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Relationship between oxytocin and maternal approach behaviors to infants' vocalizations

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ABSTRACT

Infants communicate their emotions to caregivers mainly through vocalizations. Research has shown that maternal oxytocin levels relate to adaptive parenting; however, little empirical research exists regarding the effects of endogenous oxytocin levels on maternal responses to infant vocalizations. Thus, in this study, we examined the relationship between mothers' salivary oxytocin levels, subjective feelings, and behavioral response to infants' emotional vocalizations. Additionally, we examined the relationship between psychological traits and maternal behavioral responses to infant vocalizations. In this study, 39 mothers were asked to stand on a balance board while listening to infant vocalization stimuli, to measure movements of their center of pressure, an index of approach-avoidance behavior. Sixty infant vocalizations (laughter, crying, and neutral) were presented for 6 s each. Afterwards, participants were asked to rate their subjective responses to each stimulus (not aroused – aroused, displeased – pleased, not urgent – urgent, and healthy – sick). Maternal oxytocin levels were negatively correlated with anterior movement of the center of pressure in response to infants' crying and babbling vocalizations, though no relationship was found between maternal approach-avoidance behavior toward infant laughter and oxytocin levels. This study indicated that maternal approach behavior toward infant vocalizations varies as a function of maternal endogenous oxytocin and the type of infant vocalization.

1. Introduction

Human infants require caregivers' assistance in many situations. Infants communicate their needs through visual, auditory, somatosensory, and olfactory cues. Specifically, auditory signals such as crying and laughing are vital to distal mother-infant communication [1]. Research suggests infants' emotional vocalizations have functions including attracting caregivers' attention, maintaining proximity with caregivers, and eliciting parenting behavior from caregivers [1,2]. Several non-human animal studies have shown that rat pups generate ultrasonic vocalizations when isolated and/or cooled outside the nest [3], and these vocalizations elicit maternal orienting and approach behavior [3–5].

Compared to non-human animal research, little is known regarding human maternal approach behavior toward infant vocalization. Bowlby [6] argued in his attachment theory that human infant vocalizations also function as signals to attract mothers' attention and motivate approach behavior. This seemingly corresponds to recent brain imaging research showing rapid neural responses in the motor and supplementary motor cortexes to infants' emotional cues [7]. Additionally, in parents, infants' cries trigger motor evoked potentials at the biceps brachii and interosseus dorsalis primus muscles [8]. These findings indicate this reactivity shows a preparatory response for caregiving [9]. In line with this assumption, a recent study observed for the first time the relationship between maternal approach-avoidance behavior and emotions embedded in infant vocalizations, showing that mothers approach sounds of an infant crying, but not laughing [10].

Human mothers do not always indiscriminately respond to infant's emotional vocalizations, but can suppress psychological and

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physiological responses. Del Vecchio et al. [11] demonstrated that mothers who rated their own infant's cries as highly aversive and showed higher heartrate reactivity to them, responded quickly to non-distressed infant vocalizations. Kurth et al. [12] found that mothers' caregiving skills and attitudes toward crying infants change with increased childcare experience, leading to calmer responses. Further, some evidence indicates that while human infant vocalizations elicit maternal attention and approach behavior—similar to non-human animals—human mothers tend to regulate aversive feelings and indiscriminate approach behavior. However, few studies have investigated underlying mechanisms regulating maternal approach behavior toward infant emotional vocalizations.

Recently, there has been increasing interest in the role of oxytocin, a peptide hormone related to caretaking behavior in humans and animals. Pedersen et al. [13] revealed that oxytocin knockout in female mice decreased pup retrieval behavior, compared to wild-type female mice. Additionally, oxytocin receptor-deficient female mice displayed significantly longer latency in retrieving and crouching over pups than control female mice [14].

