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Maternal oxytocin response during mother–infant interaction: Associations with adult temperament

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Abstract

Oxytocin is a neuropeptide associated with social affiliation and maternal caregiving. However, its effects appear to be moderated by various contextual factors and stable individual characteristics. The purpose of this study was to investigate the relationship of self-reported state and trait measures (such as temperament, mood and affect) with peripheral oxytocin response in mothers. Fifty-five first-time mothers participated in a semi-structured procedure, during which time repeated peripheral oxytocin levels were measured before, during and after an episode of mother–infant interaction. The maternal oxytocin response was then calculated, based on the difference in oxytocin concentration between initial baseline and interaction phase. Mothers also completed state measures of positive and negative affect and depression, and trait measures of temperament, personality disturbance and depression across time. Regression analyses determined which factors were independently associated with maternal oxytocin response. The trait measure of adult temperament emerged as a significant predictor of oxytocin response. Two out of four Adult Temperament Questionnaire factor scales were independently associated with oxytocin response: Effortful Control was negatively associated, whereas Orienting Sensitivity was positively associated. No state measure significantly predicted oxytocin response. The results indicate that mothers who show an increased oxytocin response when interacting with their infants are more sensitive of moods, emotions and physical sensations; and less compulsive, schedule driven and task oriented. These findings link differences in individual temperament in new mothers with the peripheral oxytocin response, which may have implications in the pharmacologic treatment of disorders such as maternal neglect, post-partum depression and maternal addiction. This article is part of a Special Issue entitled Oxytocin, Vasopressin, and Social Behavior.

Keywords

Oxytocin; mother–infant relations; Temperament; State; Trait; Maternal

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Introduction

The neuropeptide/hormone, oxytocin, is strongly associated with social and affiliative behavior (Insel, 2010), including the onset of maternal behavior in mammals (Pedersen et al., 1982) and mother–infant bonding in humans (Feldman et al., 2007, 2010; Gordon et al., 2010; Strathearn et al., 2009). While it is most well known for its peripheral actions during labor, delivery and breastfeeding, centrally produced oxytocin may also affect the development of parenting behavior. For example, in rat and sheep models, an injection of oxytocin into the cerebrospinal fluid facilitates the onset of maternal behavior in virgin animals (Kendrick et al., 1987; Pedersen et al., 1982), while an oxytocin antagonist drug blocks the establishment of maternal caregiving in parturient animals (Fahrbach et al., 1985; Keverne and Kendrick, 1992). In humans, plasma oxytocin concentrations measured during early pregnancy and one month after delivery predict positive and adaptive maternal behaviors, such as affectionate touch, motherese vocalization and mother-to-infant gaze (Feldman et al., 2007). A further study has shown that oxytocin levels are associated with interactive synchrony between parent and child (Feldman et al., 2011). Oxytocin therefore appears to play an important role in promoting responsive parental caregiving.

Over the past decade, an increasing number of randomized controlled trials of intranasal oxytocin have demonstrated effects on social and affiliative behaviors, although no study has specifically examined its effects in mothers. Compared with placebo, intranasal oxytocin enhances cooperation in response to social cues (Declerck et al., 2010), facial emotion recognition (Marsh et al., 2010; Rimmele et al., 2009), eye gaze (Gamer et al., 2010; Guastella et al., 2008a), trust (Baumgartner et al., 2008) and attachment (Buchheim et al., 2009), but appears to reduce some aspects of cognitive functioning, such as recall performance (Heinrichs et al., 2004) and memory storage (Bruins et al., 1992).

