The Effect of Reproductive Experience on Psychological Processing of Infant Auditory Cues: Postprint

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Abstract

Mothers, particularly human mothers, exhibit exceptional sensitivity to the unique acoustic features, emotional valence, and survival cues embedded in infant cries and laughter. This article evaluates various cognitive experimental paradigms developed using infant cry materials and investigates maternal performance across psychological functions including perceptual sensitivity, attention allocation, and emotional processing of infant cries. Maternal capacities for perception, attention, and emotional processing of infant vocalizations are significantly superior to those of non-mothers, with heightened activation in multilevel networks extending from the primary auditory cortex to the prefrontal-limbic system. Neuromolecular agents such as oxytocin and dopamine, alongside environmental factors like parenting experience and socioeconomic-cultural contexts, exert important modulatory effects on maternal psychological processing abilities. Current research broadly supports cognitive reorganization theory, which proposes that adaptive modifications in brain structure and function facilitate enhanced mutual well-being in the mother-infant dyad. Nevertheless, future investigations should expand multimodal integrated research designs, differentiate distinct psychological functions experimentally, and elucidate the underlying neural mechanisms in greater depth.

Full Text

Impacts of Reproductive Experience on Mental Processing of Infant Auditory Cues

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Abstract

Mothers, especially human mothers, are extremely sensitive to unique acoustic features, emotional valence, and survival cues contained in infant cries and laughter. This article reviews studies on how reproduction alters a mother's perceptual sensitivity, attention allocation, and emotional processing of infant cries, focusing on various behavioral paradigms based on infant crying stimuli that have been employed in this line of research. Mothers have significantly better perceptional, attentional and emotion processing of infant cries and laughter than non-mothers. Greater activation has been observed in mothers than non-mothers in the multi-layered neural networks, including primary auditory cortex and prefrontal-limbic system. Neurochemical signals, such as oxytocin and dopamine, and sociocultural factors, such as parenting experience and cultural differences are found to be important modulators of mother's psychological functions. Existing findings support the cognitive reorganization theory, suggesting that brain structure and functions are reorganized to serve mothering behaviors to promote the inclusive fitness of the mother and the young. Future studies need to adopt multimodal designs to distinguish psychological functions to better understand underlying neural mechanisms.

Keywords: infant auditory cues, reproductive experience, maternal behavior, neuroendocrine mechanisms, cognitive reorganization theory

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Reproductive experience refers to the physiological, psychological, and sociocultural experiences of women during pregnancy, childbirth, and postpartum parenting. This experience profoundly impacts the female brain and psyche, an effect closely linked to hormonal fluctuations during the reproductive process (李想 et al., 2013; Markon et al., 2021). Following delivery, maternal estrogen and progesterone levels drop to pre-pregnancy baseline within 24 hours. Such dramatic hormonal shifts can affect emotional regulation, leading to heightened emotional sensitivity and even depressive tendencies. Approximately 39% of mothers experience "postpartum blues" (Landman et al., 2024). During lactation, oxytocin (OXT) secretion increases substantially, which not only triggers maternal instincts but also facilitates emotional bonding between mother and infant. Meanwhile, prolactin (PRL), in addition to promoting milk production, may enhance maternal responsiveness to infant needs (Lévy, 2016). The ability of mothers to accurately interpret infant signals and respond appropriately is termed "maternal sensitivity."

The high-intensity demands of infant care often lead to reallocation of maternal attentional resources. Some mothers may experience transient memory lapses, colloquially known as "mommy brain." The folk wisdom embedded in the teasing phrase "one pregnancy, three years of foolishness" appears to mock cognitive decline during pregnancy, yet it actually aligns remarkably well with neuroscientific findings on reproductive neuroplasticity (Hoekzema et al., 2017). Research reveals that postpartum mothers exhibit reduced gray matter volume in brain regions associated with the default mode network (DMN), such as the prefrontal and parietal cortices—a change closely linked to enhanced "maternal focus" (e.g., more acute detection of infant needs). From an adaptive perspective, this phenomenon resembles "functional reallocation" in biological evolution, optimizing neural network configuration through a U-shaped trajectory of gray matter volume (decreasing during pregnancy and gradually recovering postpartum). Cognitive-related regions (e.g., prefrontal cortex and hippocampus) undergo structural reorganization (Servin-Barthet et al., 2023) aimed at strengthening the mother-infant signal monitoring system, significantly enhancing new mothers' sensitivity and accuracy to infant cues (Swain & Ho, 2017). Functionally, activation patterns in the anterior cingulate cortex (ACC), amygdala, prefrontal cortex (PFC), nucleus accumbens, insula, and DMN all undergo postpartum changes that are tightly associated with maternal sensitivity or caregiving behavior (De Pisapia et al., 2013; Feldman, 2015; Kim et al., 2014; Swain et al., 2014; 张火垠 et al., 2019).