Oxytocin has been shown to modulate human parenting behavior, as maternal peripheral oxytocin levels are positively correlated with sensitive parenting behavior in mother-infant interactions (e.g. Ref. [15,16]. Conversely, Elmadih et al. [17] reported that mothers who respond highly sensitively to their children have lower baseline plasma oxytocin levels, compared with less sensitive mothers. These studies, despite controversial and variable effects, have reported a relationship between peripheral oxytocin levels and parenting behaviors. However, such investigations have failed to address possible mechanisms for the effects of oxytocin on parenting behavior. Interactions between infants and parents are complex and affected by various multidimensional factors, such as the child's characteristics and behavior, or the existence of others [18]. Thus, in the present study, among multiple parenting behaviors, we focused on maternal responsiveness to infant vocalizations. Infant vocalizations can trigger caretaking behavior, yet they can also lead to inappropriate parental behaviors, such as child maltreatment. Addressing oxytocin's effects on maternal responses to infant vocalizations could contribute to a deeper understanding of oxytocinergic mechanisms underlying parenting behaviors in human mothers.

Infants' cries and laughs both elicit strong activation in the amygdala [19]. The amygdala is activated by emotionally arousing stimuli, whether pleasant or unpleasant [20]. In a parenting situation, amygdala activation is regarded as a sign of emotional salience [21,22]. Research shows that oxytocin suppresses amygdala activity and reduces anxiety in mice (e.g., Refs. [23]. Additionally, in women, administration of oxytocin was associated with reduced responses in the amygdala to crying [24] or laughing infants [25]. Further, it has been shown that the stronger caregivers experienced aversive feelings and heartrate responses to an infant's crying, the quicker they responded [11]. Thus, we could hypothesize that caregivers with low oxytocin levels might respond to infants' emotional vocalizations due to feeling stronger salience and anxiety toward the sounds.

In the present study, we addressed maternal endogenous oxytocin effects on postural movement and subjective feelings toward infants' emotional vocalizations. We used an approach-avoidance paradigm, in which participants were asked to stand on a force plate to measure postural movement toward emotional signals. This paradigm has previously been used to investigate valence effects on approach-avoidance behavior [26]. Additionally, since little empirical research exists regarding approach-avoidance behavior toward infant vocalizations in humans, it is necessary to investigate psychobiological factors underlying maternal behaviors. Thus, we aimed to explore the deeper mechanism of maternal behaviors from a psychological and neuroendocrinological viewpoint. We hypothesized that given its anxiolytic effects [23], oxytocin would decrease subjective arousal, urgent feelings, and approach behavior toward infant vocalization, as this approach behavior was caused by maternal aversive and urgent feelings [10,11].

2. Materials and methods

2.1. Ethics statement

Before the experiment, participants were provided with an information sheet outlining the study's general purpose and informed they could withdraw at any time, without penalty. All participants signed a consent form. All methods employed in this study were approved by the Ethics and Safety Committees of NTT Communication Science Laboratories and were in accordance with the Declaration of Helsinki.

2.2. Participants

Thirty-nine healthy mothers aged 26–43 years (34.2 ± 4.1 years; mean ± *SD*) participated in the experiments. A subset of participants (n = 21) was drawn from our previous study [10] and the data on center of pressure (COP) and subjective ratings were reported there. The sample size was determined by a preliminary power analysis, which indicated that achieving 0.80 power at an alpha level of 0.05 for a medium size (0.40, based on the criterion by Cohen [27]) for correlation analysis required a sample of 44 participants using the software G*Power version 3.1.9.2 [28]. Although there were some limitations, such as the planned period of the experiment and some participants cancelling participation of the study, we approximated the number of participants as closely as possible. To investigate the relationship between the maternal COP movement and maternal oxytocin in this approximate sufficient sample size, we recruited additional participants (n = 18), and first reported the relationship between them.[3] All were nursing at least one child under 24 months (11.7 ± 6.8 months old). Eighteen participants were primiparous women. Participants were informed they would hear samples of infants' voice stimuli, and a riding board would be used to measure the position of their COP. They were asked to provide a saliva sample, describe their emotions, and complete several questionnaires. They provided informed consent and were paid for their participation. The experiments were performed in a sound-insulated room.

