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Natural variations in maternal and paternal care are associated with systematic changes in oxytocin following parent–infant contact

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Summary Animal studies have demonstrated that the neuropeptide oxytocin (OT) plays a critical role in processes of parent–infant bonding through mechanisms of early parental care, particularly maternal grooming and contact. Yet, the involvement of OT in human parenting remains poorly understood, no data are available on the role of OT in the development of human fathering, and the links between patterns of parental care and the OT response have not been explored in humans. One hundred and twelve mothers and fathers engaged in a 15-min play-and-contact interaction with their 4–6-month-old infants and interactions were micro-coded for patterns of parental touch. Results showed that baseline levels of plasma and salivary OT in mothers and fathers were similar, OT levels in plasma and saliva were inter-related, and OT was associated with the parent-specific mode of tactile contact. Human mothers who provided high levels of affectionate contact showed an OT increase following mother–infant interaction but such increase was not observed among mothers displaying low levels of affectionate contact. Among fathers, only those exhibiting high levels of stimulatory contact showed an OT increase. These results demonstrate consistency in the neuroendocrine basis of human parental interactions with those seen in other mammals. The findings underscore the need to provide opportunities for paternal care to trigger the biological basis of fatherhood and suggest that interventions that permit social engagement may be recommended in conditions of diminished maternal–infant contact, such as prematurity or postpartum depression.

1. Introduction

The expression of parenting behavior in mammals is critical for the growth, survival, and adaptation of the young and for the formation of affiliative bonds (Leckman et al., 2004; Carter et al., 2005). The neuropeptide oxytocin (OT) has been shown to play a key role in processes of parent–infant bonding across a range of mammalian species, including rats, prairie voles, sheep, and primates (Kendrick et al., 1987; Holman et al., 1995; Neumann, 2008; Maestripieri et al., 2009). The administration of OT antagonists disrupts the development of maternal behavior (Pedersen et al., 1985; Pedersen and Boccia, 2003), and pregnancy, lactation, and

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maternal behavior increase OT receptor binding in brain areas central for parenting and the reward parents derive from their infants (Ross and Young, 2009). The oxytocinergic system that supports bond formation in mammals functions as a bio-behavioral feedback loop; maternal–infant touch and contact increase the expression of OT (Francis et al., 2002), while the administration of OT, in turn, leads to the induction of maternal behavior (Pedersen and Prange, 1979). In monogamous species that exhibit biparental care, OT is also associated with fathering and paternal behavior (Gubernick et al., 1995; Cho et al., 1999; Wynne-Edwards, 2001; Bales et al., 2004). Yet, while understanding the neuroendocrine basis of parenting is central for the study of human development, much less is known about the involvement of OT in human parenting, and the mechanisms linking the OT response with the species-typical maternal and paternal behavior or the provision of parent–infant contact have not been explored in human parents.

An important feature of the oxytocinergic system that underlies the formation of affiliative bonds is its modification by early social experience (Meaney, 2001; Champagne et al., 2008). Drawing on natural within-species variations in maternal care, particularly the licking-and-grooming and arched back nursing (LG-ABN) behaviors typical of parturient rat mothers, researchers found that maternal female rats exhibiting high levels of LG-ABN showed greater OT receptor densities in brain areas central for parenting, including the medial preoptic area, the lateral septum, and the paraventricular nucleus of the hypothalamus, as compared to mothers exhibiting low LG-ABN (Francis et al., 2000; Champagne et al., 2001). In rats, the mother's high or low LG style was stable over time and was transmitted from mother to daughter through mechanisms of early experience (Champagne et al., 2001, 2003). Females bred to a strain of low LG-ABN mothers and reared by high LG-ABN dams showed the high licking-and-grooming parenting pattern toward their own infants and exhibited the brain OT profile typical of the high LG-ABN strain (Francis et al., 2000; Champagne, 2008). Studies in nonhuman primates have similarly demonstrated correlations between plasma OT and the degree of maternal–infant grooming and contact (Maestripieri et al., 2009). Taken together, these findings suggest that both central and peripheral OT is related to individual variations in affectionate contact between mother and young.

