SOCIAL NEUROSCIENCE
2020, VOL. 15, NO. 4, 380–384
https://doi.org/10.1080/17470919.2020.1764093

Routledge
Taylor & Francis Group

OPEN ACCESS Check for updates

Maternal brain in the process of maternal-infant bonding: Review of the literature

Faranak Gholampour[a], Madelon M. E. Riem[b] and Marion I. van den Heuvel[c]

[a]Faculty of Social Sciences, Doctoral School of Sociology, Eötvös Loránd University, Budapest, Hungary; [b]Department of Medical and Clinical Psychology, Tilburg University, Tilburg, The Netherlands; [c]Department of Cognitive Neuropsychology, Tilburg University, Tilburg, The Netherlands

ABSTRACT

The mother-infant relationship is one of the most important bonds among all mammals and develops when a mother shows emotional and physical attention toward her infant. Studies suggest that maternal brain alterations, including structural and functional changes, may help mothers to form a strong bond with their infant. Investigation of mothers' unique response to her own infant, when smiling, crying or playing, could be the first step to uncover the neural bases of maternal-infant bonding. Studies are beginning to explore maternal brain changes underlying the process of mother-infant bonding. In this short review, we present an overview of the growing literature about maternal brain changes and neural responses to infant stimuli, which may underlie the process of forming the maternal-infant bond in healthy, non-clinical samples. Taken together, the maternal brain network consists mostly of areas related to salience/reward and emot processing, including the precuneus cortex, medial frontal cortex, anterior cingulate cortex, orbitofrontal cortex, caudate and nucleus accumbens, amygdala, and insula. Recommendations for future research are also discussed.

ARTICLE HISTORY

Received 4 October 2019
Revised 18 March 2020
Published online 25 May 2020

KEYWORDS

Maternal-infant bonding; maternal brain; neural changes; infant

Bonding is a special connection between mothers and infants, partners, family, or friends. In mother-infant bonding, a mother can recognize her infant and show an affectional attachment toward the infant to protect him/her and give warmth, comfort, and food (Broad et al., 2006). According to Kennell and Klaus (1976), maternal-infant bonding is about a mother's affections, emotions, and attitudes toward her infant. Bonding includes nurturing behaviors such as holding, hugging, rocking, singing, feeding, gazing, and kissing. There are other important factors including face-to-face interaction, having eye contact, skin-to-skin touching, smelling, and smiling, that are all vital to have a good and high-quality mother-infant bonding (Feldman et al., 2011; Perry, 2002). Importantly, the emotional bond between mother and child forms the infants' first model for close relationships and is strongly associated to the infant's survival and cognitive development in the future (Rossen et al., 2016).

Recent studies have suggested that maternal brain alterations may help mothers to form strong bonding with their infant and develop good caregiving practices, starting in the prenatal period (Barba-Müller, Craddock, Carmona & Hoekzema, 2019). In all mammalian species, pregnancy and parturition are related to changes in the maternal brain involved in motivation, emotional and physical nurturance, and attention to the infant (Piallini et al., 2015). The maternal brain network consists of multiple brain areas, including multiple cortical regions and the limbic system, which act to support various forms of maternal bonding behavior (Kohl & Dulac, 2018). In the postpartum period, both hormones and interactions with the baby are connected to complex structural and functional changes in the maternal brain. These changes in the maternal brain may be of the utmost importance, since the survival of the infant dependents on the mother's efforts and actions (Barba-Müller, Craddock, Carmona & Hoekzema, 2019).

Yet, little is known about maternal brain changes underlying mother-infant bonding. Understanding how a mother responds uniquely to her own infant, when smiling, crying or playing, could be the first step to know about the neural bases of maternal-infant bonding (Strathearn et al., 2008), since these facial cues from infants play an important role in drawing out maternal care and attention (Thompson-Booth et al., 2014). In the current review, we present an overview of the growing literature about the maternal brain and its neural responses to infant stimuli (faces, cries, etc.) that may underlie the process of forming the maternal-infant bond.

CONTACT Marion I. van den Heuvel m.i.vdnheuvel@tilburguniversity.edu Department of Cognitive Neuropsychology, Tilburg University, Warandelaan 2, Tilburg 5037AB, The Netherlands

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Neural bases of the maternal brain

The process of becoming a mother initiates changes in maternal brain structure and function that might facilitate mother-infant bonding (Dudek et al., 2020; Swain et al., 2007). The findings of a longitudinal neuroimaging study by Hoekzema et al. (2017) showed that human pregnancy leads to long-lasting alterations in maternal brain structure. They investigated the changes in gray matter across pregnancy and two years after pregnancy by using MRI. They found that pregnancy is associated with long-lasting gray matter volume reductions in the maternal brain in regions affecting the anterior, posterior, cortical midline, and specific sections of the bilateral prefrontal and temporal cortex. Furthermore, they examined the changes in gray matter volume across pregnancy in relation to bonding by using the Maternal Postnatal Attachment Scale (Condon & Corkindale, 1998). The analyzes showed that the reduction of gray matter volume significantly predicted the quality of maternal bonding and the absence of hostility toward their newborns in the postpartum period. These reductions continued for at least two years post-pregnancy and prepared women for the transition into motherhood. Structural and functional neural plasticity in the human brain in the early postpartum period may therefore help the mother to accept her new role and making a bond with her baby, especially by measuring activity in the mothers' brains in response to their babies' auditory or visual stimuli (Kim et al., 2016; Swain et al., 2014a).