2.3. Procedure

Participants were instructed to abstain from breastfeeding 1 h before the start of the experiment. Participants were given general information regarding the experiment upon their arrival at the lab, and their written informed consent was obtained. Then, at least 3 mL of unstimulated saliva was collected in a conical tube for each participant, using the passive drool method. From each saliva sample, 1 mL was used to determine oxytocin levels. The experimental procedure consisted of two tasks. In the first task, participants' postural sways were recorded during the presentation of infant vocalizations. In the second task, participants were asked to rate their subjective feelings in response to each infant vocalization. The same vocalization stimuli were used in both tasks. After the two experiments, participants were asked to complete the questionnaires.

2.4. Experimental tasks

2.4.1. Postural task

The present study employed an approach-avoidance task [26], using a Wii balance board with four weight sensors as a force plate to measure mothers' postural sway. Wii balance boards have been confirmed as valid

[3] Although the present study added and reported additional participants from a previous study [10], the purpose of this study was to examine a different research question, which was to examine the correlation between salivary oxytocin levels and maternal responses, contrary to the previous study. Although the procedure was designed to ensure the necessary sample size for the correlation analysis, there is room for improving this procedure in future.

and reliable measuring tools for assessing standing balance and postural sway, as professional-grade force platforms [29]. In this paradigm, COP was measured during the presentation of stimuli at 40 Hz. Participants were asked to stand on the board. Forward movement of participants' COP was defined as approach, while backward movement was defined as avoidance. Previous research using this paradigm revealed that people move forward in response to pleasant pictures and backward in response to unpleasant pictures [26].

The first 10 min of the posture task were to familiarize participants with the experimental setup. Participants were asked to get on the Wii balance board and listen to three sample voice stimuli for practice. Next, they listened to 60 infant voice stimuli while standing on the Wii balance board. The order of the voice stimuli was completely randomized for each participant. The intertrial interval was 9–15 s and the duration for each stimulus was 6 s. After every 10 stimuli, participants got off the board and sat on a chair to rest for 1 min. Hot Soup Processor version 3.5 (Onion Software, Japan) was used to present vocal stimuli and record COP. In order to reduce the influence of outliers, outlier data for COP was winsorized. COP data were once standardized and winsorized at 3 *SD* from the mean value using DescTools package [30]. In these processes, all values lower than −3 *SD* and higher than +3 *SD* were replaced by −3 *SD* or +3 *SD* values.

2.4.2. Subjective rating task

After completing the posture task, participants were asked to rate their emotional responses to each voice stimulus they heard (not aroused – aroused, displeased – pleased, not urgent – urgent, and healthy – sick) using a visual analog scale (VAS) ranging from 0 to 1 [31]. The VAS was presented on a PC screen using PsychoPy2 1.82 [32]. The length of the VAS line segment was approximately 20 cm, and participants placed the cursor over the VAS, which ranged from 0 to 1. According to the position, PsychoPy2 calculated the value to the nearest one one-hundredth. To evaluate the degree of participants' intent to approach or avoid the voice stimuli, we also asked them to rate their desire to pick up the baby (pick up) or leave the baby alone (ignore) using a VAS.

2.4.3. Infants' voice stimuli

Experimental voice stimuli were collected from the NTT infant voice database [33], which included voice samples recorded from 3- to 12-month-old infants. Two authors and one experiment cooperator independently labeled each voice stimulus as "crying," "babbling," or "laughing." If all three people gave a stimulus the same label, we defined the property of this stimulus. Consequently, we collected 20 crying, 20 babbling, and 20 laughing voice samples, for 60 samples total. Each lasted for 6 s. If the duration was less than 6 s, the sound was repeated until the duration reached 6 s. We carefully modulated the sound pressure level of each stimulus not to exceed 70 dB (A).

2.5. Oxytocin analysis

2.5.1. Chemicals

Protease inhibitor cocktail tablets were purchased from Roche Diagnostics (Switzerland). Oxytocin ELISA kits were obtained from Enzo Life Sciences (USA). Trifluoroacetic acid (TFA) was purchased from Wako Pure Chemicals (Japan). Acetonitrile (ACN) and oxytocin were purchased from Kanto Chemical (Japan).