Human mothers, like other mammalian mothers, engage in the species-typical forms of affectionate contact. In humans, maternal affectionate contact is expressed in holding the infant in a cradling position and providing affectionate touch, including caresses, soft kisses, light pokes, hugs, and gentle touches that do not serve a specific instrumental purpose. The mother's high or low affectionate contact style is similarly stable over time and contributes to the infant's neurobehavioral, cognitive, and social–emotional growth (Feldman and Eidelman, 2003; Feldman, 2007). Similarly, plasma OT levels in human mothers were found to be individually stable from early pregnancy to the postpartum and to predict the expression of maternal behavior in the postpartum, suggesting a priming effect of OT on the initiation of parenting behaviors (Feldman et al., 2007; Levine et al., 2007). However, it is not known whether the provision of affectionate contact is related to systematic changes in OT. Revealing similar mechanisms in humans may have important implications for the study of human bond formation and for the care of pathological conditions associated with diminished maternal–infant affectionate contact and disrupted bonding, such as premature birth or postpartum depression, each of which impacts approximately 10–15% of current births in industrial societies (March of Dimes, 2006; Serretti et al., 2006).

Research on the neuroendocrine basis of fathering in humans is especially scarce and the mechanisms linking paternal behavior and the oxytocinergic system remain poorly understood. Research in biparental fathers have pointed to the involvement of OT in the development of fathering (Young et al., 2001). Biparental fathers showed an increase in plasma OT during pregnancy (Gubernick et al., 1995), and the degree of paternal exposure to pup stimuli and the amount of paternal care is associated with OT (Ziegler, 2000). Thus, although fathers do not experience pregnancy, birth, or lactation, similar neuroendocrine pathways are thought to mediate the initiation of fathering and mothering in mammals (Wynne-Edwards and Timonin, 2007). The links between OT and the mesolimbic dopaminergic pathways in monogamous fathers suggest that OT modulates paternal reward pathways through attachment-related stimuli from partner and child (Young et al., 2001). In several biparental species fathers exhibit parenting behavior similar to mothers (Bredy et al., 2004; Frazier et al., 2006; Ahern and Young, 2009), yet fathers tend to engage in a specific mode of parental contact. Following separation, monogamous mothers and fathers increased their parenting behavior; however, mothers engaged in licking and contact while fathers provided tactile stimulation, carried the infants in space, and encouraged exploratory behavior (Lonstein and De Vries, 1999). Thus, it is possible that whereas hormones associated with birth, lactation, and affectionate contact may induce hormonal changes in mothers, tactile stimulation and active forms of behavior such as exploration may shape the neuroendocrine basis of fathering.

Like mammals, human fathers engage in interactions that involve proprioceptive and stimulatory contact and their play is often directed toward active exploration of the environment (Lamb, 1976; Parke and Sawin, 1976). Father–child interactions typically take the form of "rough-and-tumble" stimulatory play and have shown to be highly rewarding and to increase the father and child's positive arousal (Feldman, 2003). Consistent with the findings that early experience activates the neuroendocrine basis of parenting, it is thus possible that the species-typical stimulatory play of human fathers induces OT release and natural variations in paternal stimulatory contact would be expressed in systematic changes in paternal OT.

In light of the above, the overall goal of the present study was to assess the involvement of the oxytocinergic system in human mothering and fathering and to address its consistency with parenting in other mammals. First, we sought to examine whether baseline levels of plasma and salivary OT in mothers and fathers are similar during the first months of parenting. Based on studies pointing to similar expressions in males and females of central OT in biparental mammals, no differences in OT levels were expected between mothers and fathers. Second, we examined whether the mechanisms that link the expression of OT with maternal and paternal care in nonhuman mammals are also observed in human parents.

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Specifically, we tested whether mothers who provide high levels of affectionate contact, but not those showing low affectionate contact, would show an increase in OT levels following mother–infant interaction. Among fathers, we examined whether fathers who display high levels of stimulatory contact, but not those demonstrating low stimulatory contact, would show an increase in OT following an episode of parent–infant interaction. Such findings will demonstrate similar mechanisms in human parents and biparental mammals, pointing to cross-species consistency in the neuroendocrine basis of bonding and its relation to patterns of parental care.

