The neuroscience of maternal love

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Maternal love, which is at the core of maternal behavior, is essential for the mother–infant attachment relationship and is important for an infant’s development and mental health. In addition, maternal love plays important roles in promoting not only the infant’s resilience, but also the mother’s. Therefore, it is crucial to clarify the neural basis of maternal love and related behaviors to understand both normal mothering and abusive and neglectful mothering. Here, we have reviewed our recent neuroimaging studies on the neural basis of maternal love and behavior. Based on the assumption that a mother’s love for her infant is invariant in any situation, we found that a limited number of the mother’s brain areas were specifically involved in maternal love, namely, the orbitofrontal cortex (OFC), striatum, anterior insula, and periaqueductal gray, suggesting that maternal love is mediated via integration of the two major neural systems in the OFC: the dopamine reward system (the OFC and striatum) and the interoceptive information processing system (the OFC, insula, and periaqueductal gray). Additionally, when the mother viewed her own infant in distress, there was significant activation in the dorsal OFC, dorsolateral prefrontal cortex, ventrolateral prefrontal cortex, dorso medial prefrontal cortex, dorsal anterior cingulate cortex, posterior cingulate cortex, caudate nucleus, supplementary motor area, and posterior superior temporal sulcus/temporoparietal junction. These results suggest that a highly elaborate neural mechanism, based on the neural basis of maternal love, mediates the diverse and complex maternal behaviors that mothers engage in when raising and protecting their own infants.

Keywords: maternal love; maternal behavior; brain; fMRI; infant; attachment; mother; orbitofrontal cortex; dopamine; reward


Introduction

Maternal love is one of the most powerful motivational factors underlying the behavior of a mother as she cares for and protects her infant. That is, maternal love is essential for the way in which a mother makes sacrifices to care for her infant; this love is a dynamic force that empowers a mother to remain vigilant and sustain the exhausting schedule involved in protecting and nurturing an infant. Bowlby [1] stated that a mother’s love during a child’s infancy and childhood is as important for the mental health of a child as vitamins and proteins are for physical health. The amount of love involved in a mother’s interactions with her infant profoundly influences the stability of the mother–infant relationship and the quality of the mother–infant attachment. In addition, maternal love plays important roles in promoting not only the infant’s resilience, but also the mother’s. Therefore, it is crucial to clarify the neural basis of maternal love and related behaviors to understand both normal mothering and abusive and neglectful mothering. Here, we have reviewed our recent neuroimaging studies of the neural basis of maternal love [2–9] and behavior, proposing schematic models for the neural processes involved.
Neuroimaging and ratings of feelings

The mother–infant attachment is not a unilateral process that depends solely on the mental state and attitudes of the mother. The infant plays an important part in the mother–infant attachment because infant behavior powerfully affects a mother’s emotions. Therefore, strong maternal attachment, which is expressed in the mother as affectionate behavior, vigilance, and protectiveness, should be induced by an infant’s attachment-related behaviors. We assumed that the neural correlates responsible for maternal behavior and its core, maternal love, could be realistically assessed by observing a mother’s brain activity as she views video clips of her own infant demonstrating a variety of attachment behaviors [10, 11].

We focused on mothers of infants who were approximately 16 months of age, had developed a specific bond to their mothers, and displayed clear attachment behaviors [9]. Attachment behaviors, exhibited by a mother’s own infant as well as other infants in two different situations, were presented to the mothers as video stimuli. In the first situation, the infant was smiling at his/her own mother while they played together (play situation: PS). In the second situation, the infant showed distress when his/her mother left (separation situation: SS). While mothers should experience happiness when watching video clips of their own infant in the first situation, they should feel anxious and protective when shown video clips of their own infant in the second situation. Because mothers are impelled to protect their infants, a biologically essential mechanism for species preservation, the neural system mediating maternal behavior should be activated more clearly when a mother views a situation depicting her own infant in distress.