2.5.2. Assay of oxytocin concentration

We measured oxytocin levels in participants' saliva. Saliva samples (at least 3 mL/person) were directly collected in conical tubes from participants. Saliva was collected from participants via passive drool into a cold tube. The saliva was then divided into equal 1 mL amounts (2 tubes and the residue). One saliva sample was used for the oxytocin assay ("cold" sample) and the other was used to calculate the recovery rate of oxytocin during processing until ELISA was performed ("hot" sample). Each sample was immediately mixed with half the amount of protease inhibitor solution (0.5 mL) to prevent oxytocin degradation. The protease inhibitor cocktail solution was prepared immediately before use, to avoid the hydrolysis of inhibitor peptides. All samples were frozen immediately and stored at −80 °C until needed for the measurement.

Oxytocin concentration measurement consisted of extraction, evaporation, and ELISA. On the day of extraction, a saliva sample was thawed and kept on ice. One-hundred pg oxytocin was added to hot samples, with which we evaluated the rate of oxytocin loss during processing until ELISA was performed. Next, 1.5 mL of TFA (0.1% in Milli-Q water; Milli-Q Advantage, Merck, USA) was added to each saliva sample. After careful mixing, the samples were centrifuged at 2400 rpm for 10 min at room temperature (centrifuge: LC-220, TOMY, Japan). The supernatant was carefully obtained for column purification. C18 columns (MonoSpin-L-C18, GL Sciences, Japan) were first washed with 5 mL of acetonitrile (ACN), then with 12 mL of 0.1% TFA. Samples were applied to the column and were again washed with 12 mL of 0.1% TFA. Finally, the columns were eluted with 6 mL of elution buffer composed of 0.1% TFA and ACN combined at a 40:60 ratio. The eluted samples were stored at −20 °C until the evaporation process.

On the day of evaporation, the eluted samples were thawed and dried with a multiple evaporator (Multivapor P-12, BUCHI, Switzerland) under very low air pressure conditions (40 mbar for ACN, 10 mbar for water) at room temperature. The dried samples were stored at −20 °C until the ELISA process.

On the day of ELISA, 220 μl of the assay buffer from the ELISA kit was added to each sample, thus concentrating the samples (220 μl from 1 mL saliva), resulting in a sample with a salivary concentration approximately 4.5 times higher than the original sample. ELISA was carried out according to the manufacturer's instructions with minor modifications. The absorption at 405 nm was read with a Model 550 plate reader (BioRad, UK). A standard single logarithmic curve was generated from eight doses of oxytocin standard (1000, 500, 250, 125, 62.5, 31.3, 15.7, 7.81 pg/mL). The curve was fit with 3-parameter-logistic curve, whose coefficient of correlation (r2) was around 0.99. The standard curves were similar across all assays. Intra-assay CV was 3.01%, and inter-assay CV was 3.98% (for 3-time measurement). When the oxytocin concentration of the cold sample was calculated as "C" pg/mL, and that of the corresponding hot sample was calculated as "H" pg/mL, the true oxytocin concentration "Ct" was evaluated as follows:

$$Ct = C^{*}220/1000^{*}100/(H - C)(pg/ml)(1).$$

The mean value of oxytocin was 13.03 (pg/ml) and *SD* was 10.12.

2.6. Questionnaires

The Childhood Trauma Questionnaire (CTQ [34]; was used to assess participants' history of childhood sexual, physical, and emotional abuse, as well as physical and emotional neglect. The CTQ has 28 items. Participants responded using a Likert-type scale ranging from 1 (never true) to 5 (very often true). Cronbach's α coefficient was 0.89.

The Childcare Anxiety Questionnaire (CAQ [35]; was used to measure childcare anxiety. The CAQ has 24 items, and participants were required to provide ratings using scales ranging from 1 (completely disagree) to 4 (completely agree). Cronbach's α coefficient was 0.90.

Trait empathy was assessed using the Interpersonal Reactivity Index (IRI; [36,37], which measures four aspects of empathy: empathic concern (EC), personal distress (PD), perspective taking (PT), and fantasy (FS). Cronbach's α coefficients were 0.65, 0.83,.83, and 0.67 for EC, PD, FS, and PT, respectively. Cronbach's α of EC and PT scale were not acceptable. So only PD and FS were used in further analysis.

