

## PRIORITY COMMUNICATION

# Oxytocin Administration to Parent Enhances Infant Physiological and Behavioral Readiness for Social Engagement

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**Background:** The social milieu provides the context for the organism's survival, endurance, and adaptation. In mammals, social participation originates within the parent-infant bond and is supported by the oxytocin (OT) system, whose functioning is transmitted from parent to child through patterns of parental care. Human studies indicate that OT administration increases affiliative behavior, including trust, empathy, and social reciprocity. Here, we examine whether OT administration to parent can enhance physiological and behavioral processes that support parental social engagement but, moreover, can have parallel effects on the infant.

**Methods:** Utilizing a double-blind, placebo-controlled crossover design, 35 fathers and their 5-month-old infants were observed twice following administration of OT or placebo to father in the face-to-face still-face paradigm. Parent and infant salivary OT were assessed at multiple time points, respiratory sinus arrhythmia (RSA) was measured in the three face-to-face still-face episodes, and social behaviors of the parent and child were micro-coded for indices of social engagement.

**Results:** Oxytocin administration increased father salivary OT, RSA during free play, and key parenting behaviors that support parental-infant bonding. Parallel increases were also found in the infant's salivary OT, RSA response, and engagement behavior, including social gaze, exploration, and social reciprocity.

**Conclusions:** Results are the first to demonstrate that OT administration to one attachment partner can have parallel effects on the other and underscore the role of OT in the cross-generation transmission of human social participation. Findings have translational implications for conditions associated with early risk for social-emotional growth, including autism and prematurity, without the need to administer drugs to young infants.

**Key Words:** Cardiac vagal tone, double-blind studies, human social affiliation, oxytocin, oxytocin administration, parent-infant bonding, parent-infant interaction

Mammalian young become members of their social group through processes occurring within the parent-infant bond that shape the infant's social orientation by means of physical contact and the species-typical repertoire of parenting behavior (1–4). Research across mammalian species has implicated the neuropeptide oxytocin (OT) in the formation of social bonds (5,6) and demonstrated that parental OT and the amount of parenting behavior the infant receives shape the organization of OT receptors in the infant's brain and its ensuing lifetime effects on social adaptation (7,8). Human studies have similarly pointed to the links between parental OT and social-affiliative processes in parent and child. Maternal and paternal postpartum social behaviors were associated with the parent's plasma OT (9); the provision of parental touch induced salivary OT increase in mothers and fathers (10); and plasma OT has been associated with bonding-related cognitions (11) and increased activations in motivational-limbic brain areas in response to infant stimuli (12). Consistent with findings in other mammals, parent and infant OT responses were interrelated and the cross-generation link was shaped by the degree of social reciprocity during infant-mother and infant-father interactions (13). On the other hand, conditions associated with disruptions to parental-infant bonding, such as maternal postpartum depression or early

abuse and neglect, correlated with dysfunctions in parental and child OT (3,14,15). Similarly, risk alleles on the *OXTR* gene implicated in autism and depression were associated with reduced maternal and paternal touch, lower maternal sensitivity, and decreased infant social gaze during interactions with mother and father (9,16). Taken together, these studies suggest that parental OT is of clear evolutionary advantage to the social adaptation of their young, that the associations of OT and parenting are observed for both mothers and fathers, and that functioning of the OT system in the parent likely shapes the capacity for social engagement in the child.

The discovery that intranasal administration of neuropeptides can reach the human central nervous system (17) has led to extant research demonstrating the involvement of OT in a host of social behaviors and cognitions (18). Oxytocin has been shown to increase empathy (19,20), theory of mind (21), trust (22), altruism (23), and positive communication between couples (24) and to improve social functioning in conditions such as autism and schizophrenia (25). Such overarching involvement of OT in social and affiliative processes is thought to stem from the hormone's central involvement in the formation of the parent-infant bond, which, in turn, enhances physiological and behavioral systems that underpin human social engagement throughout life (3,26,27). Thus, OT administration paradigms afford an empirical framework to study processes that support the initiation of the human infant into social participation and the cross-generation transmission of OT by utilizing designs that are not merely correlational. This is a rare opportunity in human research due to the obvious constraints on assessing OT at the brain neurochemical level or applying cross-fostering paradigms. Two important questions that have not yet been addressed in studies on the cross-generation transmission of OT and social participation in humans are whether manipulations that increase parental OT can enhance parental-infant bonding by increasing the parent's

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physiological and behavioral response in systems that support social engagement and whether pharmacologic interventions to the parent can have parallel effects on the infant without direct hormonal manipulation to the child.