2. Methods

2.1. Participants

Participants were 112 parents, including 71 mothers and 41 fathers (not couples) and their 4–6-month-old infants (M = 166.3 days, SD = 12.6). All parents were healthy with at least 12 years of education and were of middle-class SES. Mothers were on average 28.7 years (SD = 5.29), completed on average 15.17 (SD = 2.47) years of education, and 81.3% of the mothers were breastfeeding. Fathers' age averaged 29.1 years (SD = 4.28) with an average education of 15.50 (SD = 2.73) years. Infants were born at term (birthweight: M = 3319.4 g. SD = 452.1), mainly (96.3%) by vaginal delivery, and received an Apgar score of 9.40 (SD = 1.56). Fifty-five percent of the infants were firstborn. At the time of the assessment, infants weighed on average 7607.25 g (SD = 1307.51) and were healthy since birth.

To determine father participation in childcare, parents were asked to rate father involvement on two items related to house-care responsibilities and childcare responsibilities on a scale ranging from no participation (1) to full participation (5). All parents in the study reported at least medium level father participation in childcare (M = 3.97, SD = .75). Similarly, to screen for parental mood disorders, parents completed the Beck Depression Inventory (BDI, Beck, 1978) and the State-Trait Anxiety Inventory (STAI, Spielberger, 1984). Parents with a score of 11 and above on the BDI or 44 and above on the STAI, indicating risk for anxiety or depression disorders, were not included in the study. Mean score of depressive symptoms was 5.15 (SD = 5.43) and of anxiety symptoms was 33.27 (SD = 7.05).

2.2. Procedure

Parents and infants arrived at the lab (1–4 PM) and visits were coordinated to the period between 1 h following the last breastfeeding and 1 h prior to the next breastfeeding. A recent study by White-Traut et al. (2009) showed that salivary OT was highest within 30 min before breastfeeding, decreased at the initiation of feeding, and increased 30 min after breastfeeding. The timing of the OT sampling was thus set to a period when OT was expected to be at baseline levels among breastfeeding mothers. Similarly, as OT peaks in the morning and declines until noon (Amico et al., 1989), we chose to sample OT in the early afternoon so that individual variations would not be confounded with diurnal changes. Following a 10-min acquainting period to the setting in which no touch between parent and child occurred, parents provided baseline saliva and plasma samples. Following this period, parent and child entered a carpeted observation room with an infant-seat mounted on a table and two cameras placed on adjacent walls that were controlled from an adjoined observation room, one focused on the parent, the other on the infant. The two pictures were combined into a single image through a split-screen generator. Parents were asked to engage in a 15-min "play-and-touch" interaction that would include any type of touch they typically use. Fifteen minutes after the end of the session a post-interaction saliva sample was collected. The study was conducted in accordance with the Declaration of Helsinki and all procedures received the approval of the Institutional Review Board. All procedures were explained to the participants before the beginning of the study and all participants signed an informed consent.

2.3. Hormone collection and analysis

2.3.1. Plasma oxytocin

Blood was drawn from antecubital veins into a 9 mL chilled vacutainer tubes containing lithium heparin that was supplemented with 400 KIU of Trasylol (Trasylol - Bayer, Germany) per 1 mL blood. Blood samples were kept ice-chilled for up to 2 h before being centrifuged at 4 °C at 1000 × g for 15 min. Supernatants were collected and stored at −80 °C until assayed.

2.3.2. Salivary oxytocin

OT from saliva was collected by Salivatte (Sarstedt, Rommelsdorft, Germany). Parents were asked to chew a roll of cotton for about 40 s. Salivettes were kept ice-chilled for up to 1 h before being centrifuged at 4 °C at 1500 × g for 15 min. The liquid samples were stored at −80 °C. To concentrate the samples by 3 or 4 times, the liquid samples were lyophilized over night and kept in −20 °C until assayed. The dry samples were reconstructed in the assay buffer immediately before analysis by Oxytocin EIA commercial Kit, consistent with previous research (Carter et al., 2007).

2.4. Determination of oxytocin

Determination of OT was performed using a commercial OT ELISA kit (Assay Design, MI, USA) consistent with previous research (Carter, 2007; Feldman et al., 2007; Levine et al., 2007; Gordon et al., 2008). 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 are <12.4% and 14.5% respectively.

