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Oxytocin and Social Bonds: The Role of Oxytocin in Perceptions of Romantic Partners' Bonding Behavior

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Abstract

In this research, we tested hypotheses about the role of oxytocin in adult human bonding. Inspired by revisiting the research on pair bonding in microtine voles that fueled psychologists' interest in the role of oxytocin in social life, we drew on recent theory from affective and relationship science to identify a well-defined bonding context for human romantic relationships. We then paired these behaviors and subjective psychological responses with a measure of naturally circulating oxytocin. In 129 romantically involved adults whose partner expressed gratitude to them in the lab, greater oxytocin over the prior 24 hr was associated with greater perceptions of the expresser's responsiveness and gratitude, as well as greater experienced love, but not general affective reward. Moreover, in this one-time conversation, higher oxytocin acted like rose-colored glasses, attenuating the effect of a partner's behaviorally coded expressive behavior on perceptions of the expresser's responsiveness. These results justify future research on the role of oxytocin in psychological aspects of growth processes.

Keywords

emotions, interpersonal interaction, neuroendocrinology, relationship quality, social perception

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One of the most provocative series of studies implicating oxytocin in social bonds involved comparison of microtine rodent (vole) species. Building on observations of differential regional brain expression of oxytocin receptors in monogamous prairie voles versus non-monogamous montane voles (Insel & Shapiro, 1992), experimenters were able to systematically enhance or disrupt female prairie voles' formation of a preference for a specific male prairie vole (i.e., a pair bond) by manipulating oxytocin in the central nervous system of the female (Williams, Carter, & Insel, 1992). Shifting from voles to humans, other theorists have suggested that the same biobehavioral system that coevolved to promote close bonds between infant and caregivers had been co-opted for use in creating close adult romantic bonds as well (e.g., Diamond, 2004). Though a key biological component of that evolved system was thought to be oxytocin (see Gonzaga, Turner, Keltner, Campos, & Altemus, 2006), now a quarter century after the initial prairie-vole findings (Williams et al., 1992), there are exceptionally few data points to address whether or how oxytocin facilitates bonding in the context of adult human attachment.

This dearth of evidence may be driven in part by the lack of well-specified operational definitions of the bonding process in adult humans (Carter, Williams, Witt, & Insel, 1992). Given recent meta-analytic evidence documenting the robust association between high-quality relationships and longevity—an effect size as large as that for smoking and larger than for obesity (Holt-Lunstad, Smith, & Layton, 2010)—basic research on the specific biopsychosocial mechanisms through which bonds are forged and strengthened becomes all the more important.

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Theoretical Specificity for Bonding and Growth Processes in Adult Humans

In the past two decades, it has become clear that of the wide variety of beneficial behaviors and processes within ongoing relationships (e.g., arguing respectfully; Gottman & Levenson, 1992), some are especially well-suited to promote the bond between two individuals (e.g., Algoe, Fredrickson, & Gable, 2013; Fredrickson, 2013; Gable & Reis, 2001). For example, affective science has shown that, as a category, positive emotions are well-suited for promoting intrapersonal and interpersonal growth (Fredrickson, Cohn, Coffey, Pek, & Finkel, 2008). Moreover, research specifying distinct functions for distinct positive emotions identifies two—love and gratitude—uniquely suited for bonding (Algoe, Gable, & Maisel, 2010; Gonzaga, Keltner, Londahl, & Smith, 2001).[1]

Then, building on the relationship-science tradition, a recent theoretical account of gratitude emphasizes the cross-partner nature of the bonding process (Algoe, 2012). While gratitude is initially caused by the kind actions of a benefactor, this account posits that the subsequent behavior of the grateful person can further draw the benefactor into the relationship. Specifically, the grateful person's behavior toward the benefactor is likely to be perceived as responsive, which involves feeling understood, validated, and cared for by the grateful person (Reis, Clark, & Holmes, 2004); theoretically, this perception should make the benefactor more interested and invested in the grateful person, which would, over similar repeated interactions, grow the relationship. Supporting this hypothesis, two previous studies showed that benefactors who perceived responsiveness when a romantic partner expressed gratitude to them in a one-time laboratory conversation reported increased relationship satisfaction 1 or 6 months later (Algoe et al., 2013; Algoe & Zhaoyang, 2015). Critically, this effect was independent from effects of perceiving responsiveness after various other types of interactions with the partner, which suggests that the behavior of expressing gratitude and perceptions of the grateful expresser's responsiveness uniquely foster relational growth.