In this study, we used a double-blind placebo-controlled design to test the effects of OT administration to the parent on the parent's and infant's hormonal, autonomic, and behavioral responses during social interactions. The social context is the setting in which OT exerts its cross-generational effects in mammals (3,28) and was thus selected as the context of observation. We examined three systems that have been shown to support social engagement in humans. First, parent and child hormonal responses were measured by multiple assessments of salivary OT. Human studies have indicated that baseline plasma and salivary OT in mothers and fathers are interrelated and are comparable during the first months of parenting (10,13,29,30), and a cross-generational correlation between parent and child salivary OT was found for both mothers and fathers (13). Similarly, intranasal administration of OT has been shown to increase peripheral OT levels (31). It was thus expected that intranasal administration would increase the parent's peripheral OT and we examined whether it would have parallel effects on the infant's OT.

Second, parent and child autonomic responses to social interactions were tested. The autonomic nervous system, particularly its parasympathetic branch, plays an important role in supporting bond formation in mammals (32). Respiratory sinus arrhythmia (RSA), the respiratory component in heart rhythms mediated by the 10th cranial nerve, the vagus, provides a measure of parasympathetic activity that indexes the mammalian capacity to flexibly respond to micro-level shifts in environmental events, thereby supporting orientation, attention, and social engagement (33). Higher RSA during mother-infant free play has been associated with more optimal maternal care and higher infant social engagement (34–36). In light of the findings that parent and infant shape each other's heart rhythms through synchronized social exchanges (37), we expected that OT administration would enhance parental RSA, which, in turn, would impact the infant's autonomic reactivity.

Finally, we examined the behavioral repertoire that indexes social engagement in humans. Postpartum human parents, like other mammalian parents, engage in a species-typical repertoire that includes touch, gaze, vocalizations, affective expression, and joint exploration of the environment (38). The expression of these behaviors has been shown to predict greater empathy, prosocial orientation, and emotion regulation in childhood and adolescence (3,38). In humans and biparental fathers, the father-specific repertoire is marked by high positive arousal, stimulatory contact, and exploratory focus (39,40) and these behaviors induce similar levels of social reciprocity to those observed during mother-child interactions (41). We conducted a second-by-second analysis of father and child behavior and assessed discrete behaviors that index engagement and social reciprocity between parent and child. We expected that OT administration would increase the father's involvement at play, which would enhance the infant's social engagement. Overall, two hypotheses guided the study. First, we expected that OT administration would enhance the father's peripheral OT, RSA response, and father-typical social behavior. Second, in light of the cross-generational effects reported in other mammals (5,6), we expected that OT administration to the father would have parallel effects on the infant's hormonal, autonomic, and behavioral response.

## Methods and Materials

### Participants

Thirty-five healthy fathers (average age 29.7 years, SD = 4.2, range 22–38) participated with their 5-month-old infants (SD = 1.25, range 4–8 months) in two lab visits, a week apart (total  $n = 70$ ). Fathers' exclusion criteria included smoking, mental or physical illness, and medication intake. All fathers were educated, middle-class, and married to the infant's mother. Infants (18 girls) were healthy with 68.5% being firstborns, and exclusion criteria included premature birth, birth-related complications, and illness. The research was approved by the Institutional Review Board and conducted according to ethical standards, and all participants signed an informed consent.