Currently, while the impact of reproductive experience on maternal psychological and brain functions has garnered considerable academic attention, most research has focused on general attention, memory processing, and emotion regulation in postpartum mothers. Fewer studies have investigated parenting-specific psychological functions such as perceptual processing thresholds for infant cues and response motivation. In human development, infant vocalizations serve as vital communication and social signals that are crucial for infant growth and survival, while also significantly influencing maternal cognitive function and emotional states. The quality of maternal behavior largely depends on mothers' precise understanding of their children's needs and the maternal responses elicited by infant sounds. Building on this, this paper reviews relevant literature, focusing on how reproductive experience influences maternal perception, attention, and emotional processing of infant auditory cues. First, we highlight significant differences between infant cries and laughter in acoustic features, informational content, and intensity of adult responses, which helps explain why infant cries are more frequently employed as core stimuli in research on reproductive experience and psychological function. Next, we review experimental paradigms previously used to study infant auditory cues. On this foundation, we examine how reproductive experience affects cognitive and emotional processing of infant auditory cues and analyze the underlying brain structures and neuroendocrine mechanisms. By integrating previous findings, we propose that the processing of infant auditory cues following reproductive experience aligns with the "cognitive reorganization theory" (Anderson & Rutherford, 2012), suggesting that brain structure and function undergo reorganization to optimize maternal behavior and promote the mutual well-being of mother and child.

1 Acoustic Characteristics of Infant Auditory Cues and Experimental Paradigms

Both infant laughter and crying represent important forms of early emotional expression, yet they differ significantly in function, structural features, and research value. Infant laughter typically occurs in low emotional arousal states, reflecting pleasure and social intention while playing a role in establishing emotional connection during parent-infant interactions. For example, mothers often respond to infants under two years through imitation, whereas after 30 months, they increasingly use language and facial expressions—a shift closely related to the development of infant social-cognitive abilities. In contrast, while laughter can also elicit positive social responses, its urgency for survival is far lower than that of crying. Crying is not merely an emotional expression but the earliest and most powerful distress signal. The fundamental frequency, rhythm, and acoustic dissonance of cries reflect not only developmental stage and physiological state (e.g., prematurity, pain, or stress; Cacace et al., 1995; Yoo et al., 2019) but also exhibit individual specificity (Lockhart-Bouron et al., 2023). These high-frequency, dissonant acoustic features cross-culturally induce discomfort, increased heart rate, and electrodermal responses in listeners (LaGasse et al., 2005), reflecting the evolutionarily adaptive functional properties of infant crying.

Infant crying typically triggers emotional arousal in caregivers, motivating them to soothe the infant. Based on this survival significance, psychological research has widely adopted infant cries as core auditory stimuli to investigate caregivers' behavioral, emotional, and neural responses. The most common paradigm is the playback experiment, designed to assess mothers' ability to recognize cries. The core design involves training and testing phases. Participants become familiar with a specific infant's cries during training and then, in the testing phase, judge the identity of presented cries (Bouchet et al., 2020; Gustafsson et al., 2013) or categorize the cause of crying (Corvin et al., 2022; Lockhart-Bouron et al., 2023). Most studies treat reproductive experience as a key variable, comparing postpartum mothers with nulliparous women or primiparous with multiparous mothers (Corvin et al., 2022; Lockhart-Bouron et al., 2023; Maupin et al., 2019), finding that cry discrimination ability positively correlates with parenting experience (Bouchet et al., 2020; Gustafsson et al., 2013).