2.5. Coding of parent–infant interactions

Interactions were micro-coded on a computerized system (Noldus, The Netherland) in .01-s frames for parental touch patterns, including cradling, affectionate touch (e.g., caress, kiss, pat, light pokes), proprioceptive touch (moving the infant in space, changing the infant's position in space, for instance, pulling him/her to sit), and stimulatory touch (e.g., quick stroke, touching the infant with objects). The parent's

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active engagement in exploratory behavior (e.g., presenting objects, re-directing infant attention to objects) was also micro-coded. The micro-level coding scheme has been validated in previous studies of normative and high-risk samples (Feldman and Eidelman, 2003, 2004, 2007; Feldman et al., 2004). Inter-rater reliability was computed for 20 interactions and reliability *kappa*s averaged .81 (range = .72—.93).

Two composites were created from the coded interactions: *Parent Affectionate Contact* was the sum proportions of time the parent held the infant in a cradle position and engaged in affectionate touch. *Parent Stimulatory Contact* was the sum proportions of proprioceptive touch, stimulatory touch, and exploratory play. To determine the high- and low-maternal affectionate contact groups, mothers in the upper tercile, who provided affectionate contact for more than 67% of the time were included in the high affectionate contact (HAC) group ($n = 32$), and those providing affectionate contact less than 34% of the time were included in the low affectionate contact (LAC) group ($n = 19$). Among fathers, those in the high tercile who provided stimulatory contact for more than 67% of the time were included in the high stimulatory contact (HSC) group ($n = 18$), and those providing stimulatory contact less than 33% of the time were included in the low stimulatory contact (LSC) group ($n = 11$).

2.6. Statistical analysis

The associations between OT, background variables, and mothers' and fathers' affectionate and stimulatory contact were examined with Pearson's correlations. ANOVAs were used to compare maternal and paternal plasma and salivary OT and the proportion of time mothers and fathers engaged in affectionate and stimulatory contact. Repeated measure ANOVAs, with salivary OT as the within subject factor and contact group (HAC vs. LAC mothers, HSC vs. LSC fathers) were computed for mothers and fathers. Following significant interaction effects, paired sample t tests were used to examine the source of the findings.

3. Results

Results are organized in six mini-sections according to the study's goals and hypotheses. In the first three sections, we demonstrate similarities and differences between mothers and fathers, inter-relatedness between plasma and salivary OT, and individual stability in OT. The next three sections address the links between OT and the parent-specific mode of tactile contact. Prior to data analysis, we examined correlations between OT and background variables. No correlations were found between OT and the parent's age, education, religiosity, hours of employment, Body Mass Index (BMI), smoking, or birth order. Among mothers, OT was unrelated to nursing status, time since last feed, or the use of medications during childbirth.

1. *Mothers and fathers show similar baseline levels of plasma and salivary OT.* Mean levels of maternal plasma OT were 365.59 pg/ml ($SD = 138.63$) and of paternal OT 405.10 pg/ml ($SD = 151.88$), with no mean-level differences between mothers and fathers, F (1, 111) = 1.95, $p = .16$ (Fig. 1). Pre-contact salivary OT was, $M = 6.17$ pg/ml, $SD = 3.10$, among mothers and, $M = 7.09$ pg/ml, $SD = 3.95$, among fathers, with no significant differences, F (1, 111) = 1.81, $p = .18$. Post-contact OT was higher in fathers ($M = 7.33$ pg/ml, $SD = 3.17$) as compared to mothers ($M = 5.92$ pg/ml, $SD = 2.78$), F (1, 111) = 5.28, $p = .022$ (Fig. 2).

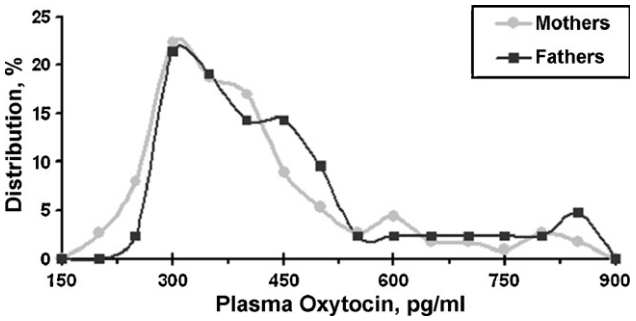

Figure 1 Distributions of plasma oxytocin concentrations in mothers and fathers. The *x*-axis shows groups for every 75 pg/ml range, presented as the highest value of each range. The *y*-axis shows the number of participants in each range group represented as the percentage of total participants.