However, some authors have highlighted the relatively small effect sizes in these studies, noting that the effects of oxytocin are most often modulated by contextual factors and/or stable individual characteristics (*state* and *trait* factors, respectively) (Bartz et al., 2011b). Our own recent study demonstrated that peripheral oxytocin levels in first-time mothers were related both to the mother’s physical proximity to her infant, and to her own adult attachment classification (measured during pregnancy using the Adult Attachment Interview) (Strathearn et al., 2009). Other studies of non-mother populations have revealed that the effect of intranasally administered oxytocin is moderated by factors such as affect valence (Guastella et al., 2008b), task difficulty (Domes et al., 2007), social perception (De Dreu et al., 2010), attachment grouping (Buchheim et al., 2009) and personality factors (Bartz et al., 2011a). Understanding the relationship between oxytocin response and individual state and trait variation is an important step in realizing the potential of oxytocin as a treatment for maternally relevant conditions, such as maternal neglect, postpartum depression and maternal addiction.

In this study, our aim was to test whether maternal oxytocin response during mother–infant interaction was associated with various self-reported state and trait measures. These included measures of current depression, affect ratings before and after mother–infant interaction (state measures); and adult temperament and depression across time (trait measures). We hypothesized that oxytocin response would be associated with both state and trait measures.

Methods

Study setting and participants

Fifty-five first-time mothers, mean age of 28 years, were recruited during the third trimester of pregnancy and assessed postnatally at 6 and 14 months. The sample was predominantly Caucasian (20% Hispanic and 13% African American) and three-quarters were married. Recruitment occurred in Houston, TX between August 2004 and April 2006, and the study was advertised at prenatal clinics and on billboards, in magazines, and on the Internet. Mothers were excluded if they were on psychotropic medication, were using cigarettes during pregnancy, were left-handed, or had any contraindication to MRI scanning (since functional MRI scanning was part of a larger study not described in the present paper – see Strathearn et al., 2008). The Institutional Review Board at Baylor College of Medicine approved the research protocol, and all subjects provided written informed consent. Study visits took place at the Human Neuroimaging Laboratory at Baylor College of Medicine.

Study design

Visit 1: pregnancy—During the third trimester of pregnancy, we collected sociodemographic data (including age, highest education completed, and yearly combined annual income), and administered the Beck Depression Inventory-II (BDI-II) (Beck et al., 1996) and the Personality Diagnostic Questionnaire 4+ (PDQ-4+) (Hyler et al., 1992).

Visit 2: mother–infant interaction and oxytocin sampling—Approximately 6–7 months after delivery, each mother and infant pair attended the second study session. Mothers were requested to abstain from caffeine and tobacco for 2 to 3 h before the visit, and reported whether or not they were still breastfeeding their infant at that time. Mothers and infants then participated in a semistructured mother–infant interaction procedure, with two periods of separation and an intervening period of mother–infant interaction, during which time four sequential measurements of serum oxytocin were collected from the mothers (Fig. 1). The periods are described below.

Baseline: Mothers were separated from their infants, after which they had an intravenous cannula inserted and blood was drawn for serum estradiol and progesterone levels. Twenty minutes later, blood was drawn for the first baseline measurement of serum oxytocin (OT 1). During this period of mother–infant separation, mothers completed the Adult Temperament Questionnaire (ATQ) (Rothbart et al., 2000), the BDI-II, and the first of two Positive and Negative Affect Schedule (PANAS) questionnaires (Watson et al., 1988).

Post free-play: Mother and infant were then reunited for a 5-minute ‘free-play’ period during which time they physically interacted on the floor. Following the free-play, the second blood sample was drawn through the previously inserted cannula (OT 2).

Post mirror interaction: Mother and infant then participated in a 6-minute modified Still-Face Procedure (Koos and Gergely, 2001), during which time mother and infant could hear and see each other via a mirror, but not interact physically. Another blood sample was obtained after this procedure (OT 3).

Baseline (post): The final oxytocin blood draw (OT 4) was obtained 20 min after the second mother–infant separation. Mothers then completed their second PANAS questionnaire.

Visit 3: 14 month follow-up—At 14-months post-delivery, each mother completed one additional BDI-II measure.

