a two-tailed paired t-test with a Bonferroni correction to examine the possibility that the activity for both the mother and unfamiliar face stimuli were greater than a chance level of 0 and to test the hypothesis that the mother's smile condition would elicit greater activity than the unfamiliar smile condition in CH1. Changes in oxyHb concentrations (task minus baseline) were analyzed by two-way repeated measures analysis of variance (ANOVA) with channel (two channels) and condition (mother or unfamiliar smile) as within-participant factors.[39]

3. Result

We examined the possibility that the responses to both the mother and unfamiliar face stimuli were greater than a chance level of 0. In the mother's smile condition, the mean value for oxyHb concentrations in CH1 was significantly increased (t (17) = 2.97, p = 0.09[-1]) (Figure 1; A, B). However, there were no significant differences in oxyHb concentrations in CH2 (t (17) = 2.06, ps > 0.06) between the two conditions. By contrast, in the unfamiliar smile condition, there were no significant changes in the concentration of oxyHb in CH1 or CH2 (CH1: t (17) = -1.73, ps > 0.10, CH2: t (17) = -0.25, ps > 0.80) (Figure 1; A, B).

We tested the hypothesis that the mother's smile condition would elicit greater activity in the right APFC than in the unfamiliar smile condition using the mean values for the oxyHb concentrations in CH1 (Figure 1; B). The concentration of oxyHb was significantly increased in the mother's smile condition as compared with the unfamiliar smile condition in CH1 and CH2 (CH1: t (17) = 3.07, p = 0.07[-1], CH2: t (17) = 1.20, ps > 0.25) (Figure 1; A, B).



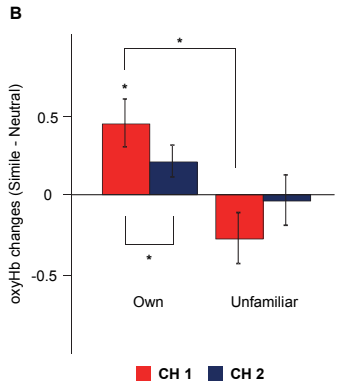


Figure 1. (A) The time course of the average change in oxyHb in APFC. Time course during the neutral (shadow line) and smiling (solid line) face stimuli. Averaged waveforms activated by own (red) and unfamiliar (blue) conditions. **(B) The magnitude of oxyHb changes in the APFC**. CH1 and 2 of the magnitude of oxyHb changes in response to viewing own-mother facial smiling against unfamiliar-mother facial smiling. Comparisons of the response magnitude of oxyHb changes (smiling minus neutral) in each condition (own: red bars, unfamiliar: blue bars). Error bars indicated SE. $^{*}p < 0.05$, vs. unfamiliar condition.

Two-way ANOVA was conducted to compare the activity in the two regions in both the mother's and the unfamiliar smile conditions. We found a significant interaction between the two factors ($F(1, 17) = 5.90$, $p = 0.03$) and the main effect of the condition ($F(1, 17) = 6.03$, $p = 0.03$), while the main effect of the channel was not statistically significant ($p = 1.00$). Subsequent analyses showed that the mother's smile conditions yielded a significantly greater oxyHb increase than the unfamiliar smile conditions in CH1 ($F(1, 34) = 10.77$, $p = 0.03^{-1}$) (Figure 1; B). No significant effects of the condition were found for CH2 ($ps > 0.30$).

In the scatter plots shown in Figure 2, the oxyHb concentrations are plotted against age in months. There were no significant correlations between age and oxyHb concentrations in CH1 or CH2 (CH1; $r = 0.17$, $ps > 0.49$, CH2; $r = 0.11$, $ps > 0.11$).

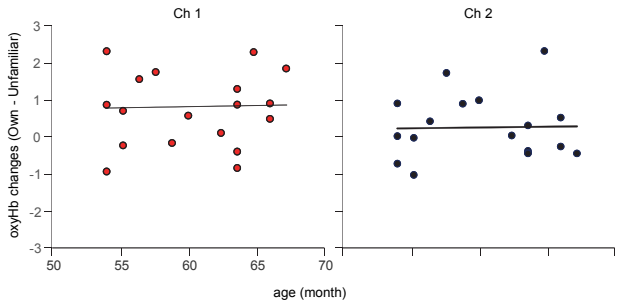


Figure 2. Scatter plots of ages and the response magnitude of oxyHb changes of own vs. unfamiliar conditions. Solid line shows correlations between ages (54 to 67 months) and oxyHb changes (own-unfamiliar conditions). No significant correlations between age (month) and the response magnitude of oxyHb changes were found at CH1 and 2.

4. Discussion

In the present study, using non-invasive NIRS brain imaging, we investigated the neural correlates of attachment to mothers in children older than 30 months old. The results revealed that viewing their mother's smiling face, which may be essential for attachment formation in early childhood, caused a significant increase in CH1 in children around 5 years of age. According to the spatial registration for NIRS,[40] CH1 areas may correspond to the APFC, including the orbital prefrontal cortex. Previous studies have shown that the APFC may be the neural correlate of the formation of attachment to mothers in infants 9–10 months old,[8] 7–8 months old[11] and 9–13 months old,[9] which is consistent with the current study investigating 5 year olds. These findings suggest that the APFC is involved in the formation of attachment in infants and young children from birth to at least 5 years of age.