The BIS/BAS scale [38,39] is a 20-item, self-report measure that assesses the behavioral inhibition system and behavioral activation system: Drive, Reward Reactivity (RR), and Fun Seeking. Answers are rated using a scale ranging from 1 (completely disagree) to 4 (completely agree). Cronbach's α coefficients were 0.81, 0.71, 0.58, and 0.68 for BIS, Drive,

RR, and Fun Seeking, respectively. Cronbach's α of RR and Fun seeking scale were not acceptable. So only BIS and Drive were used in further analysis.

Impulsiveness was assessed using the Barratt Impulsiveness Scale 11th (BIS-11; [40]. The BIS-11 consists of 30 items, each rated on a 6-point Likert scale ranging from 1 (rarely/never) to 6 (almost always/always). It has two factors: non-planning impulsivity (α = 0.69) and motor impulsivity (α = 0.76). This two-factor structure was based on the Japanese version of BIS-11 [41]. Cronbach's α of non-planning impulsivity was not acceptable. So only motor impulsivity was used in further analysis.

The Buss-Perry Aggression Questionnaire (BPAQ [42]; was used to assess participants' aggressiveness. Responses were provided using a 5-point Likert scale ranging from 1 (extremely uncharacteristic of me) to 5 (extremely characteristic of me). The BPAQ has four subscales. Total scores were calculated, and higher scores indicated higher trait aggression (α = 0.87).

2.7. Statistical analysis

We regarded $p < .05$ as statistically significant for each analysis, using two-tailed testing. To test the hypothesis that salivary oxytocin levels are related to maternal COP movement and subjective feelings in response to infant vocalizations, partial correlation analyses were run while controlling for mothers' age, children's age, and each participant's number of children, as these variables have been shown to effect responses to infant vocalizations and oxytocin levels [43–45]. Number of children was a dummy factor (one = −0.5; two or more = 0.5). Additionally, we conducted partial correlation analyses between maternal COP and each questionnaire to investigate what changes in maternal COP in response to infant vocalizations reflected, and to deepen our understanding of the relationship between salivary oxytocin and maternal responses to infant vocalizations. In this analysis, a multiple test correction was conducted using the Bonferroni method. R version 3.6.0 was used for all statistical analyses.

3. Results

Data of some participants were excluded from relevant statistical analyses because their COP data was not recorded due to technical failure (n = 2). Additionally, data of some participants were excluded from relevant statistical analyses due to insufficient saliva volume (n = 2) or technical failure of oxytocin assay (n = 4). Missing data were managed using pairwise deletion.[4] Differences in COP and subjective ratings between sound categories were reported in Supplementary materials.

3.1. Salivary oxytocin levels and subjective ratings

To investigate the relationship between oxytocin levels and subjective feelings toward infant vocalizations (crying, laughing, and babbling), we conducted partial correlation analyses for each sound category, controlling for mother's age, child's age, and number of children. No significant correlations were found between salivary oxytocin levels and each subjective rating (Table 1 and Figure S1).

3.2. Association between salivary oxytocin and COP

First, bivariate correlations without control variables (age, child age, and the number of children) were performed. The correlation between oxytocin levels and COP for the babbling condition was significant ($r = -0.47$, $p = .007$). The correlations between oxytocin levels and COP for the crying condition ($r = -0.25$, $p = .177$) and laughing condition ($r = 0.09$, $p = .619$) were not significant. There was a positive correlation between maternal age and oxytocin levels ($r = 0.36$, $p = .048$). In addition, maternal age was medium correlated with the COP for the crying condition, although not significantly ($r = 0.31$ (>0.30, Cohen [46]), $p = .315$), and we considered it necessary to control for age. We performed partial correlation analyses between salivary oxytocin levels and COP for each sound category, controlling for mother's age, child's age, and number of children. Salivary oxytocin levels were negatively correlated with COP in the crying condition ($r = -0.41$, $p = .030$) and neutral condition ($r = -0.49$, $p = .009$). Salivary oxytocin levels were not significantly correlated with COP in the laugh condition ($r = 0.12$, $p = .550$). These results were shown in Fig. 1.

Table 1
Partial correlation coefficients between salivary oxytocin levels and subjective ratings.

