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Birthing parents' neural response to infant cry: moderating effects of oxytocin and perceived childhood care

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Abstract

Individuals who perceive the caregiving they received from their parents as more caring tend to bond better with their infants and show more sensitive parenting behaviors. Early caregiving experiences are also related to differences in the functions of hormonal systems, including the oxytocinergic system. The current study examined how perceptions of childhood maternal care relate to parenting behaviors, oxytocin levels, and neural responses to infant stimuli. Perceived childhood maternal care was measured using the Parental Bonding Instrument (PBI) for 54 first-time birthing parents. Salivary oxytocin and observations of parenting behaviors were assessed during parent–infant play at 3.5 months postpartum. Neural activation while listening to infant cry was measured with fMRI. More positive perceptions of childhood maternal care and higher oxytocin were interactively related to greater anterior cingulate activation to own infant's cry. Higher oxytocin levels were associated with reduced left cuneus activation in response to own infant's cry when compared with control cry and matched noise. Findings suggested that positive memories of childhood caregiving may have protective functions for birthing parents with high oxytocin levels during the early postpartum period, a time when parents need to manage increased stress and form an exclusive bond with their baby.

Keywords: oxytocin; postpartum; sensitive parenting; neuroimaging; childhood care

The postpartum period is a time of transformation and reorganization accompanied by substantial neural, hormonal, and psychosocial changes for new parents. This is a time when many first-time parents reflect on their childhood relationships with their own parents and begin to conceptualize who they want to be as caregivers (Handelzalts et al. 2018, Narayan et al. 2020). The childhood experiences new parents had with their own parents have a long-lasting impact on their neural and hormonal responses to their children (Kim et al. 2009, Strathearn et al. 2009, Riem et al. 2012, 2016, Unternaehrer et al. 2015). During the postpartum period, oxytocin plays a key role in social bonding and functions to decrease stress (Feldman et al. 2007, 2010a, Levine et al. 2007, Tops et al. 2007, Ross and Young 2009, Gordon et al. 2010a, Elmadih et al. 2014, 2016, Kim and Strathearn 2016). Growing research suggests that early social experiences and oxytocin interact to influence human affiliative behaviors (Feldman et al. 2013, Fang et al. 2014, Riem et al. 2016, 2020). To date, few studies have examined the interactive relationship between oxytocin and childhood experiences in impacting neural adaptation to parenthood. The current study investigated how the neural and behavioral responses to infant cues were interactively associated with perceived childhood care and oxytocin levels of birthing parents. The current study focused on birthing parents, and the term parent was used in the following paragraphs addressing birthing parents to keep concise.

Early caregiving relationships convey enduring vulnerability or protection against later life stressors, particularly during sensitive developmental stages such as the postpartum period (Ainsworth and Bowlby 1991, Slade et al. 2012). The postpartum period can be especially challenging for individuals who recall cold or unaffectionate caregiving, and such parents may question their capability to nurture their own child. The Parental Bonding Instrument (PBI) measures adults' perception of their childhood caregiving experiences retrospectively, and it consisted of two subscales (i.e. care

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and overprotection) (Parker et al. 1979). Studies indicated discrepancies between retrospective self-reports and objective measures of childhood experiences (Hardt and Rutter 2004, Danese and Widom 2020). However, own perceived childhood experiences have great agreement with the ratings of other family members and had important implications for various developmental outcomes including mental health outcomes and own parenting behaviors (Parker 1989, Kitamura and Suzuki 1993, Barrig Jo 2008, Danese and Widom 2020). Negative perceptions of childhood maternal care are associated with heightened risk for postpartum depression and anxiety as well as with mother–infant bonding difficulties (Boyce et al. 1991, McMahon et al. 2005, Mayes and Leckman 2007, Choi et al. 2010, Grant et al. 2012, Hall et al. 2015, Ohara et al. 2018, Fukui et al. 2021). Parents who report low childhood maternal care had daughters who were likely to also report low childhood care (Miller et al. 1997).

On the other hand, positive perceptions of childhood care measured with the PBI were related to increased observed parental sensitivity (Barrig Jo 2008, Burrous et al. 2009). Moreover, positive parenting protects individuals from a variety of environmental risk factors, including low social economic status, homelessness, and adverse childhood experiences (Ge et al. 2009, Chen et al. 2011, Flouri et al. 2015, Lucke 2024, Tadjine and Swords 2024). More specifically, recalling positive childhood experiences helped parents exposed to childhood trauma create positive memories with their own kids (Tadjine and Swords 2024). In addition, higher benevolent childhood experiences were associated with better perceived parenting effectiveness in a group of homeless parents (Lucke 2024). Negative childhood experiences were also negatively associated with baseline oxytocin levels in adults (Opacka-Juffry and Mohiyeddini 2012, Goh et al. 2021, Mielke et al. 2023). Taken together, perceived childhood maternal care conveys risk or resilience for parenting behaviors in the next generation.

Of particular interest to the current study is how childhood caregiving experiences interact with the neuroendocrine system to shape caregiving behavior. The neuropeptide oxytocin is highly implicated in maternal-infant bonding and may function differently depending on early life experiences. Most of the existing literature suggests that endogenous oxytocin promotes maternal-infant bonding and sensitive parenting. During the postpartum period, oxytocin plays a key role in the initiation of parental behaviors (Rosenblatt 2002, Levine et al. 2007). Higher endogenous oxytocin promotes parent–infant bonding and sensitive parenting such as increased affectionate touch, positive affect (Feldman et al. 2007, 2010a, 2010b, 2011, 2012, 2013, Gordon et al. 2010a).