Considering these findings, we more recently conducted a careful investigation of expressions of gratitude to understand how likely they are to impact the key outcome of perceived expresser responsiveness (Algoe, Kurtz, & Hilaire, 2016). By focusing on specific behavioral and subjective psychological components of the process, this work contributed to the operational definition of adult human bonding that we rely on in the current study (see Fig. 1). Specifically, building on research differentiating the social consequences of gratitude versus other positive emotions (Algoe & Haidt, 2009), researchers behaviorally coded video-recorded expressions of gratitude between romantic partners in the lab for the extent to which the expresser praised the benefactor's actions. As predicted, the extent to which the expresser used this behavior was positively correlated with the extent to which the benefactor reported feeling understood, validated, and cared for by the expresser (i.e., perceived expresser responsiveness). Additional analyses revealed two secondary pathways through which praise within a gratitude expression may draw in a benefactor: by making the benefactor feel loved and rewarded (Algoe et al., 2016).

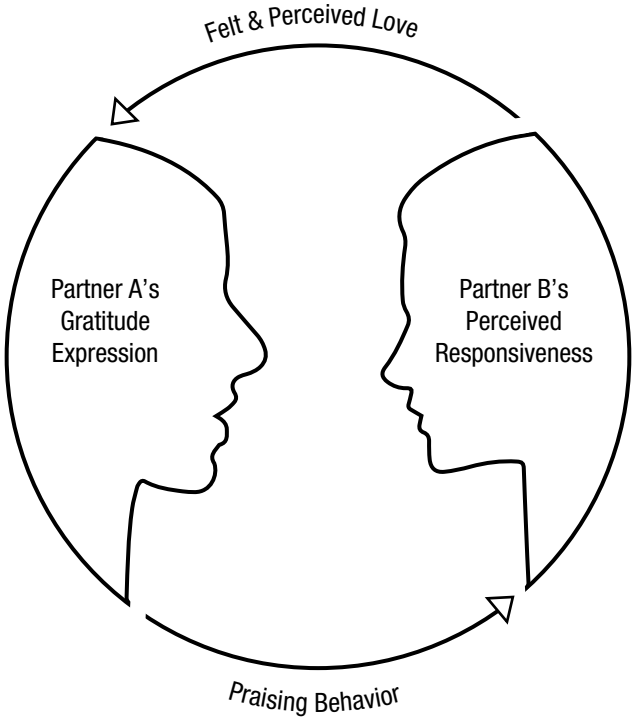

Fig. 1. Components of adult human bonding through gratitude. Partner A's expression of gratitude—particularly when it includes praise of Partner B's actions—is associated with Partner B's perception of the expresser's responsiveness (primary outcome), as well as experienced love (secondary outcome; Algoe, Kurtz, & Hilaire, 2016). In turn, perceived expresser responsiveness is associated with Partner B's future personal and relationship satisfaction (Algoe, Fredrickson, & Gable, 2013; Algoe & Zhaoyang, 2015).

Evidence for Oxytocin in the Romantic Bonding Process

Though many researchers study the role of oxytocin in social life, adult attachment relationships are qualitatively different from other relationship types (e.g., Hazan & Diamond, 2000), and we take seriously the conclusions from recent reviews that context matters

for understanding oxytocin's effects (e.g., Bartz, Zaki, Bolger, & Ochsner, 2011). Therefore, we focused our literature search according to the theoretical question at hand (e.g., Williams et al., 1992): Only four studies measured or manipulated oxytocin and subsequently measured behavior or subjective responses related to interpersonal bonding processes in human adult romantic relationships. All provide promising evidence in support of the thesis that oxytocin facilitates the bonding process; for example, one study positively links plasma oxytocin with self-reported hugging of the partner (Light, Grewen, & Amico, 2005), and another study links it with the couples' collective behaviors in a live social interaction (Schneiderman, Zagoory-Sharon, Leckman, & Feldman, 2012).[2]

