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Explaining individual variation in paternal brain responses to infant cries

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ABSTRACT

Crying is the principal means by which newborn infants shape parental behavior to meet their needs. While this mechanism can be highly effective, infant crying can also be an aversive stimulus that leads to parental frustration and even abuse. Fathers have recently become more involved in direct caregiving activities in modern, developed nations, and fathers are more likely than mothers to physically abuse infants. In this study, we attempt to explain variation in the neural response to infant crying among human fathers, with the hope of identifying factors that are associated with a more or less sensitive response. We imaged brain function in 39 first-time fathers of newborn infants as they listened to both their own and a standardized unknown infant cry stimulus, as well as auditory control stimuli, and evaluated whether these neural responses were correlated with measured characteristics of fathers and infants that were hypothesized to modulate these responses. Fathers also provided subjective ratings of each cry stimulus on multiple dimensions. Fathers showed widespread activation to both own and unknown infant cries in neural systems involved in empathy and approach motivation. There was no significant difference in the neural response to the own vs. unknown infant cry, and many fathers were unable to distinguish between the two cries. Comparison of these results with previous studies in mothers revealed a high degree of similarity between first-time fathers and first-time mothers in the pattern of neural activation to newborn infant cries. Further comparisons suggested that younger infant age was associated with stronger paternal neural responses, perhaps due to hormonal or novelty effects. In our sample, older fathers found infant cries less aversive and had an attenuated response to infant crying in both the dorsal anterior cingulate cortex (dACC) and the anterior insula, suggesting that compared with younger fathers, older fathers may be better able to avoid the distress associated with empathic over-arousal in response to infant cries. A principal components analysis revealed that fathers with more negative emotional reactions to the unknown infant cry showed decreased activation in the thalamus and caudate nucleus, regions expected to promote positive parental behaviors, as well as increased activation in the hypothalamus and dorsal ACC, again suggesting that empathic over-arousal might result in negative emotional reactions to infant crying. In sum, our findings suggest that infant age, paternal age and paternal emotional reactions to infant crying all modulate the neural response of fathers to infant crying. By identifying neural correlates of variation in paternal subjective reactions to infant crying, these findings help lay the groundwork for evaluating the effectiveness of interventions designed to increase paternal sensitivity and compassion.

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1. Introduction

Crying is the principal means by which newborn infants shape parental behavior to meet their needs. While this mechanism can be highly effective, crying, particularly when prolonged and inconsolable, can also be an aversive stimulus that leads to parental frustration and even abuse [6]. On the other hand, sensitive responding to infant distress predicts secure infant attachment, which in turn predicts positive social and emotional development [26,31]. Thus, a significant challenge that parents face is to respond to this potentially aversive stimulus with sensitivity and compassion rather than frustration.

In this paper, we investigate paternal brain responses to infant crying. We focus specifically on fathers for three reasons. First, fathers have recently become more involved in direct caregiving activities in the U.S. and other modern, developed nations [19,79]. Second, research on fathers lags behind research on mothers even though paternal involvement is known to be associated with multiple positive developmental outcomes [68,70]. Third, fathers are more likely than mothers to physically abuse infants and infant crying is a known trigger for infant abuse [6]. Thus, it may be more challenging for fathers to respond sensitively to infant crying. Indeed, fathers report finding infant crying more aversive than mothers do [80]. While earlier studies focused on the average neural response to infant crying among parents [51,52], in this study we attempt to explain variation in the neural response to infant crying among fathers with the hope of identifying factors that are associated with a more sensitive and compassionate response.

The neurobiology of parental behavior is understood in great detail in rats. Numan [59] argues that adult rats have separate systems motivating approach and avoidance of offspring, and that parental behavior emerges when the former exceeds the latter. The medial preoptic area (MPOA) is a critical node that both activates the mesolimbic dopamine (approach) system and inhibits an avoidance circuit that runs from the medial amygdala to the periaqueductal gray of the midbrain (PAG). In both male and nulliparous female rats, several days of habituation to pups are required to suppress the avoidance system to the point where parental behavior is exhibited. However, pregnancy-related hormones like prolactin and estrogen augment MPOA function so that maternal behavior emerges at parturition. Oxytocin (OT) also facilitates parental behavior through actions at MPOA [63], but also acts at each node of the mesolimbic DA system (VTA and NA) to facilitate DA release in NA [61]. Is Numan's model of maternal care relevant to paternal care? Studies in California mice support this possibility since MPOA lesions inhibit paternal behavior, and pup exposure increases Fos-like immunoreactivity in the MPOA in new fathers [25]. Furthermore, optogenetic stimulation of MPOA galanin neurons facilitates paternal behavior in mice [78].

