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Oxytocin, cortisol, and triadic family interactions

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ABSTRACT

The neuropeptide oxytocin (OT) supports the development of parenting in mammals primarily through its impact on parent–infant proximity and touch behaviors; however, much less is known about the links between OT and parental touch and contact in humans. In this study, we examined the relations between maternal and paternal OT and patterns of touch and contact in the family unit during triadic interactions. Thirty-seven parents and their firstborn child were seen twice: during the 2nd and 6th postpartum month. Plasma OT and salivary cortisol (CT) were assessed with ELISA methods. At six months, triadic mother–father–infant interactions were videotaped and micro-coded for patterns of proximity, touch, and gaze behavior. Triadic synchrony, defined as moments of coordination between physical proximity and affectionate touch between the parents as well as between parent and infant while both parent and child are synchronizing their social gaze, was predicted by both maternal and paternal OT. Among mothers, triadic synchrony was also independently related to lower levels of CT. Results highlight the role of OT in the early formation of the family unit at the transition to parenthood.

Oxytocin (OT), named for quick delivery [1] and known for its involvement in uterine contractions during birth and lactation [2], has long been considered a maternal mammalian hormone. Animal research has shown that central OT injections rapidly induce maternal behavior [3,4] and studies have pointed to the role of maternal touch and contact patterns, such as licking-and-grooming behavior, in the consolidation of the brain OT system in both mother and infant [5–8]. Studies have similarly underscored the importance of touch and contact in the cross-generation transmission of OT in mammals [9–13]. In humans, OT has been implicated in a variety of skills related to social affiliation, including increased trust [14], reduced couples' conflict [15], attenuated response to fearful social cues [16], and improved ability to infer the mental states of others [17]. However, to our knowledge, no study has addressed the links between OT and triadic family interactions, the first social group in which the human infant takes part.

The role of OT in human parental behavior and parent–infant bonding has recently become an area of interest. Research has indicated that mothers exposed to infant stimuli showed an increased fMRI BOLD response in brain areas rich in OT receptors [18]. An increase in maternal plasma OT from the first to the third trimester of pregnancy was associated with maternal bonding to the fetus [19], and higher levels of maternal plasma OT in the first trimester predicted more maternal behavior in the postpartum, including greater amounts of maternal affectionate touch [20]. Similar levels of plasma OT concentrations were found in new mothers and fathers across the first six months of parenting and OT levels were related to the parent-specific behavioral repertoire including positive affect, "motherese" vocalizations, and affectionate touch in mothers and stimulatory contact and exploratory behavior in fathers [21]. Finally, following a session of parent–infant contact, an increase in parental OT levels was found only among mothers who provided high levels of affectionate touch and among fathers who provided high levels of stimulatory contact but not among those who exhibited low levels of the parent-specific pattern of touch and contact [22]. Taken together, these studies point to the relations between OT and patterns of touch and contact in humans, yet the involvement of OT in the development of the whole-family process has not yet been assessed.

Research on the development of parent–infant bonding has mainly focused on the mother–infant dyad as the primary relational unit whereas the development of triadic mother–father–infant interactions received less attention. Several studies addressed the development of the whole-family process during the transition to parenthood [23–25]. For instance, four-month-old infants were found to be capable of responding to subtle social signals between their parents and shift their focus of social gaze following change in the co-parental behavior [25]. Researchers have similarly pointed to a "triangular capacity" appearing in the first months of life that enables infants to function within a multi-person triadic context [26]. Parents and their four-month-old firstborn child were found to

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engage in triadic interactions described as "cohesive" and characterized by social gazing between family members, positive affect, and mutual contact among the three participants and such triadic synchrony was predicted by lower infant negative emotionality, less maternal anxiety and depression, and higher paternal involvement and support. Similarly, higher family-level cohesiveness was shaped by the nature of the interactions between each parent and the child during parent–child sessions, with more reciprocal parent–child interactions leading to more synchronous triadic sessions [27]. Based on dynamic systems' theory applied to the study of family systems, the construct of "triadic synchrony" [25,28] implies that there is coordination between the various sub-systems in the family and that the spousal, mothering, and fathering sub-systems cohere into a unified higher-order process that is marked by synchrony and cohesiveness [29–33].