### Procedure

Fathers were instructed to abstain from alcohol or caffeine during the experiment day and avoid food intake 2 hours before arrival. Upon arrival, infant was separated from father and cared for by a trained research assistant. Following a short assessment of father's affect with Positive and Negative Affect Schedule (42), fathers self-administered either oxytocin or placebo under the supervision of the experimenter. Forty minutes after administration, infant joined father in the observation room (room size = 10 m<sup>2</sup>). Infant was seated in an infant seat mounted on a table. Father and infant were connected to electrocardiograph (ECG) monitor-interbeat intervals (IBI) logger (12 bit, 1000 samples/second/channel, 3992/6-IBI BioLog System; UFI, Morro-Bay, California) and their ECG signals were simultaneously sampled during interaction. Father and infant were observed in the well-validated face-to-face still-face paradigm (FTFSF) (43), in which the parent interacts with the infant freely for 3 minutes, refrains from social engagement for 2 minutes, and resumes play for an additional 2 minutes. Father-infant interaction began approximately 45 minutes after substance administration. All experiments were held between 13:00 and 17:00, to control for diurnal variations in OT.

### Oxytocin Versus Placebo

Fathers were asked to self-administer 24 IU of either oxytocin (Syntocinon Spray; Novartis, Basel, Switzerland; three puffs per nostril, each containing 4 IU) or placebo. The placebo was custom designed by a commercial compounding pharmacy to match drug minus the active ingredient. Administration order was counterbalanced, and participants and experimenters were blind to drug condition.

### Salivary Oxytocin Collection and Analysis

Father and infant saliva samples were collected at multiple time points: T1 (baseline)—before substance administration (father only); T2—40 minutes after administration before interaction; T3—20 minutes after interaction began; and T4—20 minutes thereafter. Saliva samples were collected by Sallivatte (Sarstedt, Rommelsdorf, Germany). Salivettes were immediately stored at  $-20^{\circ}\text{C}$  to be centrifuged twice at  $4^{\circ}\text{C}$  at 1500g for 15 minutes within 1 month. All samples were then stored at  $-80^{\circ}\text{C}$  until further processed and then transferred to  $-20^{\circ}\text{C}$ . The samples were reconstructed in the assay buffer immediately before analysis. This procedure was used since analysis was conducted blind to condition and concentrations were expected to differ significantly between conditions.

Determination of oxytocin was performed using a commercial oxytocin enzyme-linked immunosorbent assay kit (Assay Design, Ann Arbor, Michigan). Although earlier research has questioned the validity of salivary OT (44), recent studies across several labs have

**Table 1.** Father and Infant Salivary Oxytocin Levels (pg/mL) in the Oxytocin and Placebo Conditions

	Oxytocin Condition		Placebo Condition		<i>t</i>
	Mean	SEM	Mean	SEM	
<b>Father</b>					
Baseline	23.20	2.70	20.91	3.86	ns
Pre-interaction	6197.97	1712.72	34.34	8.12	3.88 <sup>a</sup>
20 minutes later	3930.57	1382.63	33.94	11.18	3.04 <sup>b</sup>
40 minutes later	736.22	166.14	21.14	2.90	4.72 <sup>a</sup>
<b>Infant</b>					
Pre-interaction	55.82	21.17	17.91	2.87	ns
20 minutes later	8227.31	1987.86	68.34	19.92	3.92 <sup>b</sup>
40 minutes later	5981.97	2786.08	55.31	13.70	2.15 <sup>c</sup>

Father and infant salivary oxytocin were measured continuously during the experiment. Baseline measurement (fathers only) was taken before administration; pre-interaction sample was taken from father and infant 40 minutes after administration; and another two assessments were taken following the start of father-infant interaction in 20-minute intervals (approximately 65 and 85 minutes after administration, respectively).

ns, nonsignificant.

<sup>a</sup> $p < .001$ .

<sup>b</sup> $p < .01$ .

<sup>c</sup> $p < .05$ .

shown that salivary OT measured by immunoassay is a reliable biomarker, is stable over time, and correlates with plasma OT and OT-related processes, such as breastfeeding (10,30,45–47). Furthermore, two recent studies from different labs showed that intranasal OT administration markedly increased salivary OT levels over several hours (48,49).

