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Neuroendocrine mechanisms for parental sensitivity: overview, recent advances and future directions

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Abstract

Early parent–infant relationships play important roles in infants’ development. New parents adapt to the developing relationship with their infants to coordinate parenting behaviors in the milieu of infant needs, hormones, moods, and stress. This review highlights research from the past two years, using noninvasive brain-imaging techniques and naturalistic tasks in mothers and fathers in relation to psychological, and endocrine measures. Recent work also connects parental brain physiology with parental sensitive behavior, parent/child outcomes and parent psychotherapy. Understanding neurobiological mechanisms underlying parenting thoughts, behaviors and moods (see Figure 1) will help identify mental health risks and contribute to parental mental health interventions and resilience.

Overview

Parental caregiving requires sensitive and contingent responses for each parent to their own child’s distress signals, such as cries. Parental caregiving, including recognition and acknowledgment of baby-signal salience, reflective self-awareness and emotion regulation toward social attachment depend on brain function [1–3]. Functional magnetic resonance imaging (fMRI) studies of brain activity as a function of baby-stimuli, have established responses in adaptable social brain circuits—highlighting those concerned with social-emotion response and regulation [4–9]. Recent advances in the study of basic neuroendocrine mechanisms that regulate parental sensitivity across stress, psychopathology and intervention for parents and their infants may inform cross-generational mental health [10] (Figure 1).

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None.

Experimentally simulating parenting to probe brain circuits

The interpretation of neuroimaging research is often limited by the extent to which experimental paradigms are able to simulate ‘real-life’ experiences. Current approaches to the parental brain involve the use of stimuli and experimental paradigms that are increasingly more likely to address relevant domains of parental function. One prototypical context for studying the brain basis of social understanding is naturalistic mother–infant interaction. In one recent attempt to experimentally approach the social synchrony that may occur during parent–infant interactions as a key aspect of parenting [11^{*}], the authors used video vignettes of three different mother–infant dyadic interactions in the scanner to probe brain responses among healthy postpartum mothers. Each participant’s interaction with their own 4–6 months old infant was videotaped and micro-coded for synchrony. The authors found that recognition of mother–infant synchrony in the vignettes activated the dorsal anterior cingulate cortex (dACC), fusiform, cuneus, inferior parietal lobule, supplementary motor area, and nucleus accumbens in the participants. Furthermore, the level of dACC activation was correlated with the participants’ own parent–infant synchrony scores. It was thus plausible to adapt naturalistic mother–infant interaction into a well-controlled experimental task in the context of an fMRI study. In another fMRI study [12^{*}], the authors found that the strength of neural responses in amygdala and hypothalamus were more sensitive to their own children’s negative (versus positive) feedback during a decision-making task involving observing infant suffering in mothers with higher dispositional personal distress when perceiving other’s suffering in general.

Neuroendocrine connections

Maternal caregiving behavior is related to a range of neuroendocrine systems, including oxytocin (OT) [13] and cortisol [14]. In a recent study [15], brain activation to infant cues was studied among healthy mothers at extremes of the maternal sensitivity spectrum. In this study, 15 mothers with the highest sensitivity (HSMs) and 15 mothers with the lowest sensitivity (LSMs) were selectively recruited from a pool based on mother–infant play interaction at 4–6 months postpartum. Brain responses to viewing videos of their ‘own’ versus an ‘unknown’ infant in 3 affective states (neutral, happy, and sad) were measured at 7–9 months postpartum. The participants’ plasma OT was measured immediately following their free-play interactions with their infant. HSMs versus LSMs showed significantly greater brain activation in right superior temporal gyrus (STG) in response to own versus unknown neutral infant and to own-happy vs. own-neutral, and the right STG activation in this contrast was negatively correlated with post-free-play OT responses in HSMs mothers. The right STG in LSMs was not differentially activated in response to own infant stimuli. In another example, dispositional personal distress was associated with greater cortisol reactivity to social evaluation stress in mothers, and mother’s ventral ACC response to positive versus negative child feedback to their parenting decisions was inversely related to parenting-related cortisol reactivity [12^{*}]. Perhaps further work will confirm these findings and reveal the directionality of brain and hormone physiology that relate to sensitive parenting.