Based on the estimation carried out using the standard adult brain, we assumed that CH1 might be located around the right APFC. This estimation with the adult standard brain measure may not be exactly the same in the young child brain because the size of the head is different between young children and adults. In the current study, the NIRS probes were placed in an area similar to previous infant studies performed in our laboratory[34] and another laboratory,[41] in which probes were attached at FP1 and FP2 according to the international 10–20 system. According to other studies using the international 10–20 system, the nasion or forehead and the frontal brain region are not so different among 3 month olds, 12 month olds, and adults, [42-45] so the estimation for the APFC position in infants and young children should be almost equivalent with the position of the APFC in adults. Therefore it can be speculated that their mother's smile activated the APFC in young children.

Bowlby argued that there is a critical period between the ages of birth and 2.5 years (0–30 months), which is an appropriate time for attachments to form, and if it does not form in this time then it cannot develop thereafter.[30] Considering this point, it is assumed that some changes would happen in the APFC, the neural correlate of attachment formation, after 30 months of age. In the current study, mothers' smiling activated the APFC in young children at the

average age of 5 years. Furthermore, there was no change in the APFC response to their mother's smile in young children from 54–67 months old. Previous NIRS studies have showed that the APFC area is involved in attachment formation in infants 9–10 months old,[8] 7–8 months old[11] and 9–13 months old.[9] From the previous and current neuroimaging studies, it can be speculated that a mother's smile continues to activate the APFC during the developmental period from 6 months to 5 years old, suggesting that the neural correlate of infant attachment stays active in the APFC after Bowlby's critical period has ceased.

This suggestion seems to contradict Bowlby's attachment theory. However, Bowlby investigated emotionally disturbed children in clinical conditions and formed attachment theory by describing the link between early infant separations from the mother and later maladjustment.[46] It is worthwhile noting that APFC activation by child cues in mothers with depression is attenuated.[47, 48] In addition, it has been also shown that there is decreased activity in the neural correlate of attachment formation in mothers with child rearing problems.[49] No report, however, has investigated the functional changes in the neural correlates of attachment in infants with emotional problems. Also in the present study, none of the participants had neurological or psychiatric disorders. Future studies should investigate the APFC response to mothers' smiles in young children with emotional problems, during and after the critical period, to clarify the neural mechanisms underlying Bowlby's attachment theory.

Our results also provide new evidence that APFC activation in response to mother's smile, after Bowlby's critical period, by directly revealing localized neural responses from the APFC area associated with the social brain network. Although indirect ERP (event-related potential) evidence revealed the functional importance of the APFC area in attachment formation in 6–67 month olds.

The current study found that viewing their own mother's smiling face activates the APFC in infants in accordance with previous studies.[8-10] Minagawa-Kawai and colleagues have shown that smiling may be a powerful reinforcer that can produce a pleasant affect.[9] Taken together, it seems that the mother's smiling evokes the neural network involved in reward processing,[23, 50, 51] especially the mesolimbic reward circuit, the front end of which is the OFC.[16, 21-25]

According to our and other studies [9, 39, 40], the dominant activity at the inferior of the APFC can be considered to originate from the OFC. However, the APFC activity may include neural activity other than from the OFC. The inferior and medial parts of the APFC are known to be associated with cognitive and emotional empathies52 and the evaluation of social behaviors.[26, 27] In addition, the APFC is also linked to a variety of social behaviors[53, 54] and monitoring outcomes or reward values.[20, 55-57] Therefore, the activation of the APFC observed in the present study could involve the reward system associated with the monitoring and evaluation of mother's smile-induced pleasantness and/or reward value, suggesting that the APFC is a neural correlate of attachment to their mother in young children.

It is possible that the APFC activation resulting from the sight of a mother's smile might be produced by familiarity rather than by attachment. To the best of our knowledge, only one study has tried to segregate the effect of familiarity from that of attachment.[58] They investigated the activation of the mother's brain when viewing her child, friends of her child, unfamiliar children and unfamiliar adults. In the present study there are limitations in concluding that the APFC is the neural correlate of young child attachment. However, an experimental strategy similar to ours has been used to elucidate the neural basis underlying attachment between mother and child in previous studies,[59-63] the results of which are consistent with ours. It would be thus appropriate to assume that the activation patterns observed here are at least partly associated with attachment.

In conclusion, our NIRS data provide clear evidence that there are different responses in young children in the perception of the smiles of their mother and unfamiliar women. This finding implies the probable presence of cortical specialization for the mother's smile in young children and suggests that the APFC is possible neural correlate for attachment in young children. Furthermore, the current study suggests that there is not a developmental change in the neural correlate for infant attachment during and after the critical period in Bowlby's attachment theory.

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