In humans as well as in other mammals, mother–infant proximity and touch play a critical role in infant development, regulating adaptive physiological and psychological functions [34–36]. Attachment theory [37] emphasizes the role of the caregiver's touch in establishing a secure bond that enables the internalization of a sense of security and freedom to explore the environment. Animal research has shown that maternal touch patterns, such as licking and grooming and arched-back nursing, carry epigenetic effects and lead to the cross generational transmission of OT and parenting behavior [5,10,38]. Among premature infants, maternal infant skin-to-skin contact (Kangaroo Care) during the immediate postpartum period was found to result in higher maternal and paternal affectionate touch at three months and in an increase in the degree of proximity and touch between spouses during triadic family interactions [35]. Guided by the family system's approach, the present study focused on the role of maternal and paternal OT in shaping the parents' capacity to engage in a synchronous and coherent triadic interaction that coordinates higher levels of touch and contact among spouses with greater contact between each parent and the child into the mutually-responsive multi-person social system.

An additional hormone that is considered a part of the neuroendocrine system that supports the parent–infant bond is cortisol (CT). Cortisol is the end product of the HPA axis that plays a central role in stress reactivity as well as in a range of social and affiliative behavior [39]. In humans, elevated levels of CT have been reported during periods of social bonding, such as falling in love or at the transition to parenthood [40,41]. CT has been consistently implicated in human maternal behavior and responsiveness to the infant [42–45], however, the associations between CT and parenting have shown to be complex, depending on multiple factors including maternal age, prior experience, and feeding patterns [46]. The transition to parenthood is among the most stressful life transitions for an individual and thus, CT was measured in addition to OT, in order to assess the effects of stress on the development of the family process and to examine the associations between hormonal indices of stress and affiliation and the nature of triadic interactions. In general, the relationships between OT and CT are complex and not yet fully understood. On the one hand, OT is considered to be an anti-stress hormone, mediating anxiolytic and relaxing effects that are associated with the calm state of breastfeeding [47–49]. On the other hand, negative [50–53], positive [54–57], and non-significant [19,58] correlations have been reported between OT and CT, suggesting that the inter-relationship between the functioning of these two systems is not yet fully understood.

In light of the above, the present study examined the links between triadic family interactions and maternal and parental OT and CT. Consistent with previous research [20,27], we expected that OT would be related to more touch and contact in the family context whereas CT would be negatively related to triadic synchrony and that each hormone would explain unique variance in the prediction of triadic synchrony. As the transition to parenthood is more stressful for mothers than fathers, we expected closer links between CT and triadic synchrony among mothers as compared to fathers.

1. Method

1.1. Participants

Thirty-seven cohabitating couples and their firstborn infant (22 girls and 15 boys) participated in this study (overall: n = 111 participants), which was part of a larger project on the transition to parenthood. All infants were healthy firstborns. Parents were seen twice, at the second month after the child's birth ($M = 6.97$ weeks, SD = 2.35) and again when the infant was approximately 6 months old ($M = 25.49$ weeks, SD = 4.61). Families were all of middle class and all parents were married. Mothers age averaged 26.26 years (SD = 3.94) and fathers' age averaged 28.81 years (SD = 4.73). Parents all completed at least high-school education and the average education was 15.35 years for men (SD = 3.27) and 15.96 years for women (SD = 2.29). Families were recruited through ads posted in the university and surrounding area and in parenting message boards online. The study was approved by the Institutional Review Board and conducted according to ethical standards. All participants signed informed consent forms prior to participation.

1.2. Procedure

Families were visited at home twice during the evening hours (4–8 PM). Mothers and fathers first completed self-report measures assessing a range of demographic and health variables (e.g., weight, height, and smoking). Next, blood was drawn for OT analysis and interactions were videotaped between each parent and the child. On the second home visit, families were videotaped in a free-play triadic interaction. To allow for an ecologically valid observation of the family process, parents were instructed that the two of them play together with the infant as they normally do and no specific position or toys were required. Parents were then given tubes for collecting saliva for CT.