However, studies of parents' oxytocin have yielded divergent findings. Elmadih et al. (2014), Elmadih et al. (2016) found that highly sensitive parents demonstrated *lower* oxytocin levels at baseline and following a parent–infant play interaction, compared to low sensitive parents. Similarly, Markova and Siposova (2019) demonstrated that higher oxytocin was associated with lower birthing parents' sensitivity. This could be because low sensitive birthing parents find parenting more stressful; higher oxytocin may then be released to regulate this stress response (Marazziti et al. 2006, Elmadih et al. 2016, Markova and Siposova 2019). Relatedly, greater interactive stress during parent–infant play is associated with elevated parents' urinary oxytocin (Feldman et al. 2011). Thus, rather than an indicator of affectionate care and bonding, elevated oxytocin in contexts of stress can be related to parenting stress and relationship anxiety (Taylor et al. 2006, Feldman et al. 2011, Tabak et al. 2011, Weisman et al. 2013).

Another potential explanation for the divergent findings is that oxytocin's role in parenting behaviors should be better understood within an interactive model that considers both contextual and individual factors (Bartz et al. 2011). Julian and colleagues (2018) found that higher salivary oxytocin was associated with more positive parenting of children aged 2–4 years among birthing parents with low adverse child experiences (ACEs) but fewer positive parenting behaviors among parents with high ACEs. Research examining the intranasal administration of oxytocin similarly demonstrated that exogenous oxytocin functions differently among adults with negative caregiving experiences (Van Ijzendoorn et al. 2011, Bakermans-Kranenburg and van Ijzendoorn 2013, Riem et al. 2014, 2020, Schwaiger et al. 2019). Hence, childhood caregiving experiences seemed to play an essential moderating role on the relationship between oxytocin and parenting.

In conjunction with the endocrine system, altered neural response is a likely mechanism through which perceptions of childhood caregiving may relate to parental behaviors. The current study examines parents' neural response to an essential signal of infant distress: the infant cry. Infant cry sounds capture parental attention and motivate approach and the initiation of caregiving behaviors (Bornstein et al. 2017). At the same time, prolonged exposure to infant cries is highly aversive; infant cries can heighten birthing parents' stress and risk for child maltreatment (Lee et al. 2007, Kurth et al. 2011, Swain et al. 2011). Across cultures, infant cry stimulates parents' brain activity in subcortical areas that serve specific functions to facilitate caregiving, such as enhancing processing of auditory information (e.g. superior temporal regions), preparing parents for action and speech (e.g. supplementary motor area), and regulating their initial negative emotional response to infant cry (e.g. superior frontal regions) (Musser et al. 2012, Bornstein et al. 2017). Parents also show enhanced responses in cortical areas involved in empathy and mentalization when listening to their own infant, including the right frontoinsular cortex, inferior parietal lobule, and inferior frontal gyrus/precentral gyrus (Hipwell et al. 2015, Kim 2016, Kim et al. 2016b, Feldman 2017, Swain et al. 2017). Importantly, enhanced parents' neural response to own infant's cry is related to increased parental sensitivity (Kim et al. 2011, Musser et al. 2012).

The neurohormone oxytocin plays an important role in coordinating neural and behavioral changes in response to an infant's cry. Higher parental basal plasma oxytocin levels are associated with enhanced activation in regions involved in limbic and motivational circuits and social cognition in response to viewing the videos of their own vs. unknown infants (Atzil et al. 2012). A few studies have suggested that higher oxytocin levels may be related to elevated activation in response to their own infant's cry (compared to a control cry) in subcortical circuits and social cognition/mentalization circuits (Swain et al. 2008, Kim et al. 2011).

Furthermore, more positive perceptions of early caregiving experiences played a protective role in the parental brain response to an infant's cry. Kim and colleagues (2009) found that parents with high perceived childhood maternal care exhibited greater activation in the middle frontal gyrus, superior temporal gyrus, and fusiform gyrus when listening to an unfamiliar infant's cry at 2–4 wk postpartum. By contrast, parents who reported low childhood maternal care showed increased left hippocampus activation when listening to infant cry, perhaps indicating greater stress reactivity to infant distress signals. Within adult populations,

higher perceived childhood maternal care has also been associated with greater activation in the right prefrontal cortex during exposure to cry (Cataldo et al. 2020).

The current study employed a functional neuroimaging (fMRI) approach to test the interactive relationship between perceived childhood maternal care and oxytocin on neural responses to infant cries. As current evidence does not converge on the directionality of oxytocin's relationship with parenting, this study would allow better understanding of the neurobiological pathway to optimal parenting. It adds to current understanding of early caregiving experience and how it shapes the function of the brain and the hormonal system and eventually protects or poses risk for the future generations. The findings of this study will contribute to a deeper understanding of interventions aimed at helping parents who experienced childhood trauma due to harsh parenting. These interventions facilitate the processing of their past experiences, support the recall of positive aspects of their childhood, and ultimately promote optimal caregiving behaviors. Additionally, we explored how differences in parents' neural response and salivary oxytocin were related to observations of caregiving behaviors (i.e. sensitivity). We predicted that higher oxytocin levels would be related to parents' elevated neural responses to infant cry sound. We also predicted that the interaction between childhood care and average oxytocin levels would be related to parents' neural responses to infant cry. We further predicted that higher oxytocin would be related to enhanced neural activation in social cognition and reward regions (e.g. middle, superior, and inferior frontal gyrus, striatum, anterior cingulate) during own infant cry vs. control cry but only in participants with high levels of childhood maternal care. Exploratory analyses were further conducted to test the hypothesis that enhanced neural activation would be related to increased parental sensitivity observed during parent–child interactions.