Infant crying immediately captures caregivers' attention, representing a key communication mechanism evolved to ensure infant survival. To further understand how reproductive experience influences cry processing, researchers have combined subjective reports, physiological responses, and neuroimaging techniques to measure mothers' emotional and cognitive reactions to cries. Studies show that mothers exhibit greater empathy, alertness, and regulatory capacity compared to nulliparous women (Giardino et al., 2008), and these response characteristics can predict future parenting sensitivity and infant attachment quality (Leerkes et al., 2022). Additionally, experiments employ cognitive task paradigms to examine the disruptive effects of infant crying. For instance, in Stroop tasks, nulliparous women perform worse under cry interference than laughter interference, indicating that cries more readily induce cognitive conflict (Dudek et al., 2016). N-back tasks assess working memory performance, revealing that infant cries most strongly disrupt nulliparous individuals (Hechler et al., 2015), while multiparous mothers show greater adaptability to interference (Pérez-Hernández et al., 2021). Go/No-Go tasks reveal the impact of cries on inhibitory control, suggesting that infant crying may disrupt cognitive control through multisensory integration mechanisms (Leerkes et al., 2021).

In summary, infant crying is not only a highly biologically based emotional signal but also an ideal experimental material that reflects differences in maternal motivation and cognitive processing. Therefore, experimental research focusing on the acoustic features and psychological responses to cries has become a crucial approach for understanding the relationship between reproductive experience and caregiving behavior.

2 Psychological Processing of Infant Cries by Individuals with Different Reproductive Experiences

Reproductive experience enhances mothers' ability to recognize infant cries and regulate attention, while also elevating the processing and responsiveness to infant emotional signals. The neural mechanisms underlying maternal behavior are both plastic and subject to environmental and individual differences.

2.1 Enhanced Perceptual Sensitivity

Perceptual sensitivity discussed in this paper specifically refers to mothers' ability to identify infant cries. Researchers have hypothesized that this ability manifests in two aspects: first, the specific recognition of one's own infant's cries, and second, the interpretation of emotions and meanings embedded in infant cries. Studies show that women with parenting experience not only demonstrate significantly superior sensitivity to infant cries compared to inexperienced individuals (Bouchet et al., 2020) but can also discriminate subtle differences in cries across various contexts by integrating acoustic features and situational information (Bornstein et al., 2017; 张火垠 et al., 2019).

Corvin et al. (2022) employed a playback paradigm to reveal the impact of parenting experience on cry recognition ability. The experiment compared adults with no parenting experience, non-parental caregivers, parents of children over five years, parents of infants under two years, and professional caregivers in identifying infant cries from different contexts (pain cries induced by vaccination versus mild discomfort cries during bathing). Results showed that experienced participants could accurately identify cry contexts for familiar infants, while inexperienced participants performed at chance level. Notably, parents of infants under two years could even recognize unfamiliar infant cries not presented during training. In contrast, parents of children over five years and experienced caregivers showed only chance-level accuracy in recognizing unfamiliar infant cries. These findings suggest that reproductive experience may enhance parents' ability to specifically recognize familiar cries and identify contextual features.

However, as parenting experience increases, parental sensitivity to infant cries gradually decreases, thereby alleviating their parenting burden (Corvin et al., 2022). Nevertheless, Lockhart-Bouron et al. (2023) found that even when parents learned about cry causes (hunger, discomfort, or separation) during training, their classification accuracy for unfamiliar infant cries remained at chance level during testing. This result suggests that mothers may not accurately distinguish the specific meanings behind infant cries.

The discrepancy between these two studies may stem from the cry materials used. Corvin et al. (2022) employed extreme contextual contrasts to explain cry comprehension across different experience groups, whereas Lockhart-Bouron et al. (2023) used more everyday cry contexts. The comparison demonstrates that emotional arousal level alters the acoustic features of infant cries, making it easier for parents to identify and respond to more urgent cries, while specific semantic contexts have minimal impact on acoustic characteristics (Lockhart-Bouron et al., 2023). Together, these findings indicate that reproductive experience indeed enhances maternal sensitivity to infant cries, particularly the specific recognition of one's own infant's cries. However, as parenting experience accumulates, parents adopt different levels of information processing strategies.