After the fMRI scan, the mother was asked to rate her feelings (happy, motherly, joyful, warm, love, calm, excited, anxious, irritated, worry, and pity) while viewing sample video clips selected from the video stimuli. The subjective ratings described as happy, motherly, joyful, warm, love, calm, and excited were significantly higher when mothers viewed their own infants compared with other infants in the PS, and they were also higher for motherly, love, and excited in the SS. In addition, there were no significant differences between the two situations in the subjective feelings of motherly and love, suggesting that a mother’s love exists in the mother herself, regardless of how she responds to her own infant in any situation.

Neural basis of maternal love

Based on the assumption that maternal love is invariant, existing in the mother herself, regardless of how she responds to her own infant in any situation, and as shown in the above results for mother’s subjective feelings [2], we found a limited number of brain areas that were specifically involved in maternal love. These areas were the right orbitofrontal cortex (OFC) and anterior insula, the periaqueductal gray (PAG), and the striatum (Fig. 1). The OFC plays an important role in the reward system. This region receives ascending dopamine projections from the ventral tegmental area (VTA) and is critical in representing stimulus-reward value [12, 13]. Correlation analyses showed that the magnitude of activation in the right OFC was positively correlated with a mother’s intensity of worry (Fig. 1) and that the magnitude of activation of the left OFC was positively correlated with the intensities of the feelings of joy and happiness. All of these feelings, both positive and negative, are important for facilitating maternal behavior.

The PAG has direct connections with the OFC [14], also receives direct connections from the limbic areas, and contains a high density of oxytocin receptors [15]. In fact, maternal behaviors may be inhibited when the PAG is pharmacologically or physically targeted [16, 17]. Additionally, the PAG is involved in endogenous pain suppression during one’s experience of intense emotional experiences such as childbirth.

The anterior insula is involved in the processing of caress-like touching between individuals [18] and is
considered to be important for affiliative behavior between mothers and infants. The insular cortex is organized in a hierarchical caudal–rostral direction, whereby primary sensory inputs projecting to the posterior insula, including somatosensory, vestibular, and visceral inputs, are progressively processed and integrated across modalities in the middle insula [19, 20]. The insula differentiates sympathetic and parasympathetic activity [21, 22], and sympathetic activity is represented in the right insula [21, 23].

Finally, the striatum receives strong projections from the OFC [24] and plays an important role in stimulus–reward learning. In turn, this learning is mediated by afferent dopamine input, such that responses associated with predictions of greater reward in a given context are reinforced and hence are more likely to be subsequently selected.

Based on the above findings, we here propose a schematic model of maternal love, as shown in Figure 2. The OFC and striatum are included in the dopamine reward system that mediates reward evaluations for the mother’s own infant and promotes maternal motivation for caretaking. Moreover, the OFC, insula, and PAG are included in the interoceptive information processing system that is related to what are known as "homeostatic emotions", which are emotions specifically relevant to our ability to self-regulate through homeostasis. Accordingly, the mother's brain is thought to be activated in such a way that the OFC integrates the reward and interoceptive processing systems, with the integration of these two systems serving to motivate maternal behavior. Based on this model, it is reasonable to assume that a mother's own infant is not only her own reward, acting as a motivation for caretaking, but that the infant is also responsible for the maternal homeostasis.

Maternal behavior based on maternal love

Mothers show a specific neural response pattern to their own infant’s distress (SS) compared with their own infant’s smiling (PS). This neural activation pattern appeared for the dorsal OFC (dOFC), dorsolateral prefrontal cortex (DLPFC), ventrolateral prefrontal cortex (VLPFC), dorsomedial prefrontal cortex (DMPFC), dorsal anterior cingulate cortex (dACC), posterior cingulate cortex (PCC), supplementary motor area (SMA), caudate nucleus, and posterior superior temporal sulcus/temporoparietal junction (pSTS/TPJ) (Fig. 3). It suggests that complicated neural processing is required for a mother to quickly recognize and respond to an infant’s distress cues.