Variables

Outcome variable: oxytocin response (OTResp)—The response in oxytocin to mother–infant interaction (OTResp) was determined by calculating the change in oxytocin concentration between baseline (OT 1) and the interaction period (mean of OT 2 and OT 3; which measures were highly correlated: r_s=.62, p<.001) (Fig. 1). OT 4 was correlated with both OT 3 and OT 2 (r_s=.44, p=.001; and r_s=.40, p=.002, respectively), but not with the baseline measure (r_s=.15, p=.29), suggesting a carry-over effect from the interaction phase. OT 4 was therefore omitted from further analyses.

Thus, a positive OTResp value indicated a relative increase in oxytocin when the mother interacted with her infant, while a negative OTResp value indicated a relative decrease. In four mothers, a single missing oxytocin value was replaced by a weighted β value.

Predictor variables—During the study visit, mothers completed various questionnaires categorized as either *state* or *trait* related measures. *State* measures were obtained at the time of mother–infant interaction procedure at 6 months post-delivery, reflecting transient fluctuations in affect or mood. These measures included reports of current affect using the PANAS, and a single measure of recent depressive symptoms using the BDI-II. *Trait* measures assessed long-term aspects of psychological functioning, which could reflect enduring personality features. This included a measure of temperament using the ATQ, a depression score derived by averaging BDI-II scores over three time points (during pregnancy, 6-months postnatal and 14-months postnatal), and a screener of personality disturbance, the PDQ-4+. Demographic variables, age, income, and education (dichotomized into college graduate or not), were included as covariates.

State measures

Affective state: The PANAS is a 20-item scale containing 10 positive (e.g. interested, excited, proud) and 10 negative words (e.g. upset, nervous, jittery) describing affective states. Each item was rated on a 5-point scale ranging from “very slightly or not at all” (1) to “extremely” (5) (Watson et al., 1988). It is a valid and widely used measure within the domain of research on affective states (Watson and Clark, 1999). The ten items for positive emotion were aggregated into a PANAS positive score (PANAS+) by calculating a mean score, and items for negative emotions were aggregated into a PANAS negative score (PANAS−). To obtain a score that captured fluctuations in affective states, the first PANAS score measured at Baseline 1 was subtracted from the second PANAS score measured at Baseline (Post) (see Fig. 1) and the resulting score was used as a state measure of affect in the analyses.

Maternal depression: The BDI-II is a 21-item screening instrument designed to assess the intensity of depressive symptoms during the previous two weeks, in both clinical and normative populations. The BDI-II demonstrates good clinical sensitivity with the Diagnostic and Statistical Manual of Mental Disorders – Fourth Edition (DSM-IV) diagnosis of depression (coefficient Alpha=.92) (Beck et al., 1996). The *state* measure of depression was a single BDI-II obtained at the 6-month postnatal visit. BDI-II scores of 0 to 9 indicate minimal depression, 10 to 18 indicate mild depression, 19 to 29 indicate moderate depression and 30 to 63 indicate severe depression. The BDI-II score was categorized into 2 groups: no depression (minimal) vs. some depression (mild, moderate or severe), for the purpose of the present study.

Trait measures

Adult temperament: Temperament was assessed using the ATQ short form (Evans and Rothbart, 2007). The ATQ short form is a 77-item self-report questionnaire with a 7-point

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rating scale divided into four factor scales and related subscales (13 total subscales). The factor scales and subscales are as follows: The factor scale of Effortful Control has the subscales of Activation Control, Attentional Control, and Inhibitory Control. The factor scale of Orienting Sensitivity has the subscales of Neutral Perceptual Sensitivity, Affective Perceptual Sensitivity, and Associative Sensitivity. The Extraversion/Surgency factor scale has the subscales of Sociability, High Intensity Pleasure, and Positive Affect. The factor scale of Negative Affect has the subscales of Fear, Discomfort, Frustration, and Sadness. Participants are asked to rate the degree to which each statement describes themselves in a range of situations. See Table 1 for scales and example items from the ATQ.

Depression across time: A *trait* measure of depression consisted of averaged BDI-II scores collected over 3 time points: prenatally, at 6-months postnatal and at 14-months postnatal. This measure was categorized as no depression (minimal) vs. some depression (mild, moderate or severe).