	Cry	Laugh	Neutral
Arousal	−0.18	0.14	−0.05
Valence	0.00	0.03	−0.06
Urgency	0.04	−0.02	−0.01
Healthy	−0.13	0.05	−0.04
Caregiving	−0.04	0.12	0.09
Harsh	−0.01	0.10	0.01

We conducted the comparison of correlation coefficients from dependent samples [47]. The analysis revealed that there was a significant difference in correlation coefficients between the crying and laughing conditions ($t(29) = -2.21$, $p = .035$), but not between the crying and neutral conditions ($t(29) = 0.50$, $p = .624$). Additionally, the correlation coefficients were significantly different between the laughing and neutral conditions ($t(29) = 2.63$, $p = .014$).

3.3. Association between questionnaire responses and COP

To explore the psychological mechanisms underlying maternal COP movement in response to infant vocalizations, we conducted partial correlation analyses between COP and several questionnaires, controlling for mother's age, child's age, and number of children. The results are shown in Table 2 and Figure S2. No correlations remained significant after correction for multiple Bonferroni correction. However, according to Cohen's [46] criteria, a correlation coefficient of 0.30 is considered a medium and 0.50 is considered a large correlation relationship. The results of this study showed that the following were applicable; motor impulsivity ($r = 0.45$) and aggression ($r = 0.45$) with COP in the cry condition, and behavioral inhibition system ($r = 0.39$) in the neutral condition.

4. Discussion

The present study aimed to examine the relationship between maternal salivary oxytocin levels and maternal subjective or behavioral responses to infant vocalizations. Although maternal oxytocin has been shown to affect parenting attitudes [15,16], a more detailed link between oxytocin and responsiveness to infant vocalizations has not been shown. In this study, participants' COPs while listening to infant vocalizations were recorded, and their subjective feelings for each voice stimulus were assessed. Oxytocin levels were quantified by ELISA from saliva collected before the task. COP during crying and babbling vocalizations and oxytocin levels were found to be negatively correlated. Moreover, mothers' COP movement positively correlated with trait aggression or impulsivity. This suggested that oxytocin is involved in maternal behavioral responses to infant vocalizations, and that oxytocin suppresses impulsive approach behavior.

[4] Missing values were also treated with multiple imputations using multivariate imputation by chained equations. We used mice [55] and miceadds [56] packages to conduct multiple imputation methods. 20 imputed datasets were created with 20 iterations per dataset. Partial correlation analyses using imputed datasets showed that salivary oxytocin levels were negatively correlated with COP in the crying condition ($r = -0.36$, $p = .043$) and neutral condition ($r = -0.46$, $p = .017$), and salivary oxytocin levels were not significantly correlated with COP in the laugh condition ($r = 0.08$, $p = .621$).

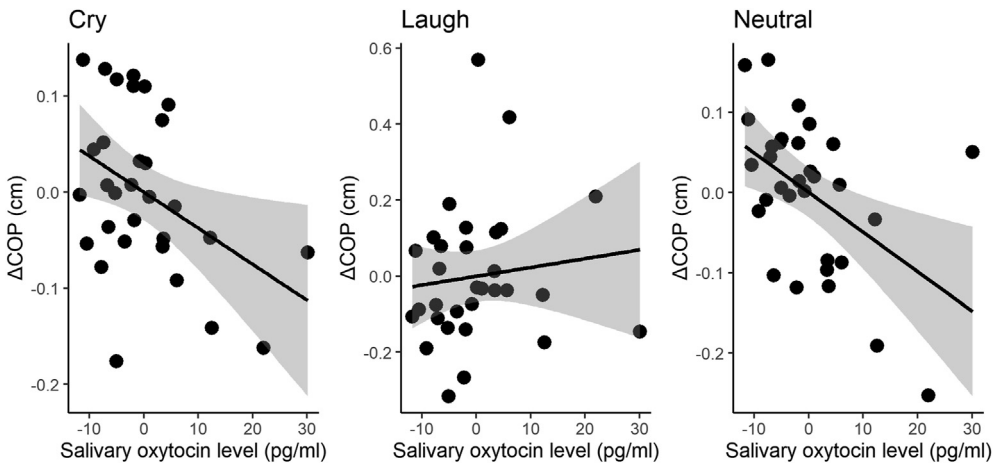

Fig. 1. Scatterplots depicting the relationship between COP (cry, laugh, and neutral condition) and salivary oxytocin levels (pg/ml). All values were residuals derived from the effects of mother's age, child's age, and number of children.