Materials and methods

Participants

Participants were 59 English-speaking, first-time birthing parents and their biological infants. Parents were recruited from the community through the WIC (Women, Infants, and Children) program and Colorado's Prenatal Plus program by distributing flyers and brochures in metro Denver areas. Exclusion criteria included history or current psychiatric illness other than depression and anxiety; current psychoactive medication use other than antidepressants; significant delivery and postnatal complications; irremovable magnetic metal in participants' body; current pregnancy; and claustrophobia. Prior to analysis, two participant was excluded due to missing PBI or oxytocin data, one participant was removed due to being an outlier on oxytocin level, and two participants were excluded due to excessive motion during fMRI. An overlapping sample from the current study has been included in previous publications (Kim et al. 2016a, 2020, 2022, Grande et al. 2021, Olsavsky et al. 2021, Aran et al. 2023). However, the current research question has not been examined.

Procedures

The study protocol was approved by the University's Institutional Review Board. Participants completed two phases: a home visit and an fMRI visit. At each phase of the study, participants provided written informed consent. The research team visited participants' homes to conduct interviews, administer questionnaires, and observe parent–infant interaction. Next, participants were invited to complete the fMRI visit.

Measures

Sociodemographic covariates

Sociodemographic information was collected via interviews and questionnaires. See additional information about sociodemographic covariates in the supplementary materials.

Parental Bonding Instrument

The PBI is a retrospective, self-report measure assessing caregiving experiences (Parker et al. 1979). The PBI is considered to capture important aspects of the childhood experience and has been used previously validated among pregnant and postpartum samples (Wilhelm et al. 2005, Murphy et al. 2010, Della Vedova et al. 2011a, Sato et al. 2021). Maternal care derived from the PBI describes aspects of emotional closeness, warmth, and understanding. An example of an item is: '(Mother) Could make me feel better when I was upset'. Maternal care had excellent internal consistency in the current study with a Cronbach's α coefficient of 0.92.

Parenting behavior

Parenting behaviors were assessed via a 15-minute videotaped parent–infant interaction during home visit. Infants' ages ranged from 2.72 to 7 months ($M = 3.5 \pm 1.68$) at the time of the interaction. Parents were asked to interact naturally with their infant without toys. Two trained researchers coded parents' behaviors from the videos using the Emotional Availability Scales, 4th Edition (EAS; Biringen 2008, Biringen et al. 2014). The EAS have been validated across cultures and have good agreement with other coding schemes of parenting behaviors (Biringen 2000, Ziv et al. 2000, Komatsu 2011, Cheung and Elliott 2016, Bohr et al. 2018, Derscheid et al. 2019, Cheung 2021). Of the four adult subscales (sensitivity, structuring, nonintrusiveness, and nonhostility) of the EAS, parental sensitivity was of particular interest to the current study as the construct best matched with the PBI perceived childhood care construct. Sensitivity scores capture the extent to which parents are emotionally attuned to their infant and can respond appropriately and flexibly to their infant's needs, and it is an important contributor to child attachment security and cognitive and emotional development (Biringen 2000, Ziv et al. 2000, Komatsu 2011, De Falco et al. 2014, Firk et al. 2018). In the current sample, parental sensitivity ranged from 3.5 to 7.0 ($M = 5.38 \pm 1.17$). The average intraclass correlation (ICC) was 0.91.

Oxytocin

Baseline and post-interaction saliva samples were collected right before and 15 minutes after the parent–infant interaction. Participants were instructed to refrain from eating/drinking and breastfeeding 70 minutes before the sample collection. Saliva samples were collected via Salivette (Sarstedt, Germany), then treated and stored in a −80°C freezer until being spun down again by centrifugation at 4°C at 4000 × *g* for 30 minutes. Oxytocin levels were determined via a commercial oxytocin ELISA kit (ENZO Life Sciences NY, USA), which has been used in prior studies (Zagoory-Sharon et al. 2023, 2024). Mean values of baseline and post-interaction oxytocin values were taken for each participant. The approach of averaging oxytocin levels across time points has been used previously when samples were highly correlated (Gordon et al. 2010b, Feldman et al. 2013). In the current sample, baseline and post-interaction oxytocin values were highly correlated ($r = 0.52$, $p < 0.001$) and a paired samples *t*-test revealed no significant difference between the two oxytocin values ($t = 1.59$, $p = 0.119$). Prior

to analysis, one outlier was removed; see additional information in the supplementary materials.

fMRI measure

Infant cry task

We assessed parents' neural responses to hearing their own infant and an unknown control infant cry using the infant cry fMRI paradigm (Swain et al. 2008). The task had two functional runs, and each run contained four conditions of 20 s stimulus blocks, including (i) own infant cry, (ii) control cry, (iii) own infant cry-matched noise, and (iv) control cry-matched noise. Each block was presented five times and was followed by an average 10-s inter-stimulus interval (range 8–12 s). Participants were instructed to respond naturally to each sound. See additional information about the infant cry task in the supplementary materials.