For human mothers, the basic pattern of brain activity in response to infant crying was first described by Lorberbaum and colleagues [51,52]. In this initial study, mothers listened to cries of unknown infants. Relative to a white noise control, unknown infant cries activated circuits implicated in maternal care in non-human animals. In particular, activations were observed within components of the midbrain dopamine systems, such as the substantia nigra (SN) and ventral tegmental area (VTA), that rat studies implicate in approach-related motivation towards offspring [59]. However, activation was not found in other critical nodes of this system, such as the MPOA and regions of the ventral striatum most consistently implicated in reward and motivation (e.g., NAC). Lorberbaum et al. also observed activation in both anterior and posterior cingulate cortex, as well as the midline thalamic nuclei, consistent with recruitment of the thalamocingulate system as outlined by MacLean [53]. In addition to these, prominent activations were observed in the right fronto-insular cortex as well as the dorsomedial prefrontal cortex (DMPFC), regions involved with emotional and cognitive empathy, respectively [72]. Thus, engagement of these two systems may facilitate maternal understanding of the mental and

emotional state of a crying infant. Finally, right lateralized activation in auditory cortices extending to the temporal pole was also observed. In summary, this initial study revealed engagement of the following five systems in response to unknown infant cries: 1) midbrain dopaminergic (approach motivation), 2) thalamocingulate, 3) fronto-insular (emotional empathy), 4) DMPFC (perspective-taking and theory of mind), and 5) right lateralized auditory cortex extending to the temporal pole.

A few studies have extended this approach to investigate how these neural responses might relate to real-world parenting. For example, Laurent et al. [48] related the neural response of mothers to their infant cries to their physiological stress reactivity in the Strange Situation, in which mothers were separated from their infants with the ability to see and hear their distress on a remote video monitor. Mothers who more strongly activated the lateral orbitofrontal cortex (OFC) in response to their infant's crying exhibited less reactive hypothalamo-pituitary-adrenal (HPA) axis responses to the Strange Situation. The authors suggest that mothers who maintain prefrontal control of HPA reactivity will not be overcome by stress and will make better parenting decisions. In another study focusing specifically on high-risk mothers, stronger anterior insula responses to own-infant cries were related to more intrusive parenting [58]. Given the anterior insula's role in emotional empathy [72,81], this finding might reflect empathic over-arousal in the mothers. Although empathy is essential for parental care, empathic over-arousal can lead to distress that interferes with compassionate behavior and effective parenting. The anterior insula is a visceral somatosensory cortex that is known to track autonomic arousal [23,24]. Child-abusing parents have a more pronounced sympathetic nervous system response to infant crying compared with non-abusive parents [34,45], and might therefore be expected to have a stronger anterior insula response to infant crying. Fathers also show robust anterior insula activation in response to infant cries, and fathers with moderate anterior insula activation are the most involved in instrumental caregiving. Fathers with low and high insula activation may be less involved due to empathic under- and overarousal to cries [55].

The paternal neural response to infant crying is likely to be modulated by characteristics of the father. For example, paternal experience might be an important modulator if fathers with more accumulated exposure to infant crying learn to more effectively regulate their negative emotional reaction to it. Second, similar to post-partum depression in mothers [20,33,65], depression in fathers is expected to decrease sensitivity to infant cues. Indeed, depressed fathers exhibit decreased positive and increased negative parenting behaviors [75]. Sleep quality is another potentially important variable. Parents of newborn infants sometimes struggle with sleep deprivation, which is known to impair emotion regulation abilities [10]. Personality is also expected to play a role, as parents who score high on neuroticism find infant cries more aversive than do their peers with lower scores on neuroticism [80]. Infanticide and Abusive Head trauma (AHT; also known as Shaken Baby Syndrome (SBS)) [21], which is most often triggered by infant crying, are associated with younger parental age, lower SES, the presence of recent stressful life events and a childhood history of parental abuse [6]. These variables might therefore also modulate the neural response to infant crying. Finally, hormone levels could also have an impact, since men with higher testosterone levels report less sympathy for infant crying [32], and both testosterone and oxytocin administration have been shown to modulate the neural response to infant crying in women [16,66].

We hypothesized that greater depressive symptomatology, lower quality sleep, higher levels of neuroticism, younger paternal age, lower SES, more recent stressful life events, a childhood history of parental abuse, and higher levels of testosterone would be associated with more negative and less positive emotional responses to infant cry stimuli, and accompanying weaker activation in components of the midbrain dopamine (VTA, SN, striatum) and thalamocingulate systems that are associated with positive parenting behaviors, along with stronger activation in the anterior insula that tracks sympathetic hyperarousal

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