For the OT assay, we used the following procedure, consistent with our research and research by others (30,45). First, all samples were concentrated by four (lyophilized) and then measured using a commercial enzyme-linked immunosorbent assay kit. Samples that yielded a value within the calibration curve of 15 to 1000 pmol/L were not re-analyzed. When samples did not yield a specific value, indicating that the value was above 1000 pmol/L, we re-assayed these samples following dilution of 1:6. Few samples yielded high values, even after the 1:6 dilution, and these were re-analyzed using dilution of 1:20. Measurements were performed in duplicate and the concentrations of samples were calculated using MatLab-7 (MathWorks, Natick, Massachusetts) according to relevant standard curves. The intra-assay and interassay coefficients were <12.3% and <21.09%, respectively.

### Autonomic Response

Electrocardiograph measurement was conducted by a dual channel portable ECG monitor-IBI logger system (12 bit, 1000 samples/second/channel). The BioLog system was equipped with active signal-conditioning electrodes attached to participants using three disposable silver-silver chloride skin surface electrode patches. IBI series were produced from ECG signals. The IBI series were linearly interpolated to form an evenly sampled time series and a high-pass filter related to the spontaneous respiratory cycle: between .12 and .40 Hz for fathers and between .24 and 1.04 Hz for infants were used. Each IBI series was visually scanned by a condition-blind researcher for outlier caused by artifacts or ectopic beats.

RSA amplitude was quantified for each episode of the FTFSF paradigm (free play, still-face, reunion) for father and child using Porges' MXEdit software (Delta Biometrics, Bethesda, Maryland) (50), which has been well-validated in parenting research. Father's resting RSA was also measured in a 5-minute baseline before infant arrived.

### Coding Father-Infant Interaction

Interactions were videotaped using Flip Mino HD digital camcorder (Cisco, Irvine, California) for offline coding. The free-play episode was micro-coded by trained observers on a computerized system (Noldus, Wageningen, Netherlands) using a validated coding scheme (51). We focused on social behaviors that characterize father-infant interaction in humans and biparental species (40). Father behavior included social gaze—looking at infant's face; positive affect—smiling, high positive arousal, and laughing; parental touch—affectionate touch (hugging, kissing, stroking) and stimulatory touch, encouraging infant exploration; and father vocalizations—infant-directed speech that is high-pitched and repetitive-rhythmic (motherese), and encouraging infant orientation to social context. Infant behavior included social gaze—looking at father's face; positive affect—smiling and laughing, touching father; and exploratory play—object manipulation. The mean duration and latency in seconds of each behavior were measured. Consistent with previous research (51), we also computed touch synchrony—episodes in which father and child share social gaze, while father provides stimulatory or affective touch.