fMRI acquisition

Scanning was conducted using two different scanners due to a scheduled scanner update: Siemens Trio ($N = 32$) and Siemens Prisma ($N = 22$). Both were 3.0 T Siemens magnet scanners using a standard 32-channel head coil, acquiring 540 T2*-weighted echo-planar-imaging (EPI) volumes. An independent *t*-test revealed no significant difference between the temporal signal-to-noise ratio (TSNR) for the Trio ($M = 231.23 \pm 31.89$) and the Prisma ($M = 218.53 \pm 39.70$), $t_{(52)} = 1.30$, $p > 0.05$, indicating no statistically significant scanner effect on TSNR. See parameters of functional and T1 data in the supplementary materials.

fMRI preprocessing

Preprocessing and statistical analysis were conducted using the Analysis of Functional Neuroimages software (AFNI) (version 19.2.04, Cox 1996). The first four pre-steady-state volumes for each run were removed. Preprocessing steps involved slice timing correction, motion correction, affine alignment, and normalization to the Talairach template as it is the default template for AFNI 19.2.04. A general linear model (GLM) was used to analyze BOLD signal changes in response to the four task conditions. Participants with excessive motion ($N = 2$; above 15% of TRs removed) were excluded from the analysis. The motion cut-off was framewise displacement in any direction exceeding 0.5 mm. See additional information in the supplementary materials.

Analysis plan

Covariate selection

Pearson's correlations were conducted to evaluate the associations between the variables of interest (perceived childhood maternal care and oxytocin levels) and sociodemographic variables as well as variables that might influence oxytocin levels; see details in the supplementary materials.

Associations among oxytocin, perceived childhood maternal care, and parental sensitivity

The associations between perceived childhood maternal care and oxytocin levels with parental sensitivity were examined using bivariate Pearson correlation in IBM SPSS Statistics (version 27). To investigate whether oxytocin moderated the effects of perceived childhood maternal care on parenting behaviors, a simple moderation analysis was conducted using PROCESS in SPSS (Hayes 2013).

Whole-brain fMRI analysis

Whole-brain linear mixed-effects models were conducted with 3dLME in AFNI (Cox 1996). A cluster extent threshold was corrected to be equivalent to whole-brain $p < 0.05$. Whole-brain analyses examined the effects of Childhood Care and Oxytocin. Within-subject factors were the four task conditions, which were grouped across Sound (Cry vs. Noise) and Identity (Own vs. Control). Interaction effects and main effects in the whole-brain analysis were examined. Covariates included were scanner type, postpartum months, and income-to-needs ratio. Post hoc analyses included additional variables associated with $p < 0.05$ in relation to the variables of interest in the whole-brain model.

Results

Sample characteristics

Parents were 25 years old on average at the home visit ($M = 25.62 \pm 5.41$). See Table 1 for detailed participant demographic information.

Sociodemographic covariates

See supplementary Table S1 for correlations between sociodemographic covariates and variables of interest. A higher average oxytocin level was associated with a higher income-to-needs ratio ($r = 0.31$, $p = 0.022$). Average oxytocin levels were also higher among participants who were breastfeeding exclusively ($M = 44.15 \pm 14.70$), compared to those who were not ($M = 35.78 \pm 14.64$), $t = -2.04$, $p = 0.046$. With regard to parenting outcomes, higher sensitivity was associated with higher participant age ($r = 0.27$, $p = 0.049$) and education ($r = 0.38$, $p = 0.005$).

Associations among oxytocin, perceived childhood maternal care, and parenting behaviors

There were no significant associations between perceived childhood maternal care or oxytocin levels with parental sensitivity. Additionally, there were no significant associations between perceived childhood maternal care and oxytocin levels. Average oxytocin levels did not moderate the effects of childhood care on parental sensitivity.

Whole-brain fMRI analysis

A four-way interaction of Childhood Care × Oxytocin × Sound × Identity was identified in the right anterior cingulate (ACC) (Table 2, Fig. 1). Follow-up repeated measures ANOVAs revealed significant contrasts for own infant cry vs. control cry ($F = 13.672$, $p < 0.001$), own infant cry vs. matched noise ($F = 16.217$, $p < 0.001$), and control cry vs. matched noise ($F = 6.001$, $p = 0.018$). Additional post hoc analyses divided the sample into low oxytocin and high oxytocin groups around the mean. In the high oxytocin group, higher care was associated with increased activation to own infant cry vs. control cry ($r = 0.45$, $p = 0.020$) and vs. matched noise ($r = 0.47$, $p = 0.017$), and reduced activation to control cry vs. matched noise ($r = -0.49$, $p = 0.012$). There were no significant associations in the low oxytocin group. Exploratory analyses revealed no significant associations with parental sensitivity.

A three-way interaction of Oxytocin × Sound × Identity was identified in the left cuneus (including the left precuneus) (Table 2, Fig. 2). Post hoc repeated measures ANOVAs revealed that oxytocin levels were associated with activations for own infant cry vs. control cry ($F = 13.404$, $p < 0.001$), own cry vs. matched noise ($F = 7.868$, $p = 0.007$), and control cry vs. matched noise ($F = 6.595$, $p = 0.013$). Higher oxytocin was associated with reduced left cuneus activation in response to own infant cry vs. control cry, reduced activation for own cry vs. matched noise, and increased activation for control cry vs. matched noise. Exploratory analyses

Table 1. Sample characteristics.