Personality pathology: Mothers were screened for the presence of personality pathology using the PDQ. The PDQ-4+ is a 99-item true/false self-report questionnaire that assesses 10 of the DSM-IV Axis II personality disorders, such as Borderline Personality Disorder, Schizoid Personality Disorder or Narcissistic Personality Disorder. The questionnaire yields a total score ranging from 0 to 99, with scores of 50 or greater being highly suggestive of a DSM-IV personality disorder diagnosis (Hyler et al., 1992), and scores less than 20 indicating a low likelihood of personality disturbance. The total score was categorized into scores <20 (non-clinical range) and scores≥20 (possible clinical range).

Blood collection and assay

Registered nurses from the General Clinical Research Center collected and processed all blood samples. Oxytocin and estradiol samples were placed in chilled heparinized tubes, kept on ice. These tubes were centrifuged to separate plasma within 2 h after collection, and the plasma was rapidly frozen and maintained at −80 °C.

Batches of oxytocin samples were sent on dry ice by overnight courier to Dr. Janet Amico’s lab at the University of Pittsburgh. Oxytocin concentrations were then determined using a sensitive and specific liquid phase radioimmunoassay, in which oxytocin antiserum does not cross-react with arginine vasopressin or other oxytocinlike peptides (Amico et al., 1985). The lower limit for detectability of the assay is 0.5 pg/ml; inter- and intra-assay coefficients of variation are <10%.

The blood samples for progesterone were placed in a serum separator tube and allowed to clot at room temperature, before centrifuging. Serum estradiol and progesterone concentrations were determined at a commercial laboratory using quantitative chemiluminescent immunoassay.

Statistical analyses

Variables were checked for normality by plotting histograms and residual plots for the regression models, and each of the ATQ factor scales and subscales was standardized. Bivariate correlations were examined for OTResp and all state and trait measures, as well as the demographic variables of maternal age, income, and education. To determine which state, trait or demographic variables were predictive of OTResp, a three-step hierarchical regression analysis was conducted with demographic variables entered in the first step, trait variables entered in the second step, and state variables entered in the third step.

To add to our understanding of the role of adult temperament in oxytocin response, post-hoc analyses further examined the differential contributions of the ATQ subscales within each significant ATQ factor scale. Two-step hierarchical regression analyses examined the unique contribution of individual subscales, using a separate model for each set of ATQ subscales, controlling for demographic variables and other significant ATQ factor scales.

Results

As shown in Table 2, the recruited sample of first-time mothers was from a diverse socioeconomic background, with a similar proportion of mothers who had not completed high school compared with mothers who had post-graduate qualifications. Around one-fifth of mothers reported mild symptoms of depression on the BDI, and almost half reported symptoms of possible personality dysfunction, based on the PDQ-4+ screener. However, only one mother scored in the range of "likely personality disturbance."

Over half the mothers (N=29) were still breastfeeding at the time of study Visit 2. However, breastfeeding status was not correlated with OTResp (r=−.03, p=.86), or with any of the individual oxytocin levels (OT 1 to OT 4). Measures of menstrual cycle (estradiol and progesterone levels) were also not significantly correlated with any of the oxytocin measures, including OTResp, or with any of the state or trait measures described.

Correlation analysis

Next, we examined whether OTResp was correlated with any of the demographic, state or trait measures described (Table 3). Although it was not correlated with any demographic or state variables, OTResp was correlated with two temperament measures: negatively with ATQ Effortful Control (r=−.34, p=.01), and positively with ATQ Orienting Sensitivity (r=.30, p=.02). Effortful Control also had a negative correlation with ATQ Negative Affect. Negative Affect was positively correlated with state depression and personality disorder risk (PDQ), and was negatively correlated with ATQ Extraversion. PDQ was negatively correlated with income and Extraversion, and positively correlated with Negative Affect and both depression measures. As expected, state and trait measures of BDI were highly correlated with each other, as were the PANAS positive and negative affect scores.