2.2 Attentional Processing

Mothers exhibit an attentional bias toward their own infant's cries, which serves as the first step in triggering emotional processing and subsequent parenting motivation. Rigo et al. (2019) used fMRI to investigate how mothers and nulliparous women process infant cries versus other sounds during self-oriented and goal-oriented task contexts. Results showed that in self-oriented tasks, all women (regardless of parity) shift attention from self-reflection to infant cry processing when hearing cries. In contrast, in goal-oriented tasks, mothers demonstrate difficulty disengaging from infant cry processing to focus on external tasks. This study reveals that infant cries may elicit instinctive maternal responses at the psychological level, with reproductive experience enabling mothers to maintain persistent attention to infant cries even while performing external tasks.

Hiraoka et al. (2023) investigated maternal attentional bias toward infant cries using a longitudinal Stroop paradigm. The study confirmed that mothers show longer reaction times when completing Stroop tasks while hearing their own infant's cries. However, from 2 to 8 months postpartum, mothers' Stroop task reaction times under cry conditions decrease more significantly. This suggests that as mothers gain more parenting experience, the attentional interference from infant cries diminishes. It also indicates that as infants age, mothers allocate progressively less attentional resources to their own children. Corroborating this, at 8 months postpartum, higher attentional bias toward infant cries correlates with lower subjective urgency ratings. These results suggest that greater maternal attentional focus on infant cries paradoxically reduces the urgency of actual parenting behaviors, likely related to experience accumulation or cognitive regulatory mechanisms.

2.3 Emotional Processing

Multiple studies have examined mothers' emotional responses to infant cries. Giardino et al. (2008) investigated responses to infant distress cries among teenage mothers, non-mother adolescents, and adult mothers. The experiment used standardized recordings of infant distress cries (high/low intensity) and neutral vocal segments, assessing stress responses through salivary cortisol sampling and heart rate monitoring. Results showed that adult mothers exhibited transient cortisol (CORT) elevation following cry stimuli, while teenage mothers showed linear cortisol decreases. Moreover, teenage mothers displayed significantly weaker heart rate acceleration than adult mothers and more gaze aversion during mother-infant interaction observations. Bjertrup, Friis et al. (2021) employed a multimodal approach combining fMRI, electrodermal response, and eye-tracking to compare primiparous mothers at 4 months postpartum with nulliparous women in their responses to infant facial expressions (neutral, moderate/high happiness, moderate/high distress) and cries. Participants passively viewed 28-second videos of infant laughter and distress cries while completing infant emotion intensity rating tasks. Results revealed that when viewing cry videos, mothers showed significantly elevated skin conductance peaks, longer fixation durations, and more positive facial expressions toward infant laughter.

These studies collectively emphasize that motherhood amplifies subjective emotional investment in infant cues, with all mothers reporting higher levels of empathy and alertness compared to non-mothers. However, despite similar self-reported empathy, physiological and behavioral responses vary across maternal groups: adult mothers show pronounced autonomic and hormonal responses to crying (e.g., elevated cortisol, accelerated heart rate), while teenage and drug-using mothers exhibit weaker physiological reactions. Furthermore, infant-specific stimuli activate maternal neuroaffective circuits, reinforcing the profound impact of maternal experience on infant cue processing. These findings indicate that while mothers generally amplify subjective parenting responses, physiological and behavioral adaptations are modulated by factors such as age, substance use, and infant familiarity.

3 Neural Network and Neuroendocrine Mechanisms

The neural processing of infant cries requires coordinated operation of multi-level neural networks. Parenting experience enhances functional connectivity in regions such as the superior temporal gyrus (STG), supplementary motor area (SMA), orbitofrontal cortex (OFC), and ACC, enabling mothers to perceive, interpret, and respond to infant emotional needs more efficiently. The primary auditory cortex performs basic signal processing and recognition of infant cries. Research consistently shows that women with reproductive experience exhibit stronger neural responses to infant cries in the STG, PFC, and limbic system (Parsons et al., 2017; Wright et al., 2017). The prefrontal-limbic system regulates maternal emotional responses and executes caregiving behaviors while ensuring emotional understanding and affective resonance with infants. Reward-motivation circuits provide positive feedback for maternal behavior. Simultaneously, neurochemicals such as oxytocin, prolactin, dopamine, and endogenous opioids (EO) shape the stability and sensitivity of maternal behavior through mechanisms of emotional resonance, stress regulation, and reward feedback.