Maternal characteristics	N (%)	Mean ± SD	Range
Age at home visit (years)	—	25.62 ± 5.41	18–37
Age at fMRI Scan (years)	—	25.70 ± 5.40	18–37
Ethnicity			
Hispanic/Latinx	26 (48.1)		
Race			
White/Caucasian	27 (50.0)		
Black/African American	2 (3.7)		
Asian	1 (1.9)		
Multiracial	4 (7.4)		
Other/Unspecified [a]	20 (37.0)		
Income-to-needs ratio (last 12 months)	—	2.58 ± 1.50	0.43–6.24
Years of education	—	14.04 ± 2.36	9–20
Handedness (right)[b]	46 (85.2)	—	—
Relationship status (Married/engaged/common law marriage/long-term relationship)	44 (81.5)	—	—
Breastfeeding exclusively (yes)	21 (38.9)	—	—
Time between home visit and fMRI visit (months)	—	1.04 ± 1.06	0.07–6.25
State anxiety symptoms (STAI-State)	—	31.66 ± 7.52	20–54
Trait anxiety symptoms (STAI-Trait)	—	35.65 ± 10.28	20–60
Depressive symptoms (BDI)	—	7.22 ± 5.12	0–22
Self-reported history of psychiatric disorder (Yes)[c]	20 (37.0)	—	—
Current anxiety or depression medication use (Yes)	4 (7.4)	—	—
Perceived maternal care	—	26.46 ± 8.54	4–36
Sensitivity	—	5.38 ± 1.17	3.5–7.0
Baseline oxytocin	—	40.87 ± 17.66	7.03–91.23
Post-interaction oxytocin	—	37.39 ± 17.08	9.26–86.03
Average oxytocin	—	39.03 ± 15.09	8.15–69.81
Infant Characteristics	**N (%)**	**Mean ± SD**	**Range**
Sex (female)	33 (61.1)	—	—
Gestational age at birth (weeks)	—	39.34 ± 1.53	36–42
Age at home visit (months)	—	3.52 ± 1.68	0.72–7.00
Age at fMRI Visit (months)	—	4.56 ± 2.04	0.89–10.65

[a]Of the 20 participants who identified their race as "Other," 10 participants self-identified their race as "Hispanic/Latinx," 5 participants as "Mexican/Mexican-American," 1 participant as "West Indian," 1 participant as "American," and 3 participants did not self-identify.
[b]2 participants missing handedness data.
[c]Self-reported history of anxiety ($N = 5$), depression ($N = 4$), depression and anxiety ($N = 7$), postpartum depression ($N = 1$), anorexia ($N = 1$), PTSD ($N = 1$), and OCD and anxiety ($N = 1$).

Table 2. Significant brain areas from whole brain analysis: Childhood Care × Oxytocin × Condition (Sound, Identity).

Regions	BA	Side	x	y	z	Cluster size	F
Childhood Care × Oxytocin × Sound × Identity							
Anterior cingulate	32	R	17	41	5	48	16.51
Oxytocin × Sound × Identity							
Cuneus	18	L	−10	−79	17	39	16.67
Oxytocin × Sound							
Inferior frontal gyrus	45	R	47	20	2	37	26.41
Superior temporal gyrus	21	R	59	−22	2	34	30.60

Note. $p < 0.05$, corrected; BA = Brodmann area, R = right, L = left; x, y, z are Talairach coordinates, and F-statistics represent the voxel with maximum signal intensity (i.e. peak value) for each cluster.

demonstrated that higher sensitivity was associated with greater activation in the left cuneus during own cry vs. noise ($r = 0.30$, $p = 0.029$) and trended toward greater activation during own vs. control cry ($r = 0.27$, $p = 0.052$).

A significant two-way interaction of Oxytocin × Sound (Cry, White noise) was identified in the right superior temporal gyrus and right inferior frontal gyrus (Table 2). Higher oxytocin levels were associated with reduced activation in both clusters in response to infant cry sounds compared to matching white noise sounds. Exploratory analyses revealed no significant associations with parental sensitivity.

Discussion

Our findings suggest that recollections of childhood caregiving experiences and the neuropeptide oxytocin have combined influences on neural adaptation to parenthood, especially for their own infants. High salivary oxytocin was related to dampened neural activation in regions important for the initial processing of emotional stimuli and implicit emotion regulation (frontal and temporal regions), which can be a sign of toning down the aversive initial response to an infant cry, as well as in regions important for mentalization (cuneus regions). However, among participants with high oxytocin levels, higher perceived childhood maternal