1.3. Hormones

1.3.1. Plasma OT

Blood for OT analysis was drawn from antecubital veins into a 9 mL chilled vacutainer tube containing that were supplemented with 400 KIU of Trasylol (Trasylol — Bayer, Germany) per 1 mL blood. Samples were kept ice-chilled for up to two hours before being centrifuged at 4 °C at 1000 × *g* for 15 min. Supernatants were collected and stored at −70 °C until assayed. Fathers were asked to refrain from food intake for at least 30 min prior to blood draw. Determination of OT was performed using a commercial OT ELISA kit (Assay Design, MI, USA) as described in earlier studies [19,20,58,59]. Measurements were performed in duplicate and the concentrations of samples were calculated by using MatLab-7 according to relevant standard curves. The intra-assay and inter-assay coefficient were less than 12.4 and 14.5%, respectively.

1.3.2. Salivary cortisol

Saliva for CT analysis was sampled on a single day during the 2 weeks following each of the home visits. In order to assess diurnal CT levels, parents were given 3 rolls of cotton (Salivettes — Sarstedt, Rommelsdorft, Germany) and were asked to place them in their mouths and chew on them for a minute until they became saturated at three time-points during a single day. The first assessment was upon waking, the second assessment was 30 min later, and the third assessment was upon going to sleep at night. As CT displays diurnal change patterns across the day, two CT morning samples were collected upon wakening and 30 min after wake-up in order to assess the awakening CT response. The third assessment before going to bed measures the diurnal HPA axis activity at its lowest level throughout the day and this measurement time-point reflects the ability of CT to unbind from receptors and drop significantly in order to allow for the calm state that enables sleep (for review see [60]). Research has shown that dysregulated basal CT levels are correlated with distress, pathology, illness and early life adversity [61–64]. As data was not collected in predetermined hours across the day, since waking and bedtime occurred at different hours for each individual, the typical assessment of CT under the curve, which reflects cortisol activity throughout the day could not be computed. In addition, the expected CT awakening response was not found in this study, either due to the parents' not being able to collect saliva exactly at awakening or because of a blunted morning stress response associated with the disrupted sleep of new parents in the first period after childbirth [Gunnar M., personal communication, June 15, 2010]. In light of these limitations regarding morning CT levels, only the evening measure of CT was analyzed in this study. This evening measure was considered to reflect basal non-reactive cortisol levels that most appropriately match basal OT levels assessed in this research as well as the stable parental behaviors that emerge during a free triadic play which were not intended to elicit stress or examine stress reactivity.

CT salivettes were kept ice-chilled in parents' freezers at home, until being collected and brought to the lab chilled. Upon arrival to the lab, samples were centrifuged at 4 °C at $1000\times g$ for 15 min. Saliva was collected and stored at −20 °C until assayed. Free CT levels were assayed using a commercial ELISA kit (Assay Design). Measurements were performed according to the kit's instructions. CT levels were calculated by using MatLab-7 according to relevant standard curves. The intra-assay and inter-assay coefficients are less than 10.5% and 13.4%, respectively.

1.4. Triadic interactions

Interactions were micro-coded by trained graduate students of psychology on a computerized system (The Observer, Noldus, The Vaggenigen, Netherlands) consistent with previous research on triadic interactions in infancy that used the same coding system [35,65–67]. Interactions were coded in three passes for each sub-system in the family: spousal, mother–child, and father–child. Consistent with previous research, infant–mother and infant–father episodes within a triadic interaction were considered moments in which each parent and the infant were looking at each other (e.g., infant gazes at father and father gazes at infant). For each sub-system we coded four behavioral categories of each partner: gaze, affect, proximity position, and touch and each category included a set of mutually-exclusive codes (an "uncodable" code was added to each category to address moments when codes could not be determined). Categories and codes for each sub-system were as follows:

(a) The parent–infant sub-system
Parent codes
Parent Gaze — to partner, to infant, to object or aspects of the environment, gaze aversion (gaze is not directed to partner, infant, or objects). *Parent Affect* — positive, neutral, withdrawn, negative; *Proximity* — infant in parent's hands or on parent's lap, infant is positioned within the parent's arms' reach, infant is far and out of parent's arms' reach. *Parental Touch* — affectionate touch (e.g., hugging, kissing, and stroking), touch of infant extremities, functional touch, proprioceptive touch (i.e., changing infant position in space), touch with another object, stimulatory touch, passive touch, none.
Infant codes
Infant Gaze — to mother, to father, to object or the environment, gaze aversion; *Infant Affect* — positive, neutral, withdrawn, negative; *Infant Touch* — touching father, touching mother, touching both parents, no touch. *Infant Proximity Position* — on parents' shoulders or in parents' hands, on parents' lap, in an infant-seat chair, free (on couch, carpet, etc.).