Kim et al. (2010b) identified structural changes in similar brain regions in mothers as Hoekzema et al. (2017), during the first few postpartum months. Brain imaging data were obtained between 2 and 4 weeks postpartum and between 3 and 4 months postpartum. The findings showed increased gray matter volumes in large regions of the prefrontal cortex, parietal lobe, and midbrain. They concluded that this postpartum period is a critical time for the development of maternal bonding. In addition, increased gray matter volume in the midbrain was associated with positive maternal-infant bonding and mother's emotions toward her baby. Changes in these brain regions may therefore be important for promoting healthy maternal-infant bonding.

Neural response to infant cues

Previous studies showed that several parts of the maternal brain are involved in response to infant's cues, including the brain reward system, especially in the amygdala and the hypothalamus (Feldman, 2015; Lenzi et al., 2009). In a study by Leibenluft et al. (2004), mothers' neural activation in response to viewing photographs of their own child, friends of their child, unfamiliar children, and unfamiliar adults was investigated by using fMRI. The findings showed that viewing pictures of their own child evoked unique patterns of neural responses. Moreover, this unique response was related to the mother-child relationship. Stronger responses and increased activation in areas associated with emotional responses such as the right amygdala, the left insula, anterior paracingulate cortex, and posterior superior temporal sulcus (STS) were found when mothers viewed a picture of their own child's face compared with the faces of familiar children. The same activation happened in the right anterior paracingulate, the left insula, the left STS, and the posterior cingulate-precuneus bilaterally after viewing a picture of their own child's face compared with the faces of unfamiliar children. They concluded that the uniqueness of these activations show that the mother-infant relationship could vary from other types of social relationships. In a study by Barrett et al. (2012), maternal brain responses to infant stimuli in 22 mothers with a three-month-old infant were measured by showing positive and negative faces of own and unfamiliar infants during fMRI scanning. The findings showed that greater amygdala response to own compared with unfamiliar positive infant faces was related to positive emotions about and strong maternal bonding to the own infant. Moreover, mothers experiencing lower levels of anxiety showed a higher amygdala response to their own infant and reported more positive attitudes toward their infants.

Reward is highly involved in shaping behavior and maternal behavior is likely one of the most strongly reward-mediated behaviors among all mammals (Nephew et al., 2015). In line with this, several studies examined maternal brain responses to infant cues and reported increased activation along reward system pathways (Bartels & Zeki, 2004; Kim et al., 2010a; Moses-Kolko et al., 2014; Noriuchi et al., 2008; Numan & Young, 2016; Strathearn et al., 2008; Swain et al., 2014a; Young et al., 2017). For example, Strathearn et al. (2008) showed that when first-time mothers observe their own infant's face, all of the key dopamine-associated reward-processing regions of the brain are activated, including the midbrain VTA (ventral tegmental area)/substantia nigra regions, the striatum, and the prefrontal cortex, as well as the primary motor area. They found that happy, but not neutral or sad own-infant faces, significantly activated nigrostriatal brain regions interconnected by dopaminergic neurons, including the substantia nigra and dorsal putamen. In another study (Wan et al., 2014), the neural basis of maternal-infant bonding was investigated by using fMRI and videotaping mother-infant interaction, when mothers viewed videos of their own infant compared to an unknown infant, and

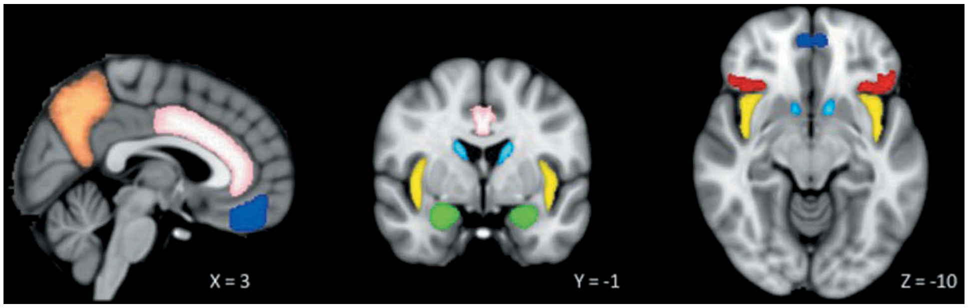

Figure 1. The maternal caregiving brain network. Precuneus cortex (orange); medial frontal cortex (dark blue); anterior cingulate cortex (pink); orbitofrontal cortex (red); caudate and nucleus accumbens (light blue), amygdala (green); insula (yellow). Regions derived using the Harvard-Oxford (sub)cortical atlas.

whether such unique neural responses were associated with behavioral and self-reported measures of mother-infant relations. The findings showed that greater own-infant response in the middle frontal gyrus was associated with higher quality of mother-infant play interactions, while greater sensory and visual area activations, and to a lesser extent, insula activations, were associated with greater perceived maternal warmth toward her infant.