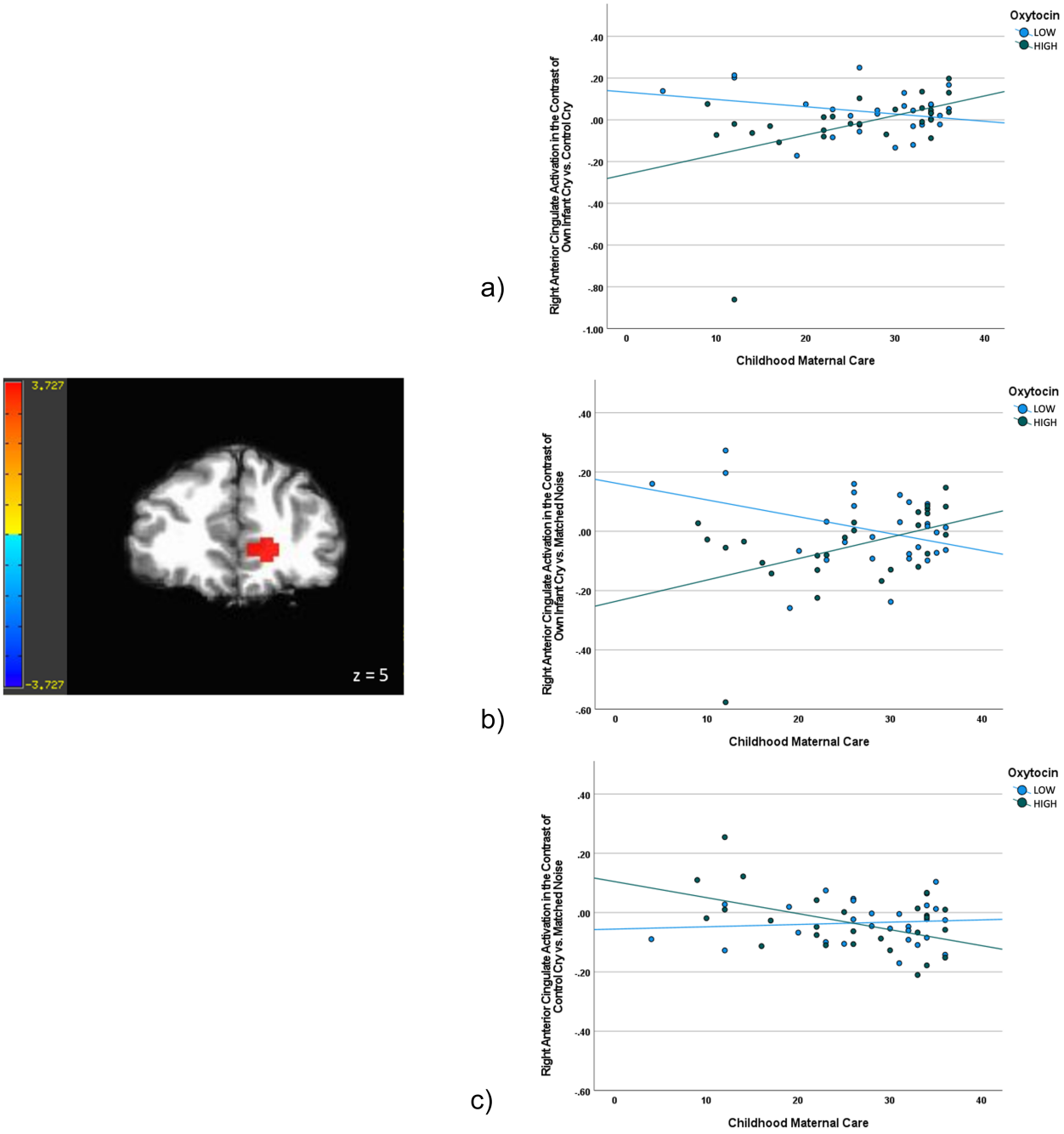

Figure 1. Right anterior cingulate activation (x, y, z = 17, 41, 5, $k = 48$, $p < 0.05$ corrected) showing a Childhood Maternal Care × Oxytocin × Sound × Identity Interaction. Oxytocin was analyzed continuously; however, for ease of interpretation, post hoc analyses examined findings by dividing oxytocin into LOW oxytocin and HIGH oxytocin groups around the mean. Among participants with HIGH oxytocin, higher care was associated with (a) greater activation to their own infant's cry vs. control cry, (b) greater activation to their own infant's cry vs. matched noise, and (c) reduced activation to control cry vs. matched noise.

care was related to increased ACC activation in response to their own infant's cry, potentially indicating more adaptive empathy and motivation for caregiving.

Our results suggested that higher childhood care paired with higher oxytocin was associated with greater activation in the right ACC during their own infant's cry (compared to control cry and to matched noise), but reduced activation during a control cry (compared to matched control noise). No such association was observed for participants with lower oxytocin levels. The ACC is known to be important for emotional response, empathy, and social reward (Völlm et al. 2006, Elmadih et al. 2016). Parents typically show heightened ACC response to their own vs. unknown child stimuli, reflecting enhanced salience and emotive processing for their own infant (Bartels and Zeki 2004, Leibenluft et al. 2004, Noriuchi et al. 2008, Barrett et al. 2012, Elmadih et al. 2016). Although the current study did not find observed parenting differences related to ACC activation, prior work suggested that greater ACC response was associated with observed positive parenting (Michalska et al. 2014), mother–infant synchrony during play (Atzil et al. 2014), and self-reported caregiving motivation (Bos et al. 2018). Our finding supports the interactionist model of oxytocin function in which endogenous oxytocin levels might