Here, we were interested in the subjective psychological response to the interaction, focusing on theoretical specificity among "good" outcomes, as well as dependence of these responses on partner behavior, to highlight the cross-partner nature of the bonding process. Notably, two of the four studies mentioned in the previous paragraph imply that oxytocin favorably colors the subjective psychological experiences caused by the bonding-relevant interactions of either expressed gratitude or sexual activity (Algoe & Way, 2014, using genotyping of *CD38*; Behnia et al., 2014, using intranasal oxytocin administration). At first blush, such positive associations may seem to run contrary to well-cited evidence regarding associations between oxytocin in women's global ratings of interpersonal distress (Taylor, Saphire-Bernstein, & Seeman, 2010). However, we reiterate that the present research question is different: When one is given an opportunity for bonding, such as when receiving an expression of gratitude, does oxytocin offer rose-colored glasses to facilitate that process?

Moreover, a novel question we address here focuses on the role of oxytocin in the cross-partner process of bonding: Does oxytocin influence the previously documented positive association between an expresser's praising behavior and the benefactor's perception of the expresser's responsiveness (Algoe et al., 2016)? If higher oxytocin levels lead to more favorable situational partner evaluations, such evaluations may not be as contingent on an expresser's behavior for people with higher levels of oxytocin, relative to those with lower oxytocin levels (i.e., offering rose-colored glasses for bonding opportunities). Alternatively, perhaps people with higher circulating oxytocin are acutely attuned to the social information conveyed by the expresser's behavior (i.e., the social-salience hypothesis; Shamay-Tsoory & Abu-Akel, 2016), which would suggest a stronger association between the partner's praise and the benefactor's perceptions of responsiveness with higher oxytocin levels. Whichever pattern may be correct, we tested the hypothesis that the previously documented association between expressers' praise and benefactors' perceptions of expressers' responsiveness is moderated by benefactors' oxytocin.

The Current Research

Building on early research (Williams et al., 1992), our study advances the conversation about oxytocin's role in promoting close adult bonds by taking a robust peripheral measure of cumulative oxytocin, observing romantic couples in a well-specified bonding context—that is, when one person expresses gratitude to the other—and measuring theoretically specified subjective psychological responses to hearing an expression of gratitude. Specifically, we predicted significant positive associations between benefactors' oxytocin and the primary outcome of perceived expresser responsiveness as well as the secondary outcome of experienced love, but not with general affective reward (see Algoe & Way, 2014). We explored associations between oxytocin and the novel outcome of perceived emotions of the expresser, namely perceived expresser gratitude, love, and general affective reward. Finally, we tested the hypothesis that oxytocin moderates the previously observed cross-partner association between expressers' praising behavior and the key outcome of benefactors' perceptions of expresser responsiveness (Algoe et al., 2016).

Method

Participants

Both members of 129 heterosexual couples (N = 258) were recruited from the greater Chapel Hill, North Carolina, region for a study on "everyday couple interactions." Couples were required to have been together for at least 1 year, and participants could not have been recently diagnosed with anxiety or depression, nor could they be taking steroid medication. Women had to be premenopausal and not currently pregnant or nursing, nor could they have been pregnant in the prior 6 months or have had an oophorectomy. Most couples were dating exclusively (76.7%), and 23.3% reported that they were married, engaged, or "living as married"; 43.4% (56 couples) were living together, and most did not have children (94.6%). On average, participants were about 24 years old (M = 23.7, SD = 5.64, range = 18–50) and predominantly Caucasian (70.9%) and non-Hispanic (90.7%). Of the remaining participants, 11.2% self-identified as being of East Asian descent, 7.4% as African American, and 4.7% as South Asian, and 5.8% indicated various other racial or ethnic backgrounds.

Design and procedure

In this observational study, each member of the couple collected his or her total urine output over the 24-hr period before attending the laboratory session together. This 24-hr urine-sampling method was selected because it is noninvasive, free from the stress and pain of having blood drawn (which may independently affect oxytocin levels; Eliava et al., 2016), and may more accurately reflect participants' oxytocin levels as they go about their daily life. Additionally, the acidic environment of urine is more likely to preserve peptides such as oxytocin, whereas enzymatic degradation is more likely in plasma (Amico, Ulbrecht, & Robinson, 1987). Oxytocin release may also be pulsatile and responsive to endocrine and psychological states, as well as various stimuli throughout the day (e.g., Eliava et al., 2016; Stuebe, Grewen, & Meltzer-Brody, 2013). Therefore, a urinary mean over 24 hr may more likely reflect participants' overall peripheral levels and serve as a cumulative index of oxytocin (Reyes et al., 2014).