Predictors of oxytocin response

The three-step hierarchical regression analyses (Table 4) indicated that demographic variables did not significantly predict OTResp. Trait variables, however, conjointly explained 47% of the variance of OTResp (F_{change} =5.45, p≤.001), with two of the ATQ factor scales, Effortful Control (b=−.74, p≤.001) and Orienting Sensitivity (b=.63, p=.002) showing significant individual contributions predicting OTResp. State variables did not explain additional variance of OTResp, once the effect of trait variables was accounted for. It should be noted that age, although not a significant predictor of OTResp in itself (b=−.01, p=.83; see Step 1), emerged as a significant predictor when entered together with trait variables in Step 2 (b=−.09, p=.04), indicating a possible suppression effect.

Post-hoc analyses of ATQ subscales

Table 5 presents post-hoc hierarchical regression analyses conducted for the two ATQ factor scales shown to significantly predict OTResp. When Effortful Control was replaced with its three subscales, Activation Control (b=−.45, p=.006), but not Attentional Control or Inhibitory Control, was shown to significantly predict OTResp (Table 5, Step 2A). However, the subscales of Orienting Sensitivity (Step 2B) did not uniquely contribute to the prediction of OTResp.

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Discussion

From relatively obscure beginnings, oxytocin has emerged as a major biological marker of social and affiliative behavior in humans, with numerous randomized placebo-controlled trials of intranasal oxytocin demonstrating its effects in altering perception, emotion, and interpersonal functioning (as reviewed in Striepens et al., 2011). Although oxytocin was originally thought to have universal effects on prosocial behavior, it is now evident that its effects are moderated by contextual factors and individual characteristics (Bartz et al., 2011b). Surprisingly few studies, however, have examined factors which moderate the effect of oxytocin in mothers themselves, despite the primary role of oxytocin in maternal caregiving (Galbally et al., 2011). This study examined the relationship between oxytocin response and a variety of state and trait measures in first-time mothers. We have demonstrated that maternal oxytocin response is significantly associated with adult temperament factors, including measures of orienting sensitivity and, most significantly, effortful control. No associations were found with other trait or state measures examined.

In the ATQ, "effortful control" refers to one's propensity to focus on executing plans, performing tasks and maintaining focus and attention (Rothbart et al., 2000). Although these characteristics may still be important in maternal caregiving, this factor scale was inversely associated with oxytocin response in first-time mothers. Other studies have shown that baseline oxytocin levels in mothers are positively correlated with mother–infant synchrony, but not with intrusiveness (i.e. maternal behavior that disregards infant cues or seeks to control infant behavior) (Atzil et al., 2011). In non-mother populations, intranasally administered oxytocin results in greater emotional empathy (Hurlemann et al., 2010), generosity (Zak et al., 2007), social cooperation (De Dreu et al., 2010), trust (Kosfeld et al., 2005) and positive communication during conflict (Ditzen et al., 2009). In our study, the negative correlation between Effortful Control and maternal oxytocin response appears to have been driven by the tendency to plan, schedule and act upon specific tasks, as measured by the Activation Control subscale, rather than to inhibit impulses (Inhibitory Control subscale) or focus one's attention (Attentional Control subscale) (Tables 1 and 5). This suggests that new mothers who are more cognitively focused on task performance and executing plans may be less responsive to their infants' affective cues.

In contrast, "orienting sensitivity" refers to one's responsiveness to sensory cues, moods and emotions. During the stages of pregnancy, childbirth and breastfeeding, new mothers gradually learn to relinquish control of their external environment, while attending more to internal sensory cues from their own body (such as during labor and delivery), and then from their new infant (such as during breastfeeding). Maternal oxytocin response during interactive mother–infant play appears to be positively associated with this important capacity. Other studies have demonstrated that oxytocin, compared with placebo, enhances perception and processing of positive social cues (Unkelbach et al., 2008), emotion recognition (Marsh et al., 2010) and sensitivity to biological (but not non-biological) motion (Keri and Benedek, 2009), although none of these studies specifically targeted mothers. However, as noted above, baseline oxytocin measures have been positively correlated with positive parent engagement (Feldman et al., 2011), and maternal bonding behaviors, such as affectionate touch and infant-directed gaze and vocalization (Feldman et al., 2007). Likewise, intranasally administered oxytocin results in an increase in fathers' responsive behavior toward their children (Naber et al., 2010).