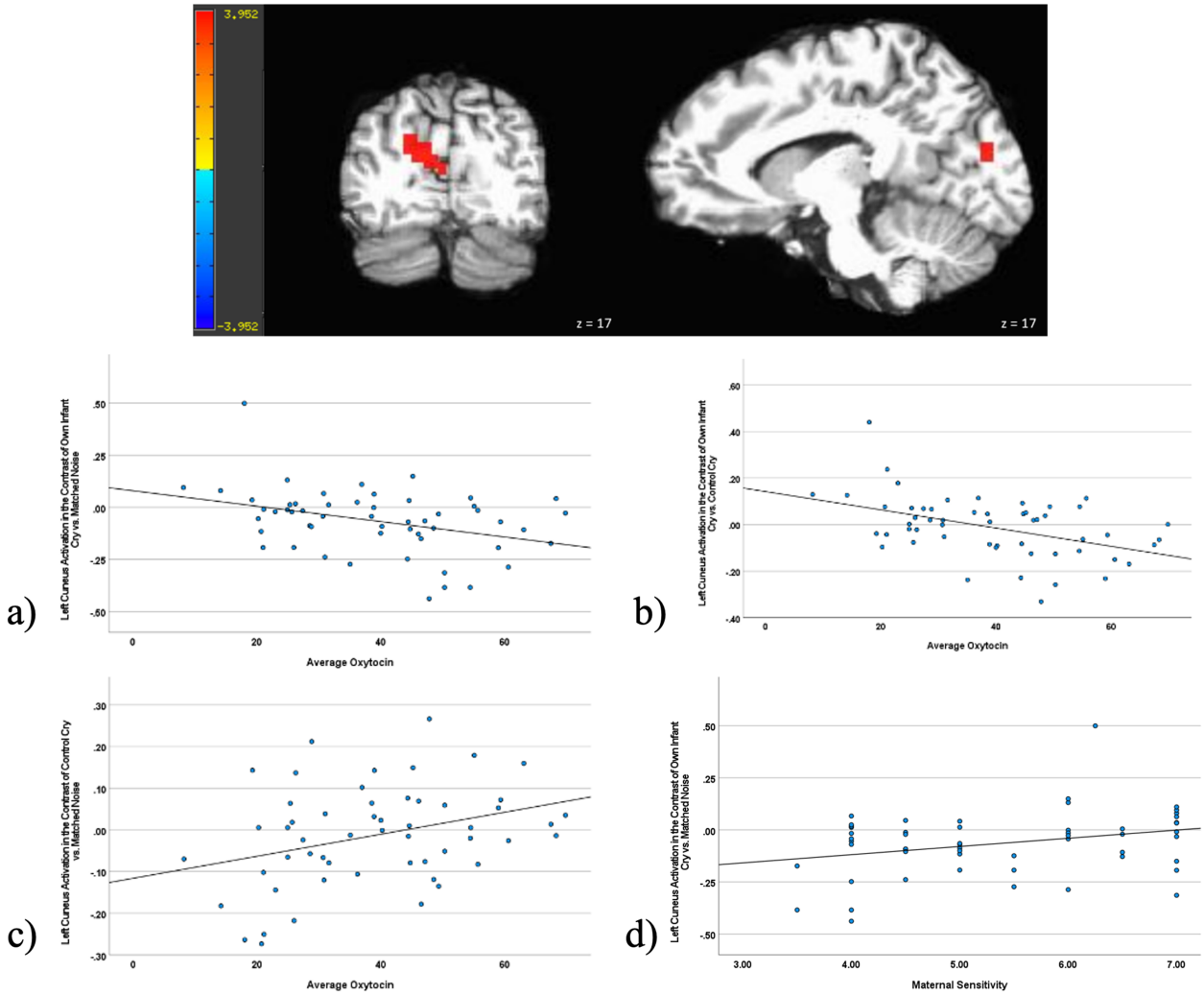

Figure 2. Left cuneus activation (x, y, z = −10, −79, 17, $k = 39$, $p < 0.05$, corrected) showing an Oxytocin × Sound × Identity Interaction. Higher maternal oxytocin was associated with (a) reduced activation in response to infant cry vs. control cry, (b) reduced activation for own cry vs. matched noise, and (c) increased activation for control cry vs. matched noise. Exploratory analyses revealed higher activation in response to own infant cry vs. matched noise was associated with (d) higher maternal sensitivity ($r = 0.30$, $p = 0.029$).

be an indicator of an individual's sensitivity to social contexts (Bartz et al. 2011). More specifically, oxytocin sensitized participants' responses to their own infant's cry in the ACC but only for those who recalled childhood parenting as warm and affectionate. The observed enhanced ACC activation during an infant's cry may reflect a compensatory response to increase motivation and empathy for the infant's cry, indicative of oxytocin's contribution to more optimal parenting when paired with an optimal childhood caregiving experience.

In addition, higher parental oxytocin was related to dampened neural activation to infant cries in the right IFG and right STG in the current study, which were known to be important for caregiving and are typically stimulated by infant cries (Kim et al. 2011, Swain 2011, Swain et al. 2011, Laurent and Ablow 2012). These findings contrast with prior research showing elevated frontal and temporal response to infant-relevant stimuli among parents with higher plasma oxytocin (Atzil et al. 2012) and among women following intranasal oxytocin administration (Riem et al. 2011, Voorthuis et al. 2014). One potential explanation is that the dampened right IFG and STG activations are indicative of implicit emotion regulation of the highly aversive stimuli (i.e. infant cries) to prepare parents for more optimal parenting (Buhle et al. 2014, Kohn et al. 2014). Thus, the dampened activation might indicate less effort required in the face of negative infant stimuli from their own infants. Another potential explanation for this observed dampening effect of oxytocin may be due to the known anxiolytic role of oxytocin in situations of interpersonal distress, including stress in the mother–child relationship (Taylor et al. 2006, Feldman et al. 2011, Tabak et al. 2011, Elmadih et al. 2014).