3.1 Neural Network Basis of Infant Cry Processing

The neural processing mechanisms of infant cries in mothers exhibit multilevel characteristics. Infant cries first activate the mother's primary auditory cortex, including Heschl's gyrus and STG, which are responsible for initial sound analysis (Bornstein et al., 2017; 张火垠 et al., 2019). Due to the specific nature of infant cries, they elicit higher STG activation than neutral sounds. fMRI studies have found that experienced mothers show significant activation in STG, SMA, and basal ganglia in response to infant cries (Bornstein et al., 2017). Enhanced functional connectivity between auditory cortex and SMA enables rapid transformation of auditory signals into motor responses, accelerating maternal perception and reaction to infant cries (Waizman et al., 2024).

As parenting experience accumulates, maternal interpretation of infant cries extends beyond basic auditory analysis to become intimately linked with emotional resonance, social connection, and motivational drive. Compared to other emotional sounds, infant cries specifically activate the posterior cingulate cortex (PCC) and insula, whereas laughter elicits stronger functional connectivity in the pre-supplementary motor area (pre-SMA). This indicates that long-term caregiving experience alters the function of brain regions involved in emotional valence evaluation and positive interaction intention (Bornstein et al., 2017). Through extended parenting, mothers' brains gradually develop a neural representation pattern that couples infant cries with specific emotional states (e.g., anxiety, empathy, caregiving motivation), enabling rapid adaptive emotional and behavioral responses when infants cry (Laurent & Ablow, 2012; Swain et al., 2011). For example, nulliparous women tend to perceive infant cries as stressors or aversive signals, whereas mothers typically interpret them as signals of need (Laurent & Ablow, 2012; 张火垠 et al., 2019). Furthermore, synchronized activation of the inferior frontal gyrus and superior temporal sulcus in the mirror neuron system enables mothers to simulate and understand infants' emotional states (Kim et al., 2011; Swain et al., 2014).

Enhanced functional connectivity in the prefrontal-limbic system constitutes the key neural foundation for high-level regulation. When mothers hear their own infant's cries, bilateral amygdala activity initially increases but then gradually decreases with attentional shifts (Firk et al., 2018). This task-dependent activation pattern is closely coordinated with the "parental brain" network (Feldman, 2015; Swain et al., 2014; 张火垠 et al., 2019). Compared to nulliparous women, mothers exhibit suppressed PFC activity when hearing non-specific infant cries, indicating that cognitive resource allocation becomes increasingly optimized with accumulated parenting experience (Bornstein et al., 2017). Research has found that even when focused on external tasks, mothers maintain background monitoring of infant cries through weak activation of the medial prefrontal cortex (mPFC) and PCC within the DMN (Rigo et al., 2019).

Functional connectivity analyses reveal significantly enhanced connectivity between the precuneus and anterior insula/ACC of the salience network in mothers, enabling rapid reallocation of resources from self-referential processing to infant need monitoring (Bornstein et al., 2017; Rigo et al., 2019). This neural signature likely reflects experience-dependent optimization of attentional resource allocation strategies in the maternal brain, allowing dynamic balance between task execution and infant need monitoring. fMRI studies demonstrate that infant cries trigger coordinated activity in the periaqueductal gray, right insula, OFC, and ACC-mPFC regions (Laurent et al., 2011). Activation levels in OFC and ACC positively correlate with maternal sensitivity to infant crying, indicating these regions play a central role in maternal emotion regulation. The dorsolateral prefrontal cortex (dlPFC) reduces excessive emotional arousal by enhancing inhibitory control over limbic regions, while the ventromedial prefrontal cortex (vmPFC) evaluates the emotional valence of infant cries and integrates physiological arousal signals from the insula (e.g., elevated heart rate) to boost behavioral responsiveness (Bornstein et al., 2017; Kim et al., 2020; Laurent & Ablow, 2012). This cross-regional coordination enables rapid integration of infant cries with social and emotional information, providing a foundation for maternal caregiving decisions (Bornstein et al., 2017; Ranote et al., 2004). Within reward-motivation circuits, the amygdala, ventral striatum, and nucleus accumbens transform infant cries into approach motivation (Atzil et al., 2011; Swain et al., 2014), while dopaminergic pathways from the ventral tegmental area to the striatum reinforce reward motivation (Kim et al., 2020; Swain et al., 2011), ensuring mothers capture infants' emotional needs and respond swiftly (Newman, 2007; Paul et al., 2019).