(b) The spousal sub-system (coded for both mother and father)
Proximity — parents in close physical contact, parents within arms' reach, parents far from each other's arms' reach. *Touch* — affectionate touch, functional touch, accidental touch, none.

Inter-rater reliability was conducted for 10% of the interactions and averaged 98% (kappa = .84). For each behavior, we computed the proportions of time out of the entire interaction this behavior had occurred and the mean durations of each episode for this behavior.

To create the composite of triadic synchrony, conditional probabilities were computed which assessed the proportion of time a behavior occurs given a certain baseline state. On the basis of our a-prior hypotheses and previous [20,25,66–68] *Triadic Synchrony* was computed for each parent as the proportions of time mothers and father were in co-parental proximity (contact between parents) and provided affectionate touch to each other given the infant was either in physical contact with the father, the mother, or both and mutual gaze was observed between the infant and one of the parents. This behavioral composite was intended to portray the degree of synchrony within the triadic family context that integrates components of proximity and contact between all family members into a communication system that includes mutual social gaze and tactile contact into the family system. This construct of triadic synchrony was based on our previous studies showing that such proximity and touch between mother, father, and infant differentiated infants who received early tactile contact (Kangaroo Care) from those not receiving such contact [20]. Similarly, we found in previous work that triadic synchrony related to micro-level patterns of touch and contact in infancy predicted children's social competence at the kindergarten during the preschool years [31], and this measure was thus selected to index triadic synchrony.

2. Results

2.1. Plasma oxytocin and salivary cortisol

2.1.1. Oxytocin

Levels of OT and evening CT at the first and second assessments are presented in Table 1. A single outlier higher than 3 SDs above mean was removed from the first assessment and 2 outliers were removed from the second assessments. OT levels in parents showed high individual stability across the study period. Pearson correlations between the two assessments were, $r = .61$, $p < .001$ for mothers and, $r = .78$, $p < .001$ for

Table 1
Plasma oxytocin and salivary cortisol concentrations in mothers and fathers at the second and sixth months postpartum.

	Fathers	Mothers	Total
	Mean (SD) pg/mL	Mean (SD) pg/mL	Mean (SD) pg/mL
Oxytocin levels			
Time 1	306.01(181.14)	291.23(88.08)	298.51(140.97)
Time 2	329.71(177.36)	325.8(164.87)	327.33(169.42)
Cortisol levels			
Time 1	5.38(2.14)	5.34(2.06)	5.36(2.08)
Time 2	5.60(1.39)	6.61(1.90)	6.09(1.72)

fathers. Plasma OT levels in fathers and mothers were comparable at both time-points. Overall there was a marginal increase in OT levels between both time-points: $t_{(60)}=-1.957$, $p=.055$. Paired comparison t tests to compare paternal and maternal levels were non-significant in both time-points of the study: $t_{(33)}=.27$, $p>.1$ for TIME 1 and $t_{(27)}=.93$, $p>.1$ for TIME 2. Considering the high correlations between TIME 1 and TIME 2 measures of OT, for all following analyses OT levels across assessments were averaged into a single score.

2.1.2. Cortisol

Evening CT levels similarly showed high individual stability: fathers, $r=.69$, $p<.001$ and mothers, $r=.47$, $p<.01$. Paired comparison t tests revealed that for fathers there was no significant change in evening CT levels from TIME 1 to TIME 2: $t_{(26)}=.63$, $p>.1$. On the other hand, for mothers there was a significant rise in evening CT levels from TIME 1 to TIME 2, $t_{(25)}=2.85$, $p<.05$. Paired comparison t test revealed that in the first assessment there were no differences between maternal and paternal evening CT levels: $t_{(37)}=-.014$, $p>.1$. However, by the 6th postpartum month mothers had higher evening CT levels compared to fathers, $t_{(25)}=-3.38$, $p<.005$. Plasma OT and Salivary Evening CT were unrelated in fathers and mothers at the two time-points of the study.