Child outcome connections

One recent study begins to fulfill the promise of connecting sensitive parenting and parental brain physiology in the first few postpartum months with later child outcome [16*]. In this study, relationships between parental thoughts/actions and brain responses to baby-stimuli in mothers and fathers in the neonatal period were studied in relation to the child's social and emotional development at toddler age. Mothers (n = 21) and fathers (n = 19) were scanned while they listened to their own and unfamiliar baby's cry in the first month postpartum. Mothers' higher levels of anxious thoughts/actions about parenting in the first month postpartum, but not at 3–4 months postpartum, were associated with lower child socio-emotional competencies at 18–24 months postpartum. Maternal neural responses in motor cortex and substantia nigra were positively and negatively associated with their anxious thoughts and actions, respectively. Meanwhile, in the fathers, a more positive perception of being a parent during the first month postpartum, but not at 3–4 months postpartum, was associated with higher socioemotional competencies in infants at 18–24 months postpartum. Paternal neural responses in auditory cortex and caudate were also positively associated with their positive thoughts, perhaps because of enhanced sensory information processing. Thus, although awaiting replication, this work implicated certain parent brain regions, associated with very early postpartum parental thoughts and behaviors that relate to their infant's future socioemotional outcome. Possible sex differences and treatment implications in these findings require further research.

Paternal Brain Research

Exploring the potential similarities and differences between mothers and fathers parenting-related brain function is another current direction of parental brain research [17,18]. Building on similar research on mothers, changes in fathers' brain structure during the first 4 months postpartum using voxel-based morphometry (VBM) analysis have been reported (n = 16) from 2–4 to 12–16 weeks postpartum [19]. Fathers exhibited an increase in gray matter volume (GMV) in several brain regions involved in parental motivation, including the hypothalamus, amygdala, striatum, and lateral prefrontal cortex. Conversely, fathers exhibited decreases in GMV in the orbitofrontal cortex, posterior cingulate cortex, and insula. The findings suggest that neural plasticity in fathers' brains may be distinct from those of mothers reported previously [20].

Parental brain in psychopathology

Parental mood symptoms are also an issue of current work and high concern given the impact on child development. Research is continuing from past studies showing that the depressed mother's amygdala may be hypo-responsive to certain standard cognitive neuroimaging challenges [21] and that dampened amygdala response may be shown among mothers with unresolved attachment trauma after viewing their own (but not unknown) infant's crying faces [22]. Using a child face empathy task [23], depressed compared to healthy mothers displayed greater reactivity of the right amygdala, which was interpreted as emotional dysregulation. Finally, amygdala reactivity was increased in a self-focused baby-cry task designed to provoke brain responses in participants with a history of adverse early life experiences sometimes described as a malevolent background 'shark music' [24**]. This

fits with the report that amygdala response to infant stimuli is a function of the personal relevance of the stimuli. Variance in the properties of infant stimuli and context of presentation, along with research using hormone challenges will be helpful to clarify the role of the amygdala in depression—especially given that often-used depression measures may not perfectly capture real-life parental dysfunction. For example, intranasal OT effects on amygdala response to infant crying was moderated by attachment security of the mothers, with OT decreasing emotional and amygdala reactivity only in mothers with insecure attachment representations [25]. Thus, parents with insecure attachment—perhaps different from other attachment classifications, may have different brain mechanisms that render them amenable to oxytocin interventions.

Parental brain under stress

Recently, some parental brain studies reported findings related to childhood poverty and other parental stress. For example, childhood poverty impacts parents—and interestingly in a sex-specific manner in the brain [26]. In females, childhood poverty was associated with increased neural activations to infant cry in the posterior insula, striatum, calcarine sulcus, hippocampus, and fusiform gyrus, but with decreased neural responses to infant cry in the same regions in males. Furthermore, neural activation in these regions was associated with higher levels of perceived annoyance elicited by infant cries and reduced motivation to approach crying infants regardless of the gender of the participants [26]. This work underlines the need for special attention to the paternal brain as mentioned above. In a related study [27], lower income was associated with reduced responses to infant cry in brain circuits that evaluate emotional valence (medial prefrontal gyrus), regulate affect (middle prefrontal gyrus) and process sensory information (superior temporal gyrus). Furthermore, lower positive perceptions of parenting were associated with reductions in infant-cry response in the right middle frontal gyrus and superior temporal gyrus.