At the lab session, one member of the couple was randomly selected to express gratitude to the other in a video-recorded conversation; after the conversation, the target of the expression of gratitude (i.e., the benefactor, who had previously done a kind thing for the expresser) reported his or her positive emotions, perceptions of the expresser's positive emotions, and perceptions of the expresser's responsiveness. (We use the term *target* rather than *benefactor* throughout the Method and Results to reflect this person's specific role as a relatively passive recipient in the situation we were studying.) Each video recording was later viewed by four trained judges, who coded the expresser's other-praising behavior. Urine was assayed for oxytocin and creatinine. Oxytocin was expressed as a ratio of oxytocin to creatinine to adjust for between-persons differences in urine concentration (see Reyes et al., 2014). Our hypotheses and analyses focused on the urinary oxytocin of the target of the gratitude expression. These methods were used in the context of a larger study; sample size from that study was determined to be sufficient to detect the hypothesized associations between oxytocin and targets' perceptions if the effect were moderate in size, at 94% power, so all available urine samples were assayed. See the Supplemental Material available online for information about other procedures.

Behavioral-gratitude task

Using a standard paradigm for observing naturalistic couple conversations, we asked participants to pick something their partner had done for them recently, for which they felt grateful; instructions for this specific task are documented elsewhere (Algoe et al., 2013; Algoe et al., 2016; Algoe & Way, 2014; Algoe & Zhaoyang, 2015). Each person selected the event and rated its importance before he or she was informed which couple member was randomly selected to be the expresser. The original study included an experimental manipulation for a different purpose (reported in Algoe et al., 2016): In an attempt to influence targets' perceptions of responsiveness, we asked expressers in one condition to focus more on the praiseworthiness of the target's actions (e.g., how thoughtful the target was), whereas in the other condition, expressers were asked to focus more on how the event benefited them (e.g., making the grateful person happy). Because it was documented in the prior publication that the manipulation did not affect perceptions of partner responsiveness, we did not have predictions that the proposed effects in the current study would be moderated by condition; we therefore collapsed data across conditions but controlled for this factor in analyses (see the Supplemental Material for more information as well as the Results section below for reports on exploratory tests for moderation by condition). After the manipulation, once they were in the lab room together, just prior to the conversation, the experimenter told the couple the following:

> While you're interacting, please feel free to talk about anything related to the positive thing [the target] did for [the expresser]. Some suggestions for the person who has the event would be to discuss why the event was appreciated and how it made you feel. When your partner is thanking you for the thing you did, you can respond to, add to, or talk about as much or as little as you would under normal circumstances. You can stop talking and let me know when you feel the conversation has come to a natural end. If five minutes pass, I will signal you to wrap it up.

Measures

Self-reported data. As indicated, the primary outcome from this interaction was perceived expresser responsiveness, with the secondary outcome being experienced love. To probe the theoretical specificity of the proposed associations (i.e., provide discriminant evidence, as in Algoe & Way, 2014), we also assessed general experienced affective reward. Moving from personal experiences to inferences about the partner's experiences, we explored the target's perceptions of the expresser's emotions (i.e., perceived gratitude and love as well as perceived reward).

Specifically, immediately after the interaction, targets indicated their own positive emotions and their perceptions of the expresser's positive emotions, in succession, on a scale ranging from 0 (*not at all true/never true*) to 6 (*very true/true all of the time*). The emotions were *satisfied, loving, warm, appreciative, admiring, peaceful, open, amused, grateful, proud*, and *inspired*. Then the target rated 10 items to assess perceived responsiveness; example items included "My partner saw the 'real' me," "My partner valued my abilities and opinions," and "My partner respected me" (Gable, Gonzaga, & Strachman, 2006). These 10 items were averaged to create the primary outcome of *perceived expresser responsiveness* (α = .94). Regarding the emotion terms, analyses focused on the target's experienced love (secondary outcome) as well as his or her perception that the expresser experienced "loving" and "grateful" feelings while expressing his or her emotions (exploratory outcomes). To assess affective reward, we computed an average of the eight emotion terms not representing love or gratitude, both as experienced by the target (i.e., experienced reward) and perceived to be experienced by the expresser (i.e., perceived reward; αs = .72 and .79, respectively).