Parenting experience profoundly reshapes processing networks through neuroplastic mechanisms, making maternal perception, interpretation, and response to infant cries more efficient. In contexts of familiar infant cries, prefrontal-insula regulatory efficacy is enhanced (Hiraoka et al., 2023), accompanied by strengthened amygdala-nucleus accumbens connectivity (Atzil et al., 2011). These neuroadaptive changes collectively construct a cognitive processing chain from acoustic feature extraction and emotional meaning attribution to behavioral decision output. Cross-cultural research indicates that although neural activation patterns elicited by infant cries show consistency across cultural groups, specific behavioral responses are modulated by social norms (Bornstein et al., 2017). Results from Bjertrup, Friis et al. (2021) suggest that healthy mothers' neural networks optimize refined processing of infant signals through experience-dependent reorganization. This experience-dependent neuroplasticity mechanism transforms infant cries from simple auditory stimuli into complex neural signals integrating emotional recognition, social connection, and motivational regulation, thereby establishing the neurobiological foundation for maternal caregiving behavior. However, studies by Giardino et al. (2008) and Landi et al. (2011) found that adolescent developmental immaturity or substance abuse may impair the neuroplasticity of maternal neural networks. Landi et al. (2011) used fMRI to compare neural responses to infant cries and emotional faces in substance-abusing versus non-substance-abusing mothers. Results showed that substance-abusing mothers exhibited generally reduced activation in STG, dlPFC, mPFC, and limbic regions, with significantly diminished neural responses to infant distress cries, likely stemming from impaired reward pathways in dopamine and glutamate systems (Landi et al., 2011). Notably, multiple studies have identified the central role of limbic structures such as the amygdala and parahippocampal gyrus in maternal responses, indicating that the integrity of emotional evaluation systems is crucial for maternal adaptation.

3.2 Neuroendocrine Basis

Oxytocin plays a crucial role in the cognitive processing of infant vocalizations. Oxytocin levels gradually increase during pregnancy and peak at delivery. Elevated oxytocin enhances functional connectivity between OFC and STG (Swain et al., 2011), potentially facilitating cognitive processing of infant auditory cues. Consequently, mothers' neural decoding of infant cry features becomes more accurate. Additionally, oxytocin and prolactin can increase functional connectivity between PFC and amygdala, thereby improving maternal perception of negative emotions and empathic responses (Kim et al., 2011).

Currently, most research focuses on the roles of dopamine and oxytocin systems in mother-infant interactions, while insufficient attention has been paid to serotonin (5-hydroxytryptamine, 5-HT) and endogenous opioids. Animal model studies indicate that 5-HT regulates emotional arousal and social interaction capacity in maternal behavior through prefrontal-limbic circuits (陈磊磊 et al., 2017; Hurley & Hall, 2011), whereas endogenous opioids are closely associated with analgesic effects and pleasurable experiences in mother-infant attachment. Research has proposed two neuroendocrine systems involving endogenous opioids: the CORT-EO stress regulation system and the DA-EO motivation-reward system. As a typical auditory stressor, infant crying accelerates neural network reorganization and improves response efficiency by moderately elevating CORT levels (Feldman et al., 2007). As a protective mechanism, endogenous opioids inhibit the HPA axis to maintain CORT stability, preventing prolonged or high-level CORT from damaging prefrontal-amygdala function and causing emotional dysregulation (杨瑜 et al., 2020). Meanwhile, the dopamine system governing "wanting" mechanisms is triggered by infant auditory cues. When mothers complete caregiving behaviors, the "liking" mechanism of endogenous opioids mediates pleasurable experiences through OFC and ACC, achieving positive emotional reinforcement (Nguyen et al., 2021). Thus, endogenous opioids not only mitigate neural damage from chronic stress but also synergize with dopamine reward signals to enhance the persistence and sensitivity of maternal behavior (Smith et al., 2011). However, research gaps remain regarding the specific operational patterns of these two systems in human mother-infant populations. No studies have systematically examined the neuromodulatory role of 5-HT in early perceptual processing of infant cries, nor have behavioral and neuroimaging studies investigated 5-HT's influence on mother-infant emotional synchrony. Additionally, although previous research using pain-induced placebo effect paradigms has confirmed the synergistic action of DA-EO systems in motivational reward pathways (Scott et al., 2008), how maternal processing of specific infant auditory cues triggers brain activation patterns similar to placebo effects awaits clarification through future neuroimaging studies.