In sum, mothers who showed an increased oxytocin response when interacting with their infant rated themselves as being more sensitive of moods, emotions and physical sensations, but less compulsive, schedule driven and task oriented.

Nevertheless, oxytocin is only one of several neuroendocrine systems – such as vasopressin, dopamine and prolactin – which may contribute to adaptive parenting behaviors (Swain et al., 2007). Dopamine, for example, is a key neurotransmitter known to play an important role in maternal caregiving responses, as implicated in both human fMRI studies (Lorberbaum et al., 2002; Strathearn et al., 2008, 2009) and non-human animal models (Champagne et al., 2004; Gammie et al., 2008). In the brain, dopamine plays a role in reward signaling and reinforcement learning, and oxytocin appears to interact with the mesocorticolimbic dopamine system to reinforce maternal caregiving in response to infant cues (Shahrokh et al., 2010; Strathearn, 2011; Strathearn et al., 2009). We have previously proposed that dopamine may be related to more "cognitive", taskoriented aspects of parenting, such as decision-making and planning (similar to those characteristics measured by the Effortful Control factor scale). One model of adult attachment proposes that secure attachment is based on an integration of both affective (intensity-based) and cognitive (temporally-ordered) information processing in the brain (Crittenden and Landini, 2011; Strathearn, 2007). Optimal maternal caregiving responses may involve *both* sensitive attunement to infant cues, via oxytocin-mediated mechanisms, and decision making and planning to meet the temporal needs of a family, as mediated by the nigrostriatal dopaminergic system (Strathearn, 2011). Additional study is required to examine whether Effortful Control is positively associated with dopaminergic functioning in the brain.

One limitation of this research is that all of the state and trait measures were self-reported, and thus susceptible to reporting bias. Correlations and statistical associations do not necessarily represent causality, and the directionality of effects in this study is unknown. For example, although the ATQ, as a measure of temperament, is assumed to be stable across time with a genetic underpinning (Rothbart et al., 2000), it is possible that lifetime patterns of oxytocin stimulation and reactivity may influence the development of these temperament characteristics, as seen in rodent models (Champagne and Meaney, 2001). Although we considered oxytocin levels during the initial mother–infant separation to be "baseline," it is possible that the change in oxytocin was due to the mother–infant separation rather than interaction.

Future studies should determine whether differences in adult temperament are associated with differences in maternal caregiving behavior. For example, is Effortful Control inversely associated with maternal sensitivity, and can temperament measures predict who will be more or less likely to respond to intranasally administered oxytocin, as a treatment for deficits in social functioning or maternal caregiving? The potential role of intranasal oxytocin in the treatment of disorders such as maternal neglect, post-partum depression and maternal addiction is currently being explored (Strathearn, 2011; Strathearn and Mayes, 2010; Striepens et al., 2011).

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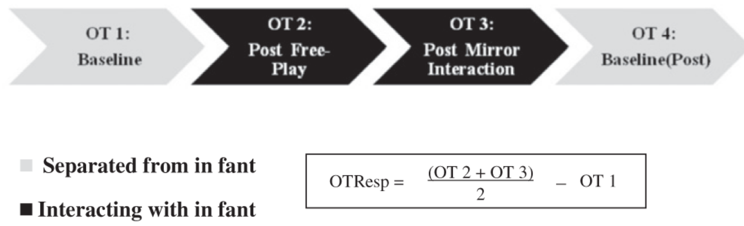

Fig. 1.

mother–infant interaction procedure and calculation of oxytocin response (OTResp). Note: Oxytocin samples were collected at four time points: (a) after a 20 minute period of mother–infant separation (OT 1), (b) after two interaction sequences (OT 2 and OT 3), and (c) after a further separation period of 20 min (OT 4).