2. *Plasma and salivary OT are inter-related.* Pearson's correlations showed that OT levels in plasma and saliva are inter-related. Correlations between plasma OT and pre-contact salivary OT were, $r = .41$, $p < .000$, and with post-contact salivary OT, $r = .33$, $p < .000$. The correlation between baseline plasma and salivary OT are presented in Fig. 3.
3. *OT is individually stable across observations.* High level of individual stability was found in the parent's salivary OT between the 1st and 2nd assessments, $r = .71$, $p < .000$.
4. *Maternal and paternal OT is differentially related to affectionate and stimulatory contact.* Overall, mothers engaged in significantly more affectionate contact than fathers. The proportion of time mothers engaged in affectionate contact out of the entire interaction was, $M = .56$, $SD = .28$, as compared to, $M = .25$, $SD = .15$, for fathers, F (1, 111) = 9.23, $p < .000$. On the other hand, fathers exhibited significantly more stimulatory contact, $M = .58$, $SD = .21$, than mothers, $M = .19$, $SD = .11$, F (1, 111) = 13.86, $p < .000$, indicating that affectionate and stimulatory contact in human parents are the typical mode of touch in mothers and fathers respectively. The relations between contact and OT were specific to the parent's typical mode of contact. Maternal affectionate contact was related to plasma, $r = .36$, $p = .002$, and salivary OT, $r = .28$, $p = .023$, but maternal stimulatory contact was unrelated to OT in plasma or saliva. Similarly, paternal stimulatory touch was related to plasma, $r = .39$, $p = .028$, and salivary OT, $r = .33$, $p = .033$, but father affectionate contact was unrelated to plasma or salivary OT.
5. *OT increases in high affectionate contact (HAC) mothers following mother—infant contact but not in low affectionate contact (LAC) mothers.* Repeated measure ANOVA indicated no overall change in maternal OT from pre- to post-contact, F (1, 48) = .53, $p = .46$, and a significant interaction of time and affectionate contact

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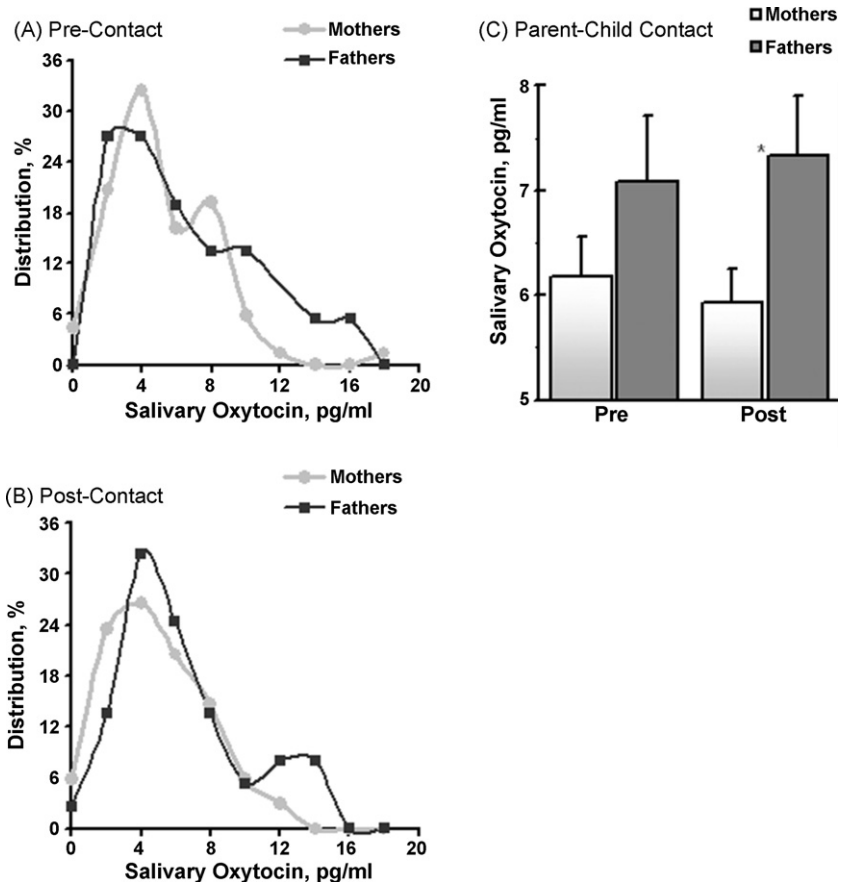