Additionally, decreased parental sensitivity was related to a dampened cuneus response (including the precuneus) to their own infant's cry. Our findings suggest that dampened cuneus activation in response to an infant's cry was further associated with lower maternal sensitivity and higher oxytocin level. The cuneus is implicated in the default mode network, and such negative association can reflect directing attention away from the cry stimuli itself and focusing more on providing timely care for their infants.

The following limitations should be noted. First, the PBI is a retrospective measure of childhood parenting experiences. The PBI assesses perceptions of parenting quality; it is not an objective or

observational measure of parenting behaviors and is also independent from assessments of adult attachment (Manassis et al. 1999, Roisman et al. 2007). It is possible that parents' recollections of their childhood maternal caregiving may differ from observational accounts. This does not negate the importance of subjective accounts of parenting. Rather, memories of childhood caregiving may have a unique and powerful influence on parental adaptation that extends beyond observed caregiving behaviors (Grant et al. 2012, Narayan et al. 2019, Fukui et al. 2021). The current study evaluated potential confounding parent and infant variables that could contribute to associations between reported childhood maternal care and observed neural findings. Besides childhood maternal care, childhood maternal overprotection and childhood paternal caregiving experiences are indispensable aspects of one's childhood caregiving experiences (Rohner and Veneziano 2001, Lamb 2004, Videon 2005, Bretherton 2010, Grant et al. 2012, Fukui et al. 2021). Hence, future studies should address the relationship between childhood maternal overprotection/paternal care/paternal overprotection, oxytocin functioning, and parental neural response to infant stimuli.

Second, the current sample represents a community sample with a limited range in childhood maternal care experiences, postpartum mood symptoms, and parenting behaviors. This may have been why there were no observed associations between parental sensitivity and perceived childhood maternal care as well as depressive symptoms in the current sample. Research is needed to extend findings to diverse parent and infant populations, including parents with adverse childhood experiences (e.g. childhood maltreatment) and parents at risk for postpartum mood and parenting difficulties. Third, the present study adopted a naturalistic study procedure, and a cautious interpretation of oxytocin results is still needed. While previous studies adopted a habituation/rest period before the baseline oxytocin collection, parents were with their infants and in a caregiving context during the whole session in the current study design. Factors that could have contributed to basal oxytocin are varied, including individual factors (e.g. parental anxiety, emotion regulation skills, ability to empathize, and attachment style), interpersonal factors (e.g. parental social sensitivity and motivation), and situational factors (e.g. parents perceiving the research home visit as being evaluative/stressful) (Bartz et al. 2011, Koven and Max 2014). It is also important to acknowledge that the aforementioned factors might also serve as important moderators for oxytocin function on caregiving, which requires further investigation. Fourth, it is not possible to infer causality of findings as measures were assessed concurrently. It is also important to note that parent oxytocin was assessed within the context of a natural, non-stress-related parent–child interaction during the home visit with their own infant about 1 month prior to the MRI visit, not during exposure to the fMRI infant cry paradigm. Given the stability of intra-individual oxytocin levels, it is likely that a parent's endogenous oxytocin level could relate to their brain response at a separate time point. However, the present study cannot speak directly to the relation between brain findings and concurrent oxytocin release during infant cry. Future research is needed to explore how oxytocin response differs across caregiving settings and relates to neural differences. We also want to note that although previous studies indicated positive associations between neural response to infant cry and more sensitive parenting behaviors (Atzil et al. 2011, Kim et al. 2011, 2020), the evidence supporting such brain–behavior association was limited to the cuneus region. Further, longitudinal research is needed to draw prospective associations between childhood caregiving experiences and subsequent neural, hormonal, and parenting differences. Lastly, future studies should include information about parents' gender identification information, as gender identification might be related to expected family roles during caregiving.

The current study is one of the first to examine both the neural and hormonal underpinnings of childhood caregiving experiences during the transition to parenthood among parents. Findings suggest that perceptions of more optimal childhood maternal caregiving combined with high maternal oxytocin may be important protective factors supporting birthing parents during their neural adaptation to parenthood. The postpartum period is a time of rapid reorganization and vulnerability to psychopathology, particularly for parents who recall their own mothers as overprotective or unaffectionate (Siddiqui et al. 2000, Della Vedova et al. 2011a). Public health and home-visiting interventions are essential for supporting new parents with negative caregiving experiences, as well as altering intergenerational patterns of parenting (Sadler et al. 2013, Lieberman et al. 2020, Slade et al. 2020, Narayan et al. 2021). In addition to exploring risk factors, the current study provides evidence for interactive, protective influences during the postpartum period. Specifically, perceptions of childhood maternal care as warm and affectionate appeared to interact with high parental oxytocin to enhance ACC response to infant cry, a region important for parental motivation and empathy. This speaks to the complexity of oxytocin in conveying both risk and resilience, depending on context and individual differences in caregiving history. Continued investigation is needed both to understand the neural and hormonal adaptations to parenthood and to promote pathways to resilience among vulnerable parents and infants.

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Supplementary data

Supplementary data is available at *SCAN* online.

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