Several brain areas have been reported to be specifically related to maternal behaviors and emotions toward her infant, such as the right orbitofrontal cortex (OFC), anterior insula, the periaqueductal gray (PAG), and the striatum (for a review, see Kikuchi & Noriuchi, 2015). According to Swain et al. (2014a), hypothalamic-mid-brain-limbic-paralimbic-cortical circuits act in concert to support maternal responses to their infants. Some researchers (e.g., Parsons et al., 2013) underscore the critical role of OFC in the parent-infant relationship. The theory is that both infant's visual and vocal cues evoke OFC activity in parents, which is vital for orienting of their attention to infant's needs, making a strong bond between them, and facilitate parenting by responding to infant's stimuli. Together, these studies demonstrate that several parts of the maternal brain, mostly related to the reward system, are activated in response to infant's cues during maternal-infant bonding in the postpartum period. See Figure 1 for an overview of brain areas implicated in maternal-infant bonding and interaction.

Future directions

Decades of research studies have provided detailed knowledge about the maternal brain in animals. Yet, comparable studies in humans are still sparse. Therefore, further longitudinal fMRI studies of human mothers are needed to confirm findings from animal studies and to better understand maternal brain patterns during maternal-infant bonding in human mothers. Importantly, animal studies have reported changes in structural and functional brain circuitry (for a review, see Pereira, 2016), while functional and structural connectivity research in human pregnancy and postnatal period is still lacking. Since the brain largely operates by its connections between brain areas, it will be an important future direction to investigate alterations in brain networks in response to pregnancy and motherhood. Moreover, the use of novel brain imaging techniques, such as hyperscanning (i.e., scanning of mother and infant simultaneously with EEG or fNIRS; see for a review Wass et al., 2020; Babiloni and Astolfi, 2014), can provide new insights into the mother-infant bond by computing "neural synchrony" between mother and infant.

Another issue that needs further attention in future research is the variability of the measures used to assess mother-infant bonding across studies. While some studies used experimental approaches such as EEG and fNIRS during the mother-infant interaction, other studies have used scanning mothers while they are observing own and standard infant-related photos. Researchers should also continue to experiment with dynamic stimuli, such as videos of babies (Swain et al., 2013).

In addition, because of the little knowledge about the structural plasticity and changes in the maternal brain during pregnancy and the postpartum period, it is not clear whether healthy bonding activates the neural bases in the maternal brain or changes in maternal brain lead to a positive or negative relationship between the mother and her infant. In other words, the direction of the effect and its causality is not clear yet. For that reason, more research using longitudinal designs is required to expand our knowledge in the field of maternal bonding and the maternal brain in the pre- and postpartum period. Some researchers (e.g., Wan et al., 2014) suggested using procedures that activate the mother and infants' attachment system in future research since these may evoke greater differentiations between participants and may better connect the maternal brain with behavior.

A final recommendation for future research is to expand exploration to the paternal brain as well, especially about traumatized fathers or whom with socio-psychological issues. In modern society, many fathers have an important parenting role in their infant's development and research has shown that the paternal brain is sensitive to caregiver experiences (Abraham et al., 2014; Swain et al., 2014b).

Conclusion

The postpartum period is an important time for a mother to form a good bond with her baby. Changes in the maternal brain may be vital for all mothers to make them ready for accepting their new role as a mother and building a strong relationship with the baby. Here, we reviewed the neural bases of the maternal brain during maternal-infant bonding in the postpartum period. From the literature we reviewed, a set of brain regions were identified that are activated during maternal-infant bonding, when the mothers show emotion, love, and attention toward their own baby and response to baby's cues (such as cry or smile). This maternal caregiving network includes areas involved in salience detection/reward processing (amygdala, striatum, precuneus), and emotion processing and regulation (anterior cingulate cortex, insula, OFC, and medial prefrontal cortex). Moreover, increases in gray matter volumes in the prefrontal cortex, midbrain, and parietal lobes are directly related to maternal feelings and behaviors toward the infant. Neural changes in the maternal brain may promote positive mother-infant relationships and develop mothers' love, emotions, attention, and bonding toward the infant. Continued examination of the maternal brain is important in order to understand why some mothers find it difficult to form a bond with their infant, such as mothers with postpartum depression and anxiety.

Disclosure statement

No potential conflict of interest was reported by the authors.

Funding

MvdH was funded by a Veni grant from the Dutch Scientific Oranization (NWO - VI.Veni.191G.025).

ORCID

Madelon M. E. Riem http://orcid.org/0000-0002-5147-7939
Marion I. van den Heuvel http://orcid.org/0000-0003-2027-6234

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