Figure 2 Distributions of pre- and post-contact salivary oxytoin concentrations in mothers and fathers. The *x*-axis for the pre- (A) and post- (B) contact assessments shows groups for every 4 pg/ml range, presented as the highest value of each range. The *y*-axis for A and B shows the number of participants in each range group represented as the percentage of total participants. Means and SE of salivary OT in mothers and fathers are presented for the pre- and post- (C) contact assessments. $^{*}p < .05$.

group, F (1, 48) = 7.86, p = .007. Paired comparison t-tests showed that among the HAC mothers group, OT increased from pre-contact (M = 6.01, SD = 2.91) to post-contact (M = 7.05, SD = 2.96), t (31) = −2.71, p = .01. However, among the LAC mothers no differences emerged between OT levels before (M = 5.70, SD = 1.94) and after (M = 5.10, SD = 2.08) maternal–infant contact, t (18) = 1.41, p = .16 (Fig. 4A).

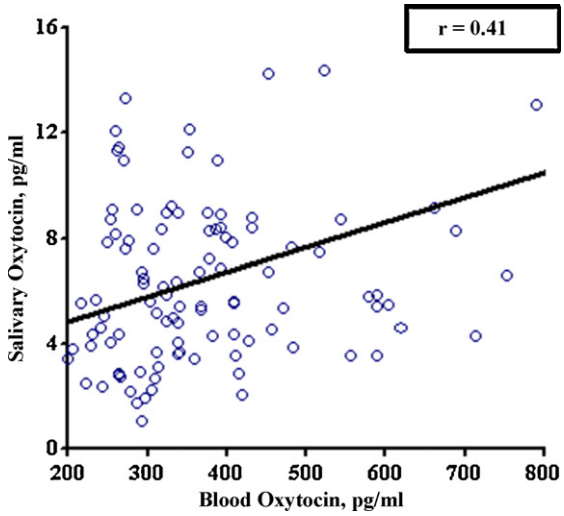

Figure 3 Correlation between oxytocin in parental plasma and saliva.

6. *OT increases in high stimulatory contact (HSC) fathers following parent–infant contact but not in low stimulatory contact (LSC) fathers*. Repeated measure ANOVA indicated no overall change in OT over time, F (1, 27) = .77, p = .38, and an interaction of time and stimulatory contact group, F = (1, 27) = 5.28, p = .029. Paired comparison t-tests showed that among HSC fathers, OT increased from the pre- (M = 7.86, SD = 4.77) to the post-contact assessment (M = 9.04, SD = 3.64), t (17) = −2.50, p = .023. However, among LSC fathers no differences in OT emerged from pre- (M = 6.65, SD = 3.51) to post-contact (M = 6.12, SD = 3.46), t (10) = .95, p = .36 (Fig. 4B). These findings support our main hypothesis on the relationship between natural variations in maternal and paternal care and systematic changes in OT in human mothers and fathers.

4. Discussion

The present findings point to consistency in the neuroendocrine basis of mammalian and human parenting as well as to

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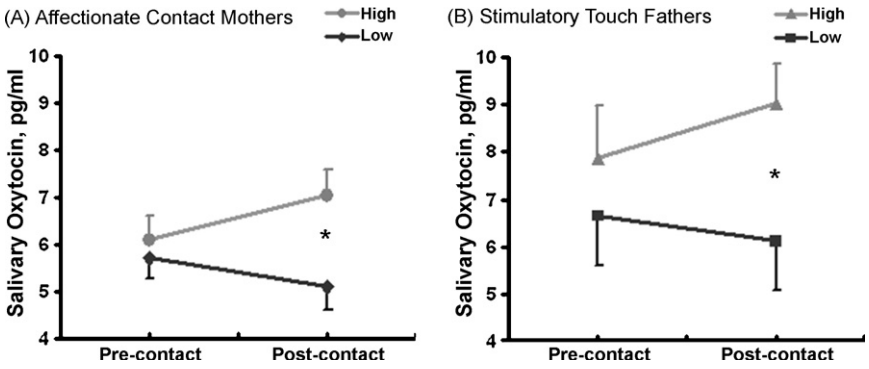