Table 2
Partial correlation coefficients between COP and questionnaire scores.

Questionnaire	Subscale	Cry	Laugh	Neutral
CTQ		0.16	0.19	−0.11
CAQ		0.24	0.20	0.04
IRI	FS	0.04	0.14	0.00
	PD	0.03	0.16	0.16
BIS/BAS	BIS	0.17	0.18	0.39
	Drive	−0.01	0.04	0.00
BIS-11	motor impulsivity	0.45	0.08	0.22
BPAQ		0.45	0.15	0.15

Note: CTQ The Childhood Trauma Questionnaire; CAQ The Childcare Anxiety Questionnaire; IRI The Interpersonal Reactivity Inventory; FS Fantasy; PD Personal Distress; BIS/BAS The Behavioral Inhibition/Behavioral Activation Scales; BIS-11 the Barratt Impulsiveness Scale 11th; BPAQ The Buss-Perry Aggression Questionnaire.

In this study, oxytocin levels were negatively correlated with mothers' anterior movements toward infants' crying and babbling vocalizations. This suggested that oxytocin has the function of suppressing approach behavior toward infant vocalizations. Infant vocalizations have been shown to attract caregivers' attention and induce approach behavior in both humans and non-human animals [3,11]. However, in humans, maternal approach behavior toward infant vocalizations is also related to physiological arousal, aversive feelings, and lack of caregiving experience [11,12]. Our findings suggested that mothers adaptively take care of children by regulating their psychological and physiological arousal. This is supported by previous hypothetical models of infant voice stimuli processing [21]. Processing of infant cues involves competition between the checking and worrying systems, based on the limbic and executive function systems and the lateral prefrontal cortex [21]. The amygdala could plausibly allow for rapid perception of information from infant cues and may support more detailed processing of cue salience and meaning [9]. Nasal administration of oxytocin reduces amygdala activity when listening to an infant's crying [24]. Endogenous oxytocin might also modulate amygdala activity and reduce the salience of infant vocalization, which would lead to attenuating approach behavior toward infant vocalizations.

In this study, a negative correlation between salivary oxytocin levels and COP was found only for crying and neutral sounds, not for laughter. Nasal administration of oxytocin suppresses amygdala activity in response to infant laughter, as well as crying [24,25]. In a previous study, infant laughter elicited amygdala activity for non-parents, while parents did not show amygdala activity in response to infant laughter, compared to infant crying [22]. Crying signals an infant's need for attention from a caregiver—who may not be present—while laughter is a pleasant vocalization made when engaging with an already-present person [48]. In the future, studies may reveal the reason behind the difference in COP movements for crying and for laughing by examining the effect of the situation and context surrounding the infants on the COP movements of mothers.

In this study, the correlational pattern between oxytocin and COP for cry, and COP for babbling was similar. However, it is possible that the motivation behind these results may be different. Approaching to crying has been shown to be positively associated with aversive feelings and heart rate responses to infant crying [11]. However, while babbling did not require urgent care (and in the current study, arousal, aversive, and caregiving intentions for babbling were rated lower than crying sounds), it is possible that feelings other than aversiveness and urgency may be associated with approach behavior to babbling sounds. There is little evidence about which brain areas are activated by babbling compared to crying or laughing, and we do not know enough about how it is processed by the mother. In future studies, we may be able to distinguish between the brain regions activated during crying and babbling by fMRI.

Oxytocin has anxiolytic effects [23]. It is possible that other endocrine hormones other than oxytocin, such as cortisol and testosterone, are behind the approach-avoidance behavior (e.g., Ref. [49]. A recent study revealed that the amount of cortisol response to a stress task is positively correlated with caregiving intentions to a crying infant [50], which seems consistent with the findings of this study. However, it is difficult to treat these hormones in a single study, so we focused only on oxytocin. Future studies should comprehensively examine the effects of multiple hormones on the approach behavior to infant vocalizations.