Table 1

Adult Temperament Questionnaire (ATQ) factor scales and subscales.

	Description	Example item
Effortful Control		
Activation Control	Executing plans, task performance	I can keep performing a task even when I would rather not do it.
Attentional Control	Attention and focus on tasks	It's usually hard for me to alternate between two different tasks.
Inhibitory Control	Inhibiting impulses	It is easy for me to inhibit fun behavior that would be inappropriate.
Orienting Sensitivity		
Neutral Perceptual Sensitivity	Sensitivity to sight, sound, odor, texture	I am rarely aware of the texture of things that I hold (reverse coded)
Affective Perceptual Sensitivity	Sensitivity to mood/overall emotions	I tend to notice emotional aspects of painting and pictures
Associative Sensitivity	Intuitive thoughts and creative ideas	I sometimes seem to understand things intuitively
Extraversion/Surgency		
Sociability	Inclination to socialize	I like conversations that include several people.
High Intensity Pleasure	Enjoying loud sounds, fast-paced activities, and intense stimulation	When listening to music, I usually like to turn up the volume more than other people.
Positive Affect	Experience of happiness and pleasure	Sometimes minor events cause me to feel intense happiness.
Negative Affect		
Fear	Anticipation of distress	Sometimes, I feel a sense of panic or terror for no apparent reason
Sadness	Experience of lowered mood or disappointment	Sometimes minor events cause me to feel intense sadness
Discomfort	Irritation to sound/light	I find certain scratchy sounds very irritating
Frustration	Experience of irritation or annoyance	Whenever I have to sit and wait for something (e.g., a waiting room), I became agitated.

Table 2

Descriptive data for main study variables (N=55).

	M (SD)	Range
Oxytocin response (pg/ml)	−.2 (1.2)	−4.2 to 3.2
Maternal age (years)	28 (4.5)	19 to 41
Infant age at Visit 2 (months)	6.4 (1.7)	4 to 11
Highest education completed by mother, *N* (%)		
High school graduate or less	12 (21%)	
Some college	15 (26%)	
University graduate	15 (26%)	
Graduate or professional training	13 (23%)	
Annual household income (*N*=54), *N* (%)		
<$30,000	15 (28%)	
$30,000–$70,000	19 (35%)	
>$70,000	20 (37%)	
Change in PANAS+ (positive affect)[a]	−.2 (.5)	−1.6 to .7
Change in PANAS− (negative affect)[a]	.3 (.7)	−1.6 to 2.1
Depression at Visit 2 (BDI)[b] (*N*=48), *N* (%)		0 to 19
Minimal	37 (77%)	
Mild	10 (21%)	
Moderate	1	
Depression across time (mean BDI, Visits 1–3)[c], *N* (%)		0 to 17
Minimal	44 (80%)	
Mild	11 (20%)	
Personality pathology (PDQ) (*N*=54), *N* (%)	3 to 50	
Non-clinical range (<20)	30 (56%)	
Possible clinical (20–49)	23 (44%)	
Likely personality disturbance (≥50)	1	
ATQ Effortful Control	4.5 (.7)	3.0 to 6.1
ATQ Orienting Sensitivity	4.9 (.6)	3.6 to 6.1
ATQ Extraversion/Surgency	4.8 (.6)	2.9 to 6.1
ATQ Negative Affect	4.0 (.7)	2.3 to 5.9

ATQ, Adult Temperament Questionnaire; BDI, Beck Depression Inventory; PANAS, Positive and Negative Affect Schedule; PDQ, Personality Disorder Questionnaire.

[a]Values indicate the first PANAS score subtracted from the second PANAS score and represent changes in mothers' affective states pre and post her interaction with her infant.

[b]BDI-II score obtained at 6 months postnatally.

[c]Average of BDI-II scores obtained prenatally, 6 months postnatally, and 14 months postnatally.