Parental brain influenced by parenting interventions

Characterization of parental brain function and dysfunction may also be informed by neuroimaging before and after parenting treatment. Current parent brain studies include Mom Power (MP) intervention, which aims to promote maternal empathy, reflective functioning, and stress reduction skills [28,29]. In one study, MP treated mothers, as compared to untreated mothers, showed decreased parenting stress and increased child-focused responses in social brain areas highlighted by the precuneus and its functional connectivity with subgenual anterior cingulate cortex—key components of social cognition; furthermore, time-dependent reduction in parenting stress was related to concomitant increased child- vs. self-focused baby-cry responses in amygdala-temporal pole functional connectivity, which may facilitate maternal ability to take her child's perspective [30^{*}]. In other unpublished data, MP significantly increased maternal empathy-dependent amygdala responses for own versus other child's joyful expressions. Finally, another intervention, Attachment and Biobehavioral Catch-up (ABC) was associated with larger increases in event related potential responses to emotional faces relative to neutral faces, which in turn was associated with observed maternal sensitivity [31].

Perhaps parenting may be conceptualized as a specific instance of altruism that may positively influence health-related outcomes and is amenable to intervention [32–34]. In further work on MP-treatment brain mechanisms, maternal amygdala's response when mothers were instructed to emotionally attune and empathize the emotions expressed by their own child (versus unknown child) was increased. Furthermore, the greater the maternal amygdala activity in response to positive versus negative child emotions, the more reduction in their parenting stress was observed from pre-treatment to post-treatment [35]. Taken together, these results suggest that enhancing child-oriented altruism can protect mothers from adverse effects of distress and stress related to caregiving, consistent with the hypothesis that prosocial motivation improves caregivers' wellbeing [33].

Future directions

Parental brain research is a quickly evolving type of research, so prospective and longitudinal studies will consider many important transition periods and environmental factors with context-sensitive paradigms.

First, the study of the parental brain will proceed with a combination of well-established paradigms and innovative and more realistic probes. Experiments known to probe certain aspects of brain function, such as executive functions and emotion response/regulation, may incorporate naturalistic and personally salient infant stimuli to integrate parental brain function with a larger body of neuroimaging literature. In addition, more naturalistic and personally relevant stimuli will be pursued to assess real-time parental brain functioning. Careful attention will be required to the measures of parental thoughts and behaviors [36] as demonstrated in a recent study in which brain activity in response to own baby-cry correlated with a measure of mental state talk, but not with more global aspects of observed caregiving [37]. Perhaps the child will be included in forms of neuroimaging that allow for more natural movement, such as with functional near-infrared spectroscopy (fNIRS) and electroencephalography (EEG) [31]. Finally, across all fields of neuro-science, imaging practices are currently coming to terms with reproducibility problems of low statistical power and analytic approaches [38]. In addition to adequately powered studies, perhaps the personalized and naturalistic approaches that have been pioneered in the study of the parental brain, and attempt to reflect real-time parental planning, responding and decision-making, may avoid some of the neuroimaging problems of other fields.

Potentially informative multimodal neuroimaging approaches may incorporate measures of functional resting state connectivity [39] and connectomics [40] in addition to functional neural activation and structural metrics. Such multimodal approaches may enhance the utility of machine learning methods in developing diagnostic and prognostic models for healthy parental adaptation vs. psychopathology [41]. Current literature suggests mixed evidence for anatomical and functional correlations. Thus far, one human study suggests structural changes occur in the maternal brain over the early postpartum, including correlations with positive perception of baby [20]. Further work on this topic may be fruitful given animal studies that suggest reduced neurogenesis in the hippocampus but increased synaptic density in the prefrontal cortex during the stressful postpartum period [42]. While training-induced increased grey matter volumes have been associated with increased

activation in the human hippocampus [43], decreased grey matter volumes were associated with increased activation in the amygdala among trauma-exposed individuals [44]. Likely further combination of neuroimaging approaches with measures of relevant hormones will be pursued.

The fact that high-stress environments, such as poverty, being a single or teenage parent, high marital conflict, and substance exposure are significant risk factors for maternal insensitivity toward infants [45–48] calls for more specific studies from brain imaging perspectives to determine specific mechanisms. Such specificity, as well as more work on the healthy parents, will be critical for developing targeted interventions and treatments that are effective to prevent psychopathology for those at risk, improve symptoms of psychopathology among parents already affected and cross generations to improve offspring mental health.

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Figure 1.

Parental brain – Early life factors, such as experience of parental warmth and previous mental health affect plastic brain circuits that determine maternal affective regulation and caregiving outcomes for mothers, fathers and their children. Adaptable circuits, some of which are overlapping, include those for salience/alarm/reward processing (amygdala, insula, ventral striatum), emotion regulation (anterior cingulate) and executive function/empathy (prefrontal cortices and precuneus) – with input from hormones such as OT and cortisol (adapted from Ref. [9]).