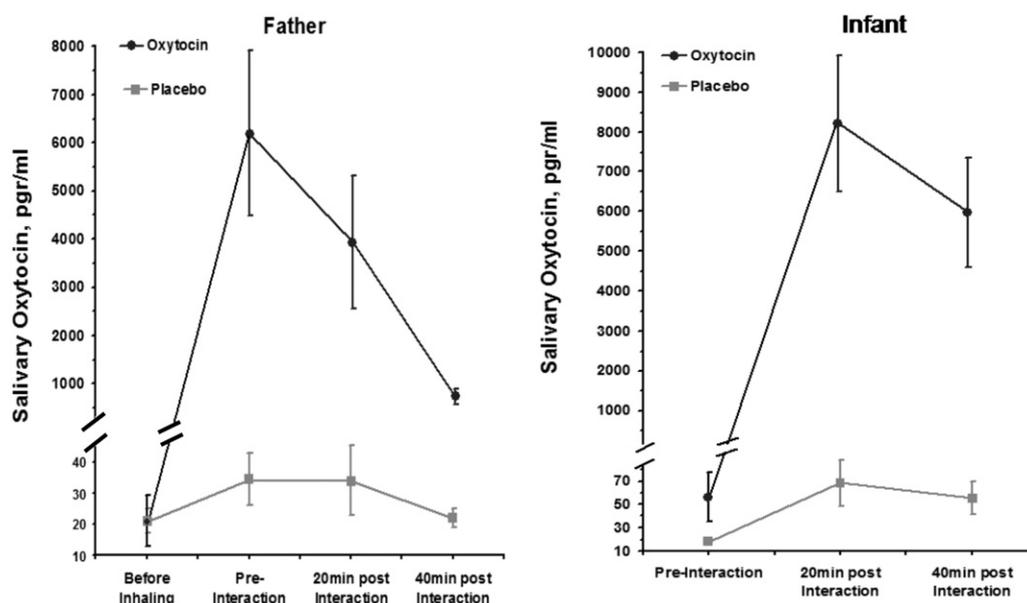
### Results

#### Salivary Oxytocin

Consistent with previous research (9,52), OT values were log-transformed before statistical analyses. Salivary OT concentrations for the four father assessments and the three infant assessments in the OT and placebo (PL) conditions and the *t* values for their difference appear in Table 1 and Figure 1. Results show no significant differences at baseline but a highly significant difference for each following assessment for both father and infant.

Repeated-measure analysis of variance (ANOVA) for the four father (log)OT assessments with condition and infant gender as the between-subject factors revealed different pattern in the two conditions,  $F(1,33) = 189.72$ ,  $p < .001$ , effect size (ES) = .85. A significant condition by time interaction effect emerged,  $F(3,99) = 75.64$ ,  $p < .001$ , ES = .69. Fathers showed a marked increase in OT between baseline and the other three assessments in the OT condition, but not in the PL condition. No infant gender effect emerged,  $F(1,33) = .24$ ,  $p > .05$ .

A repeated-measure ANOVA for infant (log)OT showed similar



**Figure 1.** Father and infant salivary oxytocin (OT) levels (pg/mL) in the oxytocin and placebo conditions. Following OT administration to father, father and infant salivary OT levels are markedly increased compared with baseline assessment. In the placebo condition, no increase is observed. Error bars represent standard error of the mean.

main effect for condition,  $F(1,33) = 118.89, p < .001, ES = .77$ , indicating that infant OT differed according to father OT status. A condition by time interaction,  $F(2,68) = 162.32, p < .001, ES = .82$ , revealed that infants in the OT condition showed a dramatic increase in salivary OT between the first (before father-infant interaction) and next assessments.

**Parasympathetic Activation**

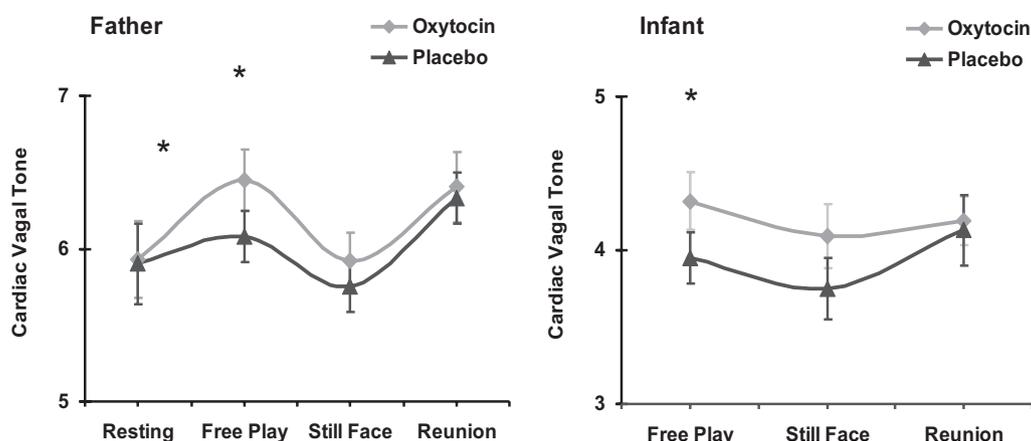
Fathers' and infants' RSA in the three episodes of the FTSSF and fathers' baseline RSA appear in Figure 2. Fathers' RSA during free play in the OT and placebo conditions were compared with paired-comparison  $t$  tests and showed higher RSA in the oxytocin condition,  $t(34) = 2.55, p < .05$ , suggesting greater autonomic readiness for social engagement. In addition, assessing the change in fathers' RSA from baseline to free play, calculated as RSA during free play

minus RSA at baseline, showed greater RSA increase in the OT condition,  $t(34) = 5.08, p < .05$ .