Considering the high associations between TIME 1 and TIME 2 in measures of CT, TIME 1 and TIME 2 CT levels were averaged into a single score from which 3 outliers higher than 2 SDs over the mean level were removed.

2.2. Correlations between hormones and triadic interaction

Paired comparison t tests revealed that triadic synchrony was comparable in mothers and fathers: $t_{(36)}=1.02$, $p>.1$ (mothers: $M=5.95$, SD = 11.06; fathers: $M=8.37$, SD = 15.81), suggesting that infants divide their time evenly in social focus to mother and father during triadic interactions. Paternal and maternal triadic synchrony scores were highly correlated: $r=.82$, $p<.001$. This high correlation is due in part to the fact that the composite includes proximity behaviors between spouses that are the same for both parents. The mean duration of an episode of parent–infant contact during family interactions was 22.35 s (SD = 43.83) and ranged from 0 to 192.12 s.

2.3. Predicting triadic synchrony

Finally, two hierarchical multiple regression equations were computed to predict triadic synchrony, once from maternal variables and once from paternal variables. In the first block, the averaged parental OT levels were entered, and in the second block the averaged parental evening CT was entered. In the third block the interaction between both hormones was entered. Results are presented in Table 2.

As can be seen, both regression models were significant and explained approximately 20% of the variance in triadic synchrony. Among mothers, OT was an independent positive predictor and CT was an independent negative predictor of triadic synchrony. It appears that in mothers more OT and less CT predict more triadic synchrony. For fathers, only OT independently predicted triadic synchrony and no relations were found between paternal CT and synchrony in the family triad, indicating that higher paternal OT predicted higher levels of triadic synchrony. The interaction of OT and CT did not predict additional variance above and beyond the two hormones in both mothers and fathers.

Table 2
Regression models predicting triadic synchrony from maternal and paternal plasma oxytocin and evening salivary cortisol.

	Mothers			Fathers		
	Beta	R^2 change	F change	Beta	R^2 change	F change
Predictors						
Oxytocin	.324*	.105	4.23*	.421**	.178	7.99**
Cortisol	−.313*	.093	4.08*	−.081	.006	.284
OT*CT	.048	.000	.004	−.794	.034	1.518
	R^2 total = .20, F (3, 34) = 4.34, $p<.05$			R^2 total = .22, F (3, 34) = 3.25, $p<.05$		

* $p<.05$.
** $p<.005$.

3. Discussion

Results of the present study provide the first data on the associations between plasma OT and family interaction patterns during triadic sessions between parents and their 6-month-old firstborn child. The findings point to similarities between OT levels in mothers and fathers and show that OT is associated with the degree of proximity and affectionate contact between all members of the family system — among spouses and between parents and child. Finally, the findings also indicate that evening CT levels in mothers, but not in fathers are negatively related to the level of synchrony with the family triad.

In this study, OT and CT did not show significant correlations at both the first post-birth period and at 6 months postpartum. However, among mothers each hormone was uniquely predictive of triadic synchrony, suggesting that each hormone specified a unique neuro-endocrine channel to the development of touch and contact in the family context. Previous research on the antenatal predictors of maternal postpartum behavior demonstrated that although OT and CT were unrelated across pregnancy and the postpartum, they were each independently predictive of the amount of maternal behavior, such as gaze to infants' face, "motherese" vocalizations, affectionate touch, and positive maternal affect during mother–infant interactions in the postpartum. Specifically, more OT and less CT were each independently predictive of more such maternal behaviors [20]. These previous results support the present findings by pointing to a potential integration of the stress and affiliation neuro-endocrine systems in the formation of parenting and the functioning of the family triad with OT indexing aspects of bonding and affiliation while CT assessing stress levels. The findings suggest that the mother's ability to engage in a synchronous and coherent family process is likely shaped by the interplay between these two hormonal systems.