Figure 4 Changes in salivary OT concentrations from pre- to post-parent—infant contact. Changes from pre- to post-contact were examined for high affectionate contact (HAC) and low affectionate contact (LAC) mothers (A) and for high stimulatory contact (HSC) and low stimulatory contact (LSC) fathers (B). *$p < .05$.

similarities and differences between human mothers and fathers during the first postpartum months. Oxytocin — a neuropeptide involved in the formation of parent—infant bonding and in processes of social affiliations throughout life — was first tested here in human fathers in relation to father—infant interactions and paternal contact. The results indicating no differences in baseline levels of maternal and paternal OT may provide initial support to perspectives that propose similarities in the hormonal pathways of mothering and fathering in biparental mammals (Wynne-Edwards and Timonin, 2007). Consistent with the findings in mammals, parent—infant tactile contact was associated with plasma and salivary OT. However, the relations between OT and parental contact were limited to the parent-specific mode of touch. Maternal OT, measured in both saliva and plasma, was related only to affectionate touch and not to stimulatory touch, while paternal plasma and salivary OT were uniquely associated with stimulatory, but not affectionate touch. Furthermore, following parent—infant contact, OT increased only among mothers who exhibited the high affectionate contact style and among fathers displaying the high stimulatory contact profile. These findings provide a human parallel to the results obtained in animal models, which showed an increase in brain OT receptors only among the high LG-ABN dams (Francis et al., 2000). Such consistency between human and animal parents in the pathways from natural variations in parental care to systematic changes in OT expression underscores the common evolutionary roots of parent—infant interactions, supports inferences from animal research to the study of human social bonding, and demonstrates that the neurobiology of human affiliation is similarly shaped by early social experience (Neumann, 2009).

Human fathers increased their OT levels in response to the father-specific form of parental care. Moreover, contact appeared to have a greater impact on fathers and the post-contact assessment showed higher OT in fathers compared to mothers. The expression of OT in monogamous fathers is closely linked to reward pathways (Young et al., 2001). The rewarding nature of father—child interactions, indicated by the fact that children prefer to play with their fathers and to be comforted by their mothers (Kotelchuck, 1976; Lamb, 1976), may have initiated the neuroendocrine basis of fathering through the father's stimulatory contact and exploratory play. Thus, although biparental care is not biologically necessary in humans — throughout human history and across cultural communities fathers have often not been involved in infant care and children nonetheless reached physical and social maturity — the sharing of childcare responsibilities may have set the biological feedback loop of father—infant bonding through daily experiences of paternal care. These findings have important implications for social policy and emphasize the need to provide opportunities for daily contact between fathers and infants during the first months of fatherhood in order to trigger the biological basis of fathering.

Mothers who provided the human form of ''licking-and-grooming'' contact, described here as high affectionate contact, increased their OT levels following mother—infant interaction. Affectionate contact is a central determinant of maternal care that integrates the discrete maternal behaviors in the gaze, affect, and vocal modalities into a comprehensive and personal maternal style that is consistent across time and context (Feldman, 2007). Maternal affectionate contact also functions to decrease the infant's physiological reactivity to stress (Feldman et al., 2010) and children deprived of maternal contact, such as premature infants, often suffer long-term disruptions to hormonal and brain systems that regulate stress (Scott and Watterberg, 1995). Animal studies indicate that infants reared by low licking-and-grooming dams show alterations in brain glucocorticoids receptors (Champagne et al., 2008) and benefit less from environmental enrichment (Parent and Meaney, 2008), and similar findings are observed for children of postnatally depressed mothers (Oberlander et al., 2008; Feldman et al., 2009; Murray et al., 2009). The present results which show systematic increases in OT in response to maternal affectionate contact may suggest that interventions to improve maternal—infant bonding in conditions such as prematurity and postpartum depression should focus on increasing the mother's affectionate contact. For instance, maternal—infant skin-to-skin contact (Kangaroo Care) in the neonatal period has been shown to promote maternal—infant bonding following premature birth (Feldman et al., 2002) and to increase maternal milk volume (Hake-Brooks and Anderson, 2008). Overall, the parallel patterns and similar mechanisms detected here between human and other mammalian parents provide some validation for the use of animal models as a starting point to uncovering the biological foundations of the human the capacity to form affiliative bonds.