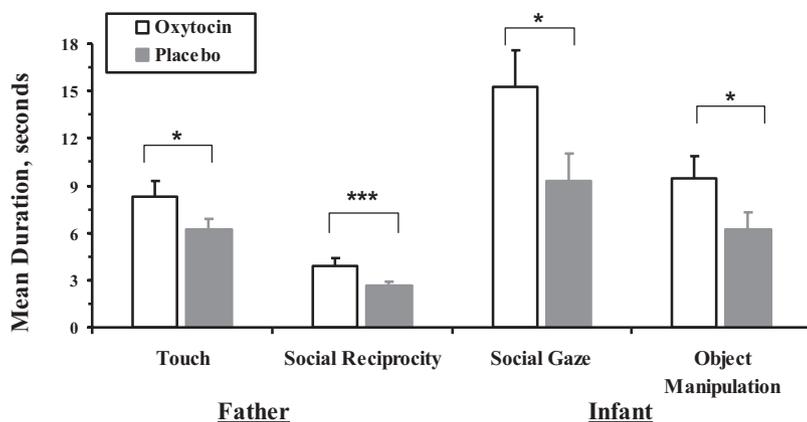
Infants' RSA during the free-play episode was similarly higher in the oxytocin condition,  $t(34) = 1.98, p = .05$ , indicating a parallel effect on the infant's parasympathetic response. A repeated-measure ANOVA conducted for father and infant separately showed no difference in overall RSA level between conditions (OT, PL), suggesting the effect was specific to the free-play episode.

**Social Engagement Behavior**

Among fathers, episodes of social reciprocity, indexing moments of infant-oriented positive vocalizations and encouragement of infant orientation to the social context, were longer in the oxytocin condition,  $t(34) = 3.69, p < .001$  (Figure 3). Similarly, in the oxytocin condition, fathers exhibited longer epi-



**Figure 2.** Participants' autonomic response (respiratory sinus arrhythmia) in the oxytocin (OT) and placebo conditions. Following OT administration to father, father and infant cardiac vagal tone during face-to-face interaction are increased (grey lines), compared with placebo. In the OT condition, fathers showed greater increase in respiratory sinus arrhythmia level from the pre-interaction to the social interaction assessment. \* $p < .05$ . Error bars are standard error of the mean.



**Figure 3.** Father and infant social behaviors in the oxytocin and placebo conditions. Bar charts present social behaviors that are enhanced in father and infant following oxytocin administration to father. \* $p < .05$ . \*\*\* $p < .001$ . Error bars represent standard error of the mean.

sodes of touch,  $t(34) = 2.11, p < .05$  (combined affectionate and stimulatory touch). The latencies (in seconds) to the first episode of father's touch and social gaze at the infant were shorter in the oxytocin condition,  $t(34) = -2.22, 2.02, p < .05$ , respectively. Infants' social behavior similarly differed across conditions. Episodes of infant object manipulation were longer,  $t(34) = 2.49, p = .05$ , and moments of social gaze toward father were longer in the OT condition,  $t(34) = 2.07, p < .05$  (Figure 3). Infants were quicker to reach the first episode of object manipulation in the oxytocin condition,  $t(34) = -2.02, p = .05$ , and took longer to avert gaze from father's face,  $t(34) = 2.25, p < .05$ , indicating closer focus on the social context.

#### Associations between Oxytocin, RSA, and Social Behavior

Father OT in the PL condition showed high individual stability ( $r_s = .47, .56, .42, p < .01$  between baseline and T2, T3, and T4, respectively) and the four assessments were averaged into a single score, which indexed the father's stable, nonmedicated level of OT. This global OT score correlated with the father's baseline OT in the OT condition ( $r = .38, p < .05$ ), further supporting the stability of salivary OT and the validity of the salivary measure. Fathers' global OT correlated with the fathers' averaged RSA in the three FTFSF episodes in the PL condition ( $r = .34, p < .05$ ). Finally, fathers' global OT correlated with fathers' touch in both the OT ( $r = .38, p < .05$ ) and PL ( $r = .36, p < .05$ ) conditions and with fathers' social reciprocity in the OT condition ( $r = .35, p < .05$ ).