Maternal CT was related to lower triadic synchrony but such associations were not found for fathers. These findings are consistent with theories suggesting that the experience of stress triggers a relationship-related affiliation response in women termed "tend-and-befriend" to counteract stress whereas men use "fight or flight" strategies to manage stress [69]. CT is associated with the development of maternal behavior during the early postpartum period and has been associated with maternal caregiving, attraction to the newborn's body odor [42], and better discrimination of infant cry [44]. However, by six months of age, increased CT levels have shown to predict negative indices of maternal behavior, such as intrusiveness and controlling maternal behavior [70]. Similarly, at 6 months touch synchrony – the coordination of affectionate with the mother and child's mutual gaze – was found to correlate with lower baseline CT in mothers and infants [71]. It is also possible that the greater physiological demands following childbirth, the physiological burden of breastfeeding, and the sleep deprivation that may be more pronounced in mothers may have contributed to the negative correlations between CT and triadic synchrony among mothers and not among fathers. The rise in evening CT concentrations found only in mothers from the 2nd to the 6th postpartum month may also represent increased stress experienced by mothers during this period. The findings indicate that by six months postpartum, maternal evening CT was higher than paternal CT and this difference may have accounted for the specific relations between maternal CT and the cohesive family process. Future research is required to further assess the exact interplay of CT and OT as biomarkers of the stress and affiliation systems in mothers and fathers and their differential impact on parenting behavior in dyadic and triadic contexts. It is also important to note that the current study focused on basal measures of both CT and OT and further research is required to explore whether reactive hormonal patterns may be involved in shaping the family-level interaction patterns.

The findings indicate that despite the traditional associations with maternal bonding, basal plasma OT levels are similar in mothers and fathers. These findings are in line with research showing similarities in women's and men's plasma [58] and cerebrospinal fluid OT levels [72]. Recent findings have pointed to the role of OT in the development of paternal behavior during the transition to parenthood and demonstrated links between paternal OT and patterns of paternal touch [21,73]. Similarly, research assessing micro-level patterns of proximity and touch in the family triad found no differences in the proportions or frequencies of maternal and paternal affectionate touch to the infant, as well as in their level of gaze, vocalizations, and positive affect during triadic interactions [25]. The present findings contribute to this line of work by showing that touch patterns in the triad, as expressed by both mother and father, are supported by maternal and paternal OT. Our data echoes the work of Meaney and colleagues' in animal models [5,7,9,10], which highlights the role of OT in maternal touch patterns, and extend this model to human parents, to fathers, and to whole-family process during the transition to parenthood.

In this study, hormonal biomarkers were sampled peripherally from plasma and saliva. Contrary to the abundant literature on salivary CT in humans, the relatively scant reports on OT in human plasma using ELISA methodology and the ethical and practical limitations in measuring central activity in humans should be considered in the interpretation of the findings. Nevertheless, animal studies point to a coordination between central and peripheral measures of OT [74,75] as well as some reports on higher peripheral levels following intranasal OT administration in humans [76]. The high stability of plasma OT levels across time reported here and elsewhere and the growing number of reports on peripheral OT in humans (for instance [77–79] support our reliance on peripheral measures. Yet, this issue should be considered a study limitation and requires much further research.

Parental touch during the first months of life is critical for the infant's growth and survival and the neuro-endocrine pathways that support parental touch behaviors in humans are thus of central importance in healthy families and in families of high risk to the parent–infant bond, such as following premature birth or when mothers suffer postpartum depression. The current study lends support to models that underscore the involvement of OT in these pathways [73] and expands these models to the family social "group". Research on OT in humans has pointed to the role of OT in initiating the "touch circuitry" between parents and infants and among couples. Warm contact and touch between couples was associated with increased OT levels [80–82]; infant tactile stimulation of the mother's nipples during breastfeeding resulted in increased maternal OT release [83]; and intense parental touch during parent–infant interactions correlated with an increase in maternal and paternal OT [22]. These findings, combined with the present results, point to the need to further assess the role of proximity and close contact between attachment partners and its contribution to the consolidation of affiliative bonds. Future studies are also needed to examine the impact of parent–infant, spousal, and whole-family contact on the infant's later social–emotional growth. Finally, it is important to assess whether touch-related interventions initiate the OT bio-behavioral feedback loop and function to increase OT levels under conditions of disruption to the parent–infant bond.

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