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It is of interest that the results of this study, as well as those of previous research (van der Post et al., 1997; Feldman et al., 2007), show no correlations between OT and breastfeeding when OT is not sampled immediately before or after breastfeeding. Possibly, baseline levels of OT represent a relatively stable trait of the individual that reflect his or her habitual mode of social relatedness and parenting style. This baseline component may tap a different aspect of the OT system as compared to the more pulsatile release of OT that occurs during specific physiological processes, such as breastfeeding or sexual intercourse. In addition, similar to the findings for California mice (de Jong et al., 2009), we found no differences in OT between first-time and experienced fathers. Perhaps by the time the infant reaches 4–6 months of age, first-time fathers have already had enough opportunities to interact with their infants to trigger the functioning of the OT system.

Although the relations between central and peripheral OT are not fully understood, studies in animals (Wotjak et al., 1998; Carter et al., 2007) and humans (Burri et al., 2008) suggest that the central and peripheral activity of the oxytocinergic system are likely to be coordinated. However, it should be remembered that Burri et al. (2008) used an intranasal administration of OT and Wotjak et al. (1998) found coordination between OT increase in the supraoptic nuclei of the hypothalamus and in plasma OT levels following an exposure to stress, and both paradigms differs from the current study. Both plasma and salivary OT have been associated with behaviors related to social affiliation (Gordon et al., 2008; Holt-Lunstad et al., 2008; White-Traut et al., 2009) and a feeling of safety and relaxation in humans (Bello et al., 2008), and these associations provide initial support for the perspective that peripheral OT measured in the two fractions is meaningfully related to emotions and behaviors associated with social bonding. Similarly, research has shown parallel increases in maternal plasma OT and in the mother's fMRI BOLD response to own infant stimuli in brain areas rich in OT receptors (Strathearn et al., 2009) and, although this design also differs from the present study, the study suggests a parallel in the response of central and peripheral OT. Previous studies have shown an increase in salivary OT in response to massage (Carter et al., 2007) and couple touch-related intervention (Holt-Lunstad et al., 2008), providing support for the use of salivary OT as a biomarker of touch-related affiliative processes. In addition, the correlation found between baseline plasma and salivary OT, albeit moderate, may provide initial evidence for the relationship between the two assessments, but much further research comparing salivary and plasma OT sampled at the same time is needed to determine the conditions under which OT in these two peripheral systems converge or diverge.

Limitations of the study should be considered in the interpretation of the findings. It is important to note that the results do not imply causal relations in the links between parental contact and OT increase and it is possible that some unmeasured factors accounted for both the high levels of parental contact and the increase in OT following parent–infant interaction. Similarly, the medium-size correlation between plasma and salivary OT may point to a shared mechanism underlying the functioning of these two peripheral systems yet suggest that much of the variance is non-shared. Further research is required to describe the complex associations between OT expression in the two fractions, and the present findings represent a first step in assessing their inter-relationship in the context of parenting. Finally, since several studies did not find an OT increase following touch (Turner et al., 1999; Ditzen et al., 2007), the conditions under which touch does or does not increase OT levels must be further studied and specified.

Much further research is required to uncover the biological, genetic, and epigenetic mechanisms involved in human parenting and to examine their similarities and differences with those observed in other mammals. Yet, the parallels described here between the neuroendocrine underpinnings of parent–infant interactions in humans and other mammals underscore the common biological roots of bond formation and emphasize the critical impact of early social experience on the human capacity to form attachment relationships.

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The NARSAD, ISD, and BSF foundations had no further role in study design; in the collection, analysis and interpretation of data; in the writing of the report; and in the decision to submit the paper for publication.

Conflict of interest

None declare.

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