Because of a procedural error, these ratings were not obtained from 1 participant. Evaluation of outliers revealed that while there were some scores greater than 3 standard deviations below the mean for all dependent measures, an obvious gap separated the low outliers from the rest of the distribution in three variables in particular. Because, empirically as well as conceptually, these extremely low outlying scores did not represent the theoretical space under investigation, they were not included in analyses on the relevant variables. This resulted in three excluded values for perceived expresser responsiveness, two for experienced reward, and one for perceptions of partner's reward.[3] To be conservative, we retained all values for the individual emotion-term items (i.e., secondary and exploratory outcomes of experienced love and perceived expresser love and gratitude) because there was not a gap in the distribution accompanying the designation of greater than 3 standard deviations to corroborate the cutoff point for the conceptual difference of these low values from those in the rest of the sample.

Urine collection and storage procedure. At least 48 hr prior to the laboratory session, participants picked up a urine collection kit and received instructions from a member of the research team. The kit contained a plastic-lined cooler with ice packs, four opaque 1 L sealable bottles, and instructions. Each 1 L bottle contained sodium metabisulfite powder (~0.03 ounces/L), which served as a preservative and prevented oxidation over the 24-hr collection period. The day before the lab session, participants were asked to void their bladders on waking, note the time, and then collect all the urine they produced over the next 24-hr period, storing it in the bottles provided and keeping it cooled in a refrigerator or in the cooler. Participants returned urine in the coolers. On return, urine volume was combined and measured. For each analyte (oxytocin and creatinine), individual samples were centrifuged and stored at −80° C until all samples could be assayed in one batch.

Urinary oxytocin and creatinine assays. Urinary oxytocin was assayed using a commercial enzyme-linked immunosorbent assay (ELISA) kit (Enzo Life Sciences, Farmingdale, NY), purchased in May 2013. We employed the extraction procedure, which reduces matrix interference and concentrates the sample, as has been described previously (Grewen, Davenport, & Light, 2010); this approach is consistent with a growing consensus about recommended best practices (McCullough, Churchland, & Mendez, 2013, though see Carter, 2014). The lower level of detection for oxytocin was 1.2 pg/ml after extraction; extraction efficiency was 99%. Intra- and interassay coefficients of variation were 4.8% and 8%, respectively.

Oxytocin of the targets was the focus of the current investigation. One participant did not provide urine. Two other participants' oxytocin values were above the level the assay could detect, and we did not receive values from the analyst. These 3 participants were thus not included in analyses. Six values were just below the lowest level of detection (i.e., .98–1.05 pg/ml), and these values were Winsorized to 1.2 for analysis. Creatinine was assayed using the VITROS CREA slide method (Ortho-Clinical Diagnostics, Rochester, NY). Oxytocin values were computed by dividing oxytocin concentration (pg of oxytocin/ml of urine) by creatinine concentration (mg creatinine/dL urine), and are expressed as a ratio of oxytocin to creatinine (oxytocin pg/mg creatinine). This ratio was log-transformed to normalize the positively skewed distribution for statistical analyses.

Observed praising behavior of expressers. The expressers used many positively valenced statements, only some of which were other praising (see Algoe et al., 2016, for a full description of the procedure and code). Four trained judges watched the videos with sound on to document the other-praising behavior, using a 5-point scale to assess the extent to which the expresser used this behavior over the course of the entire conversation; the scale ranged from 1 (*no or one minor statement of praise*) to 5 (*excellent expression of benefactor's praiseworthiness*; intraclass correlation coefficient = .866).

Table 1. Descriptive Statistics for Study Variables

Variable	Range	*M*	*SD*
Perceived expresser responsiveness	3.60–6.00	5.45	0.59
Experienced love	2.00–6.00	5.46	0.78
Experienced reward	2.88–6.00	4.68	0.79
Perceived expresser gratitude	0.00–6.00	5.11	1.27
Perceived expresser love	2.00–6.00	5.36	0.87
Perceived expresser reward	1.38–6.00	4.41	0.96
Expresser's other-praising behavior	1.00–5.00	3.15	0.96
Urinary oxytocin (pg/mg Cr)	1.03–16.88	4.93	2.91
Urinary oxytocin (pg/mg Cr; log transformed)	0.01–1.23	0.63	0.24

Note: Values shown are for targets. Outliers greater than 3 standard deviations below the mean are excluded. The urinary oxytocin metric is oxytocin pg/mg creatinine (CR); nontransformed values are provided for reference, but log-transformed values were used in the analyses.