Although approach behaviors related to infant vocalizations were correlated with some psychological traits, they did not remain significant after multiple Bonferroni correction. However, according to Cohen's [46] criteria, a correlation coefficient of 0.30 is considered medium and 0.50 is considered a large correlation relationship: impulsiveness and aggression with COP in the cry condition, and behavioral inhibition system with COP in the neutral condition. These results suggest that approach behavior toward infant crying would be related to the inability to regulate impulsiveness. These results were consistent with a previous study which posited that aggression has an approaching aspect [51]. To date, several studies have demonstrated that oxytocin has a positive effect on adaptive parenting behavior (e.g. Ref. [15,16]. However, several points have remained unclear regarding the underlying role of oxytocin in adaptive parenting behavior. To our knowledge, this study is the first to propose the function of oxytocin in regulating the response to infant vocalization, which may be associated with trait aggression and impulsivity. BIS activation is associated with negative experiences such as

those inducing fear or anxiety, therefore, individuals with high BIS show attentional bias towards negative events [52]. The babbling sounds used in this study were rated as more unpleasant and urgent than laughter, and showed a similar tendency in COP behavior as those that occur when listening to cries. Mothers with high BIS may have experienced negative feelings toward the babbling, causing an attentional bias toward it. As mentioned above, it is difficult to interpret the correlation between BIS and COP found in this study because the psychological and neural responses that occur while listening to babbling remain unclear. In any case, the correlations found in this study were weak and could not be considered statistically significant. In future research, more focus will be needed to examine the individual characteristics behind maternal approach behavior to infant vocal vocalizations.

Unlike COP responses, there were no significant associations between oxytocin and subjective ratings. We hypothesized that oxytocin would be associated with arousal, urgency, and unpleasantness related to infant vocalizations. A possible interpretation is there would be different mechanisms between generating subjective feelings and COP movement. It is possible that social desirability or norms (e.g., regarding how a crying baby should be treated) influenced subjective ratings regarding infant stimuli. However, movement in response to infant vocalization is rapid [9]. Thus, a strength of our study was that explicit (subjective ratings) and implicit (COP movement) maternal responses to infant vocalizations were measured in a single study.

The present study had several limitations. First, this study did not consider individual differences in the effects of oxytocin. It has been shown that oxytocin's effects on parental sensitivity could vary according to mothers' childhood experiences [53]. It is possible that such individual differences may moderate oxytocin's effects on postural responses to infant vocalization. Future studies should examine the interaction effects between oxytocin and other individual characteristics on mothers' behavioral responses to infants' emotional vocalizations. Second, this study did not use control sounds and did not recruit non-parent participants or fathers. Therefore, careful consideration is required when generalizing our findings to other caregivers or non-parents. Previous research has indicated that mothers show specific responses to infant vocal stimuli [22], suggesting there are differences in how mothers and non-mothers process infant vocalizations. Future research should extend the present study to include control conditions and non-parent participants, in order to investigate whether our findings are specific to mothers. Lastly, the meta-analysis of Valstad et al. [54] did not find a significant association between central and peripheral oxytocin levels at baseline. However, to date, many studies on human mothers have confirmed the association between peripheral oxytocin level at baseline and nurturing behavior (e.g. Ref. [15,16]. Although the temporal dynamics of central and peripheral oxytocin levels in humans are not fully understood at this time, it is possible that peripheral oxytocin levels, at least during the baseline period, are linked to nurturing behavior. Although more detailed mechanisms need to be studied in the future, this study may contribute to our understanding of the role of oxytocin in human parenting behavior.

5. Conclusion

We presented maternal behavioral and neuroendocrinological data which indicated that maternal endogenous oxytocin regulates parental behavior. We also provided evidence for the underlying psychological mechanisms of such behavior. Our findings supported the idea that human mothers have a regulatory behavioral mechanism, and this mechanism is induced by the oxytocinergic system. We believe clarifying this neuroendocrine basis will make an important contribution to the field of parenting and developmental science.

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Data statement

Data and R code for the analyses and producing manuscript can be accessed at Data in Brief.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.cpnec.2020.100010.

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