Father baseline OT in the OT condition showed stability from baseline to T2 ( $r = .35, p < .05$ ), marginal stability to T3 ( $r = .30, p = .08$ ), and no association with T4. Fathers' OT response to administration (average of T2, T3, and T4 in the OT conditions) correlated with the infants' OT response to fathers' administration (average of T3 and T4 in OT condition),  $r = .35, p < .05$ . No correlations emerged between father or child OT response with RSA. Child OT response correlated with father's touch,  $r = .41, p < .01$ , with longer latencies to father gaze aversion,  $r = -.36, p < .05$ , with greater child object manipulation,  $r = .37, p < .05$ , and with father-child touch synchrony—moments when father and child shared social gaze is integrated with paternal touch,  $r = .48, p < .01$ .

Finally, father's affect was measured before and 40 minutes after administration and no differences were found in fathers' self-reported emotions in either session (42). Importantly, mean durations, proportions, and frequencies of fathers' positive, neutral, and negative emotional expressions showed no differences between OT and PL conditions, indicating that the findings are specific to affiliative processes expressed during moments of social engagement.

#### Discussion

The current findings are the first to show that OT administration enhances functioning in physiological and behavioral systems that underpin parental-infant bonding in humans and that OT administration to parent can have parallel effects on the child without direct hormonal manipulation to the infant. These findings demonstrate the involvement of OT in the cross-generational transmission of parenting in humans by utilizing an experimental, and not a correlational, research design. Oxytocin administration markedly increased the fathers' salivary OT, autonomic response during free play, and parenting behavior, particularly touch and social reciprocity. In parallel, the infants' peripheral OT increased, infant RSA was higher during social play, and infants displayed more social gaze and exploratory behavior, indicating greater social engagement when fathers inhaled OT. Peripheral OT and RSA have been associated with higher levels of infant social behavior (3,35), and disruptions to parental-infant bonding, in cases such as premature birth or maternal postpartum depression, are expressed in lower peripheral OT (14), lower RSA (53), and reduced social behavior (54). In addition, peripheral OT, RSA, and parent-infant social behaviors have each been shown in longitudinal studies to be stable within individuals over time (11,27,55). Thus, the findings point to the effects of OT on enhancing the individually stable markers of bonding in parent and child.

Oxytocin is a neurohormonal system that dynamically engages body and brain, organism and environment, and separate partners within an attachment relationship (3). The findings demonstrate the integrative effects of OT administration at three levels: between central and peripheral OT, between OT response in parent and child, and between the OT and parasympathetic systems. The link between brain and peripheral OT activity has been an issue of continuous controversy; yet, researchers have suggested that the two are coordinated (56). One potential pathway involves the effects of alterations in brain OT on visceral functioning, particularly the vagus, which lead to an increase in peripheral OT levels (57). This hypothesis is consistent with the findings that vagal stimulation leads to OT release in the brain (58). Porges and Carter (59) suggest that the oxytocinergic and autonomic systems enhance each other through positive feedback mechanisms and jointly establish a sense of safety that enables the formation of affiliative bonds (28,59,60). This conceptualization is consistent with the known anxiolytic effects of OT on internal state and social behavior (61). Similarly, Bos *et al.* (62) suggest that gonadal steroids and neuropeptides jointly influence bonding by increasing OT-dopamine interactions. In contexts perceived as safe, estrogen and OT increase

parasympathetic efference and inhibit amygdala output to the brainstem, leading to increased prefrontal activity and OT-dopamine interactions that enhance the motivation to bond (62). Thus, OT is thought to induce a physiological state that provides the neurobiological substrate for social engagement (3,59). Yet, despite research showing OT effects on brain activations (63), whether and how nasal administration of peptides reaches the brain are largely unknown. Possibly, similar to the mechanism suggested for vasopressin, the inhaled peptide reaches the ventricular cerebrospinal fluid and then enters the extra-cellular space of the brain (17,64), but much further research is required to chart this pathway in detail (64).