Results

See Table 1 for means and standard deviations for each dependent and independent variable. See Table S1 in the Supplemental Material for correlations between variables.

Oxytocin and psychological responses

To test the main effects of targets' urinary oxytocin on each outcome of interest, we conducted linear regressions with urinary oxytocin as the primary predictor and condition and gender as the control variables. See Table 2 for unstandardized regression coefficients and confidence intervals (CIs). Results from these models were consistent with hypotheses. Urinary oxytocin was significantly positively associated with the primary and secondary outcomes of interest, perceived expresser responsiveness ($p = .005$) and experienced loving as a result of the conversation ($p = .001$). In addition, exploratory analyses showed that oxytocin was significantly positively associated with perceptions of the theoretically relevant emotions of the partner—how grateful ($p = .027$) and loving ($p = .009$) the expresser felt. It was not, however, associated with the more general aggregated measures of experienced reward ($p > .250$), nor perceived expresser reward ($p > .250$).

Controlling for conversation duration, whether the couple lived together, or whether they were dating versus committed to the long term (i.e., engaged, married, or cohabiting) did not change the conclusions of any of these analyses. Controlling for relationship satisfaction did not change the conclusions about primary, secondary, or discriminant outcomes; however, the target's perceptions that the expresser felt grateful ($b = 0.92$, $p = .078$, 95% CI = [−0.11, 1.95]) and loving ($b = 0.64$, $p = .064$, 95% CI = [−0.04, 1.31]) were no longer significantly associated with oxytocin in these analyses.

Given our sample size and prior findings (Algoe et al., 2016; Algoe & Way, 2014), we had no predictions that gender or condition would moderate this main effect, but we tested that possibility for exploratory purposes. Neither gender nor condition moderated the association between urinary oxytocin and any of these outcomes, except in the case of perceptions of expressers' affective reward.[4]

Targets' Oxytocin × Expressers' Other-Praising Behavior

Previous research documented the cross-partner effect of expressers' other-praising behavior on the key outcome of the targets' perception of expresser responsiveness (Algoe et al., 2016), and here we tested whether this effect was moderated by targets' oxytocin. (See the Supplemental Material for exploratory tests of this effect on the secondary and exploratory outcomes, which were not the original focus of this research question.) To do so, we added two variables to the model used in the previous analyses: expressers' other-praising

Table 2. Unstandardized Regression Coefficients From Models Predicting Oxytocin's Effect on Targets' Psychological Responses to Expressers' Praise

Outcome	Oxytocin (pg/mg Cr)	Condition	Gender
Perceived partner responsiveness	0.69 [0.211, 1.177]**	−0.10 [−0.307, 0.118]	0.20 [−0.031, 0.438]
Experienced love	1.07 [0.456, 1.691]**	−0.05 [−0.315, 0.225]	0.10 [−0.196, 0.398]
Experienced reward	0.33 [−0.329, 0.991]	−0.14 [−0.432, 0.145]	0.24 [−0.072, 0.560]
Perceived expresser gratitude	1.16 [0.136, 2.183]*	−0.50 [−0.951, −0.054]	−0.10 [−0.594, −0.394]
Perceived expresser love	0.97 [0.248, 1.691]**	0.01 [−0.303, 0.328]	0.19 [−0.153, 0.541]
Perceived expresser reward	0.29 [−0.514, 1.093]	−0.03 [−0.320, 0.382]	0.12 [−0.265, 0.505]

Note: Total *df* in these models ranged from 117 to 120. Values given in brackets are 95% confidence intervals. Condition and gender were included as covariates in all analyses. CR = creatinine.
*$p < .05$. **$p < .01$.