Table 3

Bivariate correlations among main study and demographic variables (*N*=55).

	1	2	3	4	5	6	7	8	9	10	11	12	13
1. OT response	1.00												
2. Age	.03	1.00											
3. Education	.01	−.09	1.00										
4. Income	.14	.49**	.18	1.00									
5. PANAS+ [a]	−.04	.28	−.17	.07	1.00								
6. PANAS− [a]	−.04	.03	−.16	−.04	−.34**	1.00							
7. Single BDI	.05	.15	.05	.01	.07	.05	1.00						
8. BDI across time	.04	.25	.00	.02	−.01	−.07	.69***	1.00					
9. PDQ	−.11	−.20	−.08	−.44***	.13	.11	.57***	.23*	1.00				
10. ATQ Effortful Control	−.34*	−.15	.26	.14	.08	−.06	−.21	−.10	−.21	1.00			
11. ATQ Orienting Sensitivity	.30*	.16	−.03	−.05	.03	.14	.22	.22	.33	.04	1.00		
12. ATQ Extraversion/Surgency	.25	.15	.06	.02	.27	−.09	−.24	−.09	−.29*	.14	.23	1.00	
13. ATQ Negative Affect	−.12	.01	−.17	−.11	−.26	.12	.41**	.26	.42**	−.36**	.12	−.50***	1.00

ATQ, Adult Temperament Questionnaire; BDI, Beck Depression Inventory; PANAS, Positive and Negative Affect Schedule; PDQ, Personality Disorder Questionnaire.

[a] Values indicate partial correlation coefficients for the second PANAS controlling for the first PANAS (baseline).

* p≤.05.

** p≤.01.

*** p≤.001.

Table 4

Hierarchical regression model exploring the roles of maternal trait and state variables controlling for demographic variables.

Steps/predictors	*b*	95% confidence interval		R^2	ΔR^2	*F*
		Lower	Upper			
Step 1: demographic variables				.03	.03	.47
Age	−.01	−.11	.09			
Education	.00	−.79	.79			
Income	.16	−.13	.44			
Step 2: trait variables				.50	.47**	3.90*
BDI over time	.25	.61	−.72			
PDQ	−.80	−1.67	.07			
ATQ Effortful Control	−.74**	−1.07	−.40			
ATQ Orienting Sensitivity	.63*	.25	1.01			
ATQ Extraversion/Surgency	.09	−.32	.50			
ATQ Negative Affect	−.29	−.69	.11			
Step 3: state variables				.51	.01	2.80*
PANAS+	.11	−1.00	1.22			
PANAS−	−.12	−.71	.48			
Single BDI	.27	−.93	1.47			

ATQ, Adult Temperament Questionnaire; BDI, Beck Depression Inventory; PANAS, Positive and Negative Affect Schedule; PDQ, Personality Disorder Questionnaire.

* $p \leq .01$

** $p \leq .001$.

Table 5

Post-hoc hierarchical regression analyses with ATQ factor scales and subscales predicting oxytocin response.

Steps/predictor	*b*	Confidence intervals		R^2	ΔR^2	*F*
		Lower	Upper			
Step 1				.00	.00	.04
Age	.01	−.06	.08			
Step 2A				.27	.27**	3.58**
ATQ Effortful Control						
Activation Control subscale	−.45**	−.75	−.14			
Attentional Control subscale	−.08	−.40	.24			
Inhibitory Control subscale	−.06	−.36	.24			
ATQ Orienting Sensitivity	.39*	.08	.69			
Step 2B				.23	.23*	2.91*
ATQ Effortful Control	−.42**	−.73	−.11			
ATQ Orienting Sensitivity						
Neutral Perceptual Sensitivity subscale	.14	−.17	.45			
Affective Perceptual Sensitivity subscale	.27	−.06	.60			
Associative Sensitivity subscale	.15	−.19	.48			

ATQ, Adult Temperament Questionnaire.

* $p \le .05$.

** $p \le .01$.