The dOFC is related to behavioral choice [25], and its activity may therefore reflect the selection of the appropriate maternal strategy for reacting to an infant’s distress. Caudate nucleus activity is involved in motor programming, suggesting that the initiation of emotion-induced behavior [26, 27] is evoked when a mother views her own infant in distress. The right VLPFC is involved in decoding emotion-related facial expressions [28–30]. Accordingly, this activity suggests that when a mother views her own infant’s attachment behaviors (i.e., calling for his/her mother), the mother recognizes the infant’s emotions based on the infant’s facial expressions. The DMPFC is involved in making sense of an emotional experience [31, 32] and in representing the emotions
or mental states evoked by interpersonal interactions [31]. In such situations, dACC activation is involved in conflicts, acting as an alarm that signals the DLPFC, which in turn underlies an executive function. On the other hand, the PCC subserves visual attention to salient stimuli and is related to memory recollection [33]. Furthermore, lesions to both the ACC and PCC impair maternal behavior in rats [34, 35]. Therefore, activation of these brain regions may indicate that a mother is paying attention to her own infant who demonstrates strong attachment behaviors. In short, a mother recognizes her infant’s emotional and mental states that are evoked by separation from his/her mother.

We also found activation of the pSTS/TPJ. By perceiving cues involving the infant’s biological motion and gaze direction, mothers may immediately try to interpret their infants’ distressed states not only by getting an infant’s intention, but also by attending to the infant’s emotional states [36–38]. The DLPFC is involved in constructing reappraisal strategies that can modulate activity in multiple emotion-related limbic areas and participates in the conscious experience of emotion, including the inhibition of potentially excessive emotion. Thus, this region is vital to the process of monitoring one’s own emotional state in making personally relevant decisions [39].

In our study, DLPFC activation was associated with a mother’s relatively complex emotional state when viewing her own infant in the SS, because positive emotions such as love and motherly feelings coexisted with negative ones such as anxiety and worry. In this complex situation, a mother’s emotional responses to her own infant might be appropriately regulated as she monitors her own emotional states and controls excessive negative emotional effects so as not to appear excessively affected to the distressed infant. Our findings that a mother responds more strongly to her own infant’s crying (SS) than to her child smiling (PS) seem to be biologically meaningful in terms of adaptation to the specific demands associated with successful infant care.

Based on these findings, a schematic model of maternal behavioral response to an infant’s distress can be depicted, as shown in Figure 4. A mother recognizes and understands her infant’s mental and emotional states on the basis of the infant’s cues (the DMPFC, VLPFC, and pSTS/TPJ). Through this saliency processing (the PCC), an alarm signal (the dACC) is conveyed to the DLPFC, which serves an executive function. Decision-making and selection of appropriate behaviors are made (the dOFC and DLPFC), and the necessary motor programs are prepared/simulated in the motor-related regions (the caudate nucleus and SMA). All of these neural processes for protecting a mother’s own infant depend on the neural basis of maternal love (the OFC, striatum, insula, and PAG). Modified from Kikuchi et al[3].
these neural processes underlying maternal responses to infant distress depend on the neural basis of maternal love (the OFC, striatum, insula, and PAG) (Fig. 2).

Conflict of interest statement

The authors declare that they have no conflicting interests.

List of Abbreviations

dACC: dorsal anterior cingulate cortex; DLPFC: dorsolateral prefrontal cortex; DMPFC: dorsomedial prefrontal cortex; dOFC: dorsal OFC; OFC: orbitofrontal cortex; PAG: periaqueductal gray; PCC: posterior cingulate cortex; dOFC: dorsal OFC; OFC: orbitofrontal cortex; VTA: ventral tegmental area

Author contributions

All authors conceived and designed the experiments, performed the experiments, analyzed the data, and read and approved the final manuscript.

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