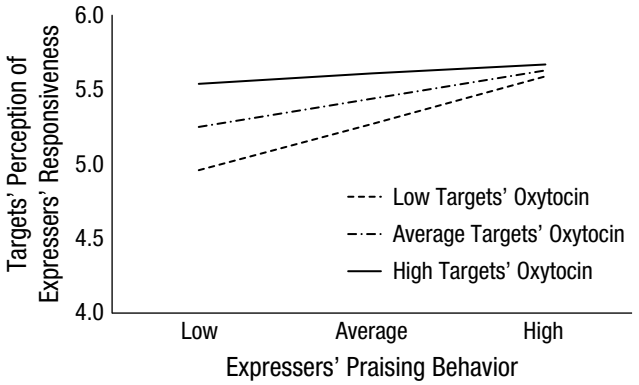

Fig. 2. Targets' mean perception of expressers' responsiveness as a function of expressers' praising behavior and level of targets' circulating oxytocin. *Low* and *high* refer to values 1 standard deviation below and above the mean, respectively.

behavior and the interaction term computed by multiplying expressers' other-praising behavior with targets' oxytocin. We used the PROCESS macro in SPSS (Hayes, 2013), which allowed us to automatically center the variables to facilitate interpretation of the data, to use bootstrapping to estimate the average effect from 5,000 samples, and to test simple slopes within the interaction if the overall interaction was significant. The interaction term was significant, $b = -0.58$, $p = .037$, 95% CI = [−1.12, −0.04], $t(107) = -2.11$. See Figure 2 for a depiction of the interaction at, above, and below 1 standard deviation from the mean of oxytocin.

The pattern of interaction is consistent with the possibility that high levels of circulating oxytocin, indexed by 24-hr urine concentration, facilitated perceptions of expresser responsiveness: For targets with high oxytocin, perceptions of the expresser's responsiveness did not depend on the expresser's behavior in that specific interaction, $b = 0.07$, $p = .410$, 95% CI = [−0.10, 0.23], $t(107) = 0.83$. However, for targets with average or low levels of oxytocin, the expresser's behavior mattered: Only those targets whose partners made use of other-praising behavior perceived that expression of gratitude as being responsive. For targets with average and low levels of oxytocin, the simple effect was statistically significant—average: $b = 0.21$, $p = .001$, 95% CI = [0.09, 0.32], $t(107) = 3.50$; low: $b = 0.35$, $p < .001$, 95% CI = [0.16, 0.53], $t(107) = 3.71$.

All conclusions held when we controlled for conversation duration, relationship satisfaction, whether the couple lived together, or whether they were dating versus committed to the long term (i.e., engaged, married, or cohabiting). Additionally, out of curiosity, we used the Johnson-Neyman technique (Johnson & Fay, 1950) to further assess the implications of these findings: This analysis showed that about 29% of this sample had oxytocin levels high enough that perceptions of their partner's responsiveness were not significantly associated with the partner's behavior. That translates to oxytocin pg/mg creatinine values greater than about 5.72 in our sample.

Discussion

We provide the first evidence linking levels of naturally occurring oxytocin with subsequent subjective psychological responses to a social behavior—expressed gratitude—that is uniquely implicated in promoting bonds between human adult romantic partners. These specific psychological responses are precisely those that should prompt the person's future investment and interest in the relationship (e.g., Algoe et al., 2013; Gonzaga et al., 2001; Reis et al., 2004). Notably, for people with high circulating oxytocin over the prior 24 hr, their partner's behavior when expressing gratitude was not associated with perceptions of that partner's responsiveness. One limitation of these cross-sectional correlational data is that our hypotheses are about oxytocin's causal role in facilitating bonding, but we cannot rule out the possibility that habitual high-quality interactions were the cause of greater cumulative levels of oxytocin. Our statistical controls help alleviate this concern somewhat, but this is the kind of important empirical question that we hope the present theoretical and methodological approaches will help address in future research.

Specifically, rather than focus on global evaluations of the relationship, we took a cue from original work (Williams et al., 1992) that examined proximal mechanisms for bonding, and we focused on the specific affective and relationship constructs involved in that process; in the future, such an approach may help address equivocal results regarding oxytocin's effects on relationship outcomes, broadly defined (e.g., Taylor et al., 2010). Additionally, one prior experiment, showing that intranasal oxytocin increased subjective experiences of attraction but not positive mood after participants viewed photos of male and female strangers, raises the possibility that the dissociated effects among "good" outcomes of perceived responsiveness and affective reward seen here and in the findings of Algoe and Way (2014) will generalize beyond the close-relationship context (Theodoridou, Rowe, Penton-Voak, & Rogers, 2009).