More notably, important controversies exist regarding the evolutionary and developmental aspects of this auditory cue-based motivation-reward neural mechanism. From an evolutionary perspective, primate studies have observed mother-infant sound preferences, suggesting this mechanism may have innate neural foundations, such as specific encoding of infant sounds in auditory cortex (Newman, 2007). However, anthropological research has found plasticity differences in neural responses to infant sounds between new and experienced mothers, with sociocultural expectations significantly enhancing activation in anterior insula and ventral striatum (Bornstein et al., 2017). This suggests that acquired experience may reshape neural reward systems through top-down regulatory pathways. Addressing this fundamental question requires an interdisciplinary paradigm that compares multimodal data from nulliparous women, novice mothers, and surrogate mothers, combined with genetic-epigenetic and caregiving environment variables, to deconstruct the dynamic interplay between innate neural predispositions and social learning effects in mother-infant auditory bonding.

4 Cognitive Reorganization Mechanisms of Mother-Infant Co-adaptation

Infant cries and laughter serve as important auditory cues for communication with the external world before language development. The uniqueness of infant crying lies not only in its distinctive acoustic features compared to other vocalizations but also in the critical need information it contains for infant health and survival. As primary caregivers, mothers can often rapidly detect and respond to infant cries. This seemingly instinctive caregiving behavior actually depends on the processing of auditory cues and crucial psychological functions. Changes in maternal perception and processing of infant auditory cues fundamentally stem from neuroplasticity in the brain.

In mature women, hormonal changes during pregnancy and childbirth (involving oxytocin, prolactin, estrogen, etc.) lead to reorganization of brain and psychological functions (Duarte-Guterman et al., 2019). During this reorganization, the cognitive processing of infant auditory cues is altered. Reproductive experience makes women more sensitive to infant cry cues, with more biased attention and stronger emotional investment. Infant crying drives the generation of maternal caregiving behavior, which in turn stimulates new rounds of hormone and neurotransmitter production and release, rewarding maternal behavior and creating a positive feedback loop.

These changes in psychological functions help mothers respond to infant needs more effectively. From an evolutionary psychology perspective, such psychological changes not only facilitate the normal initiation and expression of maternal behavior, thereby increasing infant survival probability, but also reflect maternal postpartum mental health. Research has found that more negative evaluations of infant cries are associated with increased risk of postpartum depression, suggesting that negative bias toward infant cries during pregnancy may predict vulnerability to postpartum depression (Bjertrup, Jensen et al., 2021).

The enhancement of psychological functions related to infant care and suppression of infant-unrelated cognitive activities align with the cognitive reorganization theory (Anderson & Rutherford, 2012). Although some studies note minor memory declines during pregnancy, Anderson and Rutherford (2012) emphasize that such changes represent not overall cognitive decline but rather reallocation of cognitive resources, prioritizing support for tasks directly involved in or regulating parenting, such as emotion recognition, social interaction, and threat perception, thereby indirectly enhancing maternal behavior. In summary, hormonal changes resulting from reproductive experience trigger adaptive reorganization of maternal brain structure and function. This neuroplastic change enhances maternal sensitivity, attentional bias, and emotional responses to infant auditory cues, while effectively activating neural circuits related to maternal behavior. Concurrently, positive feedback mechanisms of neurotransmitters further strengthen maternal caregiving motivation. Additionally, sociocultural expectations and norms regarding the maternal role not only influence maternal cognitive processing and parenting behavior but are also reflected in brain activation patterns. Of course, brain functional changes and cognitive reorganization do not merely represent selfless maternal sacrifice for offspring. Neuroendocrine regulation also ensures through various pathways that mothers do not suffer neural functional damage or psychological dysfunction during long-term offspring care. Therefore, cognitive reorganization theory posits that maternal-related neuroplasticity and cognitive restructuring jointly optimize parenting behavior and bidirectionally promote mother-infant