Fathers' OT response following administration was associated with the magnitude of the infants' OT response. Furthermore, infant OT response correlated with the behavioral repertoire typical of the father-infant bond, including father stimulating and affective touch, infant object exploration, and moments of touch synchrony, when shared social gaze is integrated with paternal touch. Touch within close relationships has been repeatedly associated with baseline OT and the OT response (3) and, possibly, the increase in paternal touch and its integration with shared gaze and joint exploration triggered OT response in the infant. Naber *et al.* (65) similarly found that OT administration increased fathers' stimulatory and exploratory play with their toddlers, indicating that OT impacts the father-specific behavioral repertoire. It is possible that OT administration begins a chain of positive feedback through mutual influences between parent and child physiology and behavior. Such synchronous biobehavioral processes may provide critical experiences for the human infant to enter the social world, maintain engagement with conspecifics, understand the nonverbal signals of interactive partners, and form reciprocity with members of the social group.

The potential for neuropeptide therapy to treat disorders of social functioning has been recently suggested, triggered by the effects of OT administration on improving key features of the disorder in autism and schizophrenia (25). The current findings may have important implications for OT-related interventions in cases of bonding disruptions that bear long-term consequences for infant growth. Maternal postpartum depression affects nearly 18% of women and 4% of men in industrial societies (66,67) and rates of premature birth approach 12% (68), and both are associated with disruptions to the OT, parasympathetic, and social-behavioral systems and with risk to child well-being. Oxytocin-based psychopharmacologic interventions to parent may prove useful in enhancing the physiological and behavioral systems that underpin social engagement in parent and child without the need to administer the drug to young infants. A similar approach can be applied to siblings of children with autism, who are at greater risk for psychopathology. Such interventions may increase the lower levels of baseline OT found in autistic children (69), which may enhance socioemotional functioning in this population (70).

Limitations of the study should be acknowledged in the interpretation of the findings. First, given the complexity of administering OT to nursing women, the study was conducted with fathers, and future research is required to examine whether the findings generalize to mother-infant dyads. Second, we relied on peripheral measurements of OT, although the connection between central and peripheral OT levels is still controversial. Since human research cannot assess brain OT and both animal (71) and human studies (31) suggest that central and peripheral OT activity is coordinated, the findings represent the measurement available in human research to date. An additional concern is that

salivary OT levels after administration may reflect oral cavity contamination resulting from method of administration. For instance, Jenkins *et al.* (72) suggested that high concentrations of drug in saliva following heroin and cocaine smoked administration resulted from oral contamination. However, our study differs in several aspects. First, we used intranasal rather than smoked administration. Second, whereas our subjects were administered .6 mg of OT (24 IU), the Jenkins *et al.* (72) participants smoked 2.6 to 10.5 mg of heroin and 40 mg of cocaine. Third, we measured salivary OT 40 minutes following administration and all participants drank at least one glass of water between administration and the first salivary assessment, whereas Jenkins *et al.* (72) began measuring salivary concentrations immediately and without water, and their 30-minute postdrug levels were closer to baseline (zero) than peak levels. Finally, this alternative explanation cannot account for the parallel increase in infant salivary OT 60 minutes after administration when infant only met father 40 minutes after administration. In addition, although we describe associations between the parent and child OT response, much further research is required to understand the specific mechanisms through which this association takes place. It is important to assess whether individual differences in the OT neuropathway, for instance, variability on the *OXTR* gene, may be related to father or child OT response following administration. Finally, it is important to examine whether a reciprocal social contact between any members of our species may lead to the coordination of the partners' OT response, autonomic activity, and behavioral expression. Such synchronized response may underlie the embedded nature of human social cognition, through which humans understand, empathize, and read the intentions of social partners by representing the other's state in one's physiology.

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