The pattern of the interaction between targets' oxytocin and expressers' praise predicting perceived responsiveness (and love; see the Supplemental Material) appears more consistent with the possibility that oxytocin offers "rose-colored glasses" for bonding opportunities with close others than that it makes people more

attuned to their social cues (Shamay-Tsoory & Abu-Akel, 2016). However, the latter social-salience hypothesis draws heavily from considerations of dopamine and reward, and it does appear more consistent with the pattern of effects presented in the Supplemental Material for the specific outcome of affective reward. There are multiple pathways to bonding, and we look forward to future research on this possible dissociation with regard to the effects of oxytocin on positive outcomes. The current study did not directly test hypotheses from any of the several prominent accounts of oxytocin's role in social life (e.g., see the thoughtful review of three explanations by Bartz et al., 2011); however, we are hopeful that the additional theoretical considerations we discuss here, from affective and relationship science, will help inform such reviews going forward. In addition, all the tested interactions—including those used to investigate gender differences—would benefit from increased sample sizes to further enhance the reliability of estimates and confidence in conclusions.

Though we await replication of our findings, we see the current data as promising initial evidence for the coevolved proximal mechanisms through which oxytocin facilitates potentially life-enhancing connections (Holt-Lunstad et al., 2010). The current findings are also a useful jumping-off point for future research targeting oxytocin's role not only in attenuating negative and physically distressing responses (e.g., Ditzen et al., 2009), but in growth processes as well (Lestanova et al., 2016).

Action Editor

Steven W. Gangestad served as action editor for this article.

Author Contributions

S. B. Algoe conceived and designed the study. K. Grewen helped develop the method for collecting 24-hr urine and oversaw data collection, storage of urine, and assay of oxytocin and creatinine. L. E. Kurtz helped collect the data. S. B. Algoe analyzed the data and drafted the manuscript, and L. E. Kurtz and K. Grewen provided critical revisions. All authors approved the final version of the manuscript for submission.

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Declaration of Conflicting Interests

The authors declared that they had no conflicts of interest with respect to their authorship or the publication of this article.

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Supplemental Material

Additional supporting information can be found at http://journals.sagepub.com/doi/suppl/10.1177/0956797617716922

Open Practices

As discussed by Finkel, Easwick, and Reis (2015), publicly sharing data from studies of romantic couples risks violating participants' confidentiality, as one spouse may identify his or her partner's data. In addition, our consent agreement with participants did not state that their data would be widely distributed. For these reasons, we chose not to apply for an Open Data badge. The instructions for reproducing some of the methods (e.g., processing of the urine samples) requires specialized training by an experienced laboratory technician. We can provide interested researchers with all verbal instructions given to participants and the questionnaires they responded to, but not the additional training required, so we did not apply for an Open Materials badge. The complete Open Practices Disclosure for this article can be found at http://journals.sagepub.com/doi/suppl/10.1177/0956797617716922. More information about the Open Practices badges can be found at http://www.psychologicalscience.org/publications/badges.

Notes

1. We consider love and gratitude as two different facets of the bonding process, on the basis of emotion theory; though the present study was not designed to test differences between them, that theorizing informs our methodological rationale.
2. We acknowledge that the study by Schneiderman et al. (2012) relied on unextracted samples of oxytocin, a method that has generated criticism (McCullough et al., 2013) and defense (Carter, 2014). In fact, each study reviewed in this section relied on a different method for measuring or manipulating the oxytocin system, and researchers agree that each has its strengths and limitations for inference. This further justifies our conclusion that more data are needed on oxytocin's role in adult human bonding processes before strong conclusions can be drawn. The current study uses yet another method (see the Design and Procedure section) to carefully build on recent findings.
3. See the Supplemental Material for results when these values are included.
4. Controlling for gender, we found that condition significantly interacted with circulating oxytocin to predict perception of expresser's affective reward from the interaction ($b = -1.53$, $p = .039$, 95% CI = [−2.97, −0.08]). The simple effects of oxytocin on perceived reward were not significant within either condition. However, there was a trend within the condition in which the expresser was instructed to emphasize the benefits to the self that implied that targets with higher oxytocin were more likely to perceive this affective reward ($b = 0.95$, $p = .065$, 95%

CI = [–0.06, 1.96]). Given the unexpected nature of the finding and the marginally significant trend, we will not interpret this further.

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