5 Summary and Outlook

This paper begins with the acoustic characteristics of infant auditory cues, describing how infant cries and laughter, as early human communication signals, differ from other auditory stimuli and elicit special responses in adults. To investigate the psychological processing of infant cries, researchers have employed classic cognitive experimental paradigms using infant cries as primary stimuli or distractors to study the psychological processes involved. This review focuses on the maternal psychological processing elicited by infant cries and its neuroendocrine underpinnings, revealing that reproductive experience enhances maternal cry sensitivity through neuroplasticity and hormonal regulation. Enhanced perceptual sensitivity to infant cries is neurally grounded in coordinated activation of STG and prefrontal-limbic systems (Corvin et al., 2022; Bornstein et al., 2017). Maternal attentional regulation capacity is optimized, allowing mothers to maintain attention to infant cries despite external interference (Rigo et al., 2019), and accumulated parenting experience strengthens prefrontal-amygdala functional connectivity, reducing attentional interference effects (Hiraoka et al., 2023). Maternal emotional resonance with infants is also strengthened, with infant cries activating OFC, ACC, and reward circuits, while oxytocin and dopamine systems enhance emotional evaluation and motivational drive to promote maternal caregiving behavior (Kim et al., 2020; Swain et al., 2011).

Reproductive experience triggers cognitive reorganization in the female brain. Gray matter volume shows U-shaped changes (Hoekzema et al., 2017), DMN resources are biased toward monitoring infant needs (Rigo et al., 2019), and dopamine-opioid reward-motivation circuits reinforce maternal behavior through positive feedback (Scott et al., 2008). This process aligns with the "evolutionary cognitive reorganization theory," wherein the brain prioritizes mother-infant interaction efficiency through functional reallocation—prefrontal regions suppress non-essential cognitive activities, limbic systems refine emotional evaluation, and auditory-motor pathways accelerate perception-to-action transformation.

Although current research has revealed neuroendocrine regulatory mechanisms underlying reproductive experience effects on infant auditory cue processing, theoretical frameworks for multisystem coordination require further validation and expansion. Building on the "evolutionary cognitive reorganization theory" proposed in this review, future research can deepen understanding of multisystem coordination in maternal behavior through the following directions.

First, current research predominantly employs single cues, which fails to reflect the complexity of multi-channel cue integration in real parenting scenarios. Future studies could integrate virtual reality technology to simultaneously collect infant cries, facial expressions, and tactile feedback data during mother-infant interactions, constructing more ecologically valid multimodal experimental paradigms. Combined fMRI could parse dynamic cooperative mechanisms in prefrontal-limbic-reward networks. For example, computational modeling could quantify OFC's integration weighting of multi-channel emotional information to clarify its evaluation-decision function in mother-infant interaction (Swain et al., 2014).

Second, existing research often examines single systems (measuring only hormone levels or brain activation), making it difficult to explain how oxytocin and dopamine drive maternal behavior through prefrontal-limbic networks. Future studies could combine functional near-infrared spectroscopy hyperscanning with multi-timepoint hormone assays to record neural synchrony and changes in oxytocin and dopamine levels during mother-infant interaction, analyzing temporal associations between neural synchrony and hormone concentrations to explore their joint regulatory mechanisms on maternal behavior.

Third, the adaptability of maternal behavior involves multilevel coordination of endocrine-neural-behavioral systems, yet current evidence remains fragmented without systematic explanation. Future research should integrate genetic-epigenetic, neuroimaging, and behavioral observation data to reveal how key molecular polymorphisms (e.g., oxytocin receptor gene OXTR, dopamine D2 receptor) contribute to individual differences by regulating amygdala-nucleus accumbens functional connectivity (Kim et al., 2020). Additionally, pharmacological interventions—such as intranasal oxytocin combined with dopamine blockers—could modulate reward region activity, further clarifying the temporal roles of different brain systems in generating maternal motivation (Landi et al., 2011; 杨瑜 et al., 2020).

Although scientists have studied the acoustic features of infant auditory cues from psychophysical perspectives since the last century and explored the impact of reproductive experience on maternal auditory processing, this field still holds vast unexplored territory. The psychological processing of infant cries and laughter not only determines the quality of mother-infant interaction but also serves as a critical window for predicting and diagnosing postpartum affective disorders. In-depth investigation of this process will help reveal how reproductive experience shapes brain structure and function, providing important theoretical support for understanding brain plasticity and intervening in affective disorders, with profound clinical and social significance.

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Note: Figure translations are in progress. See original paper for figures.