Oxytocin and Social Bonds:

The Role of Oxytocin in Perceptions of Romantic Partner Bonding Behavior

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Abstract

This research tests 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 upon recent theory from affective and relationship science to identify a well-defined bonding context for human romantic relationships. We then pair 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-hours was associated with greater perceptions of expresser responsiveness and gratitude, greater experienced love, but not general affective reward. Moreover, in this one-time conversation, higher oxytocin appeared to serve as rose-colored glasses, attenuating the effect of a partner's behaviorally-coded expressive behavior on perceptions of expresser responsiveness. Results justify future research on the role of oxytocin in psychological aspects of growth processes.

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One of the most provocative series of studies implicating oxytocin in social bonds came from 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., 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 bio-behavioral system that co-evolved 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 smoking and larger than obesity (Holt-Lunstad, Smith, & Layton, 2010) -- basic research on the specific bio-psycho-social mechanisms through which bonds are forged and strengthened becomes all the more important.

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., Fredrickson, 2013; Gable & Reis, 2001; Algoe, Fredrickson, & Gable, 2013). 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 in to 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, in two studies, benefactors who *perceived responsiveness* when a romantic partner expressed gratitude to them in a one-time laboratory conversation reported greater future relationship satisfaction one or six months later (Algoe et al., 2013; Algoe &

[1] We consider love and gratitude as two different facets of the bonding process, based on emotion theory; though this study is not designed to test differences between them, that theorizing informs our methodological rationale.

Zhaoyang, 2015). Critically, this effect was independent from effects of perceiving responsiveness after various other types of interactions with the partner, suggesting that the behavior of expressing gratitude and perceptions of the grateful expresser's responsiveness uniquely foster relational growth.

As such, a more recent study carefully investigated expressions of gratitude to understand how they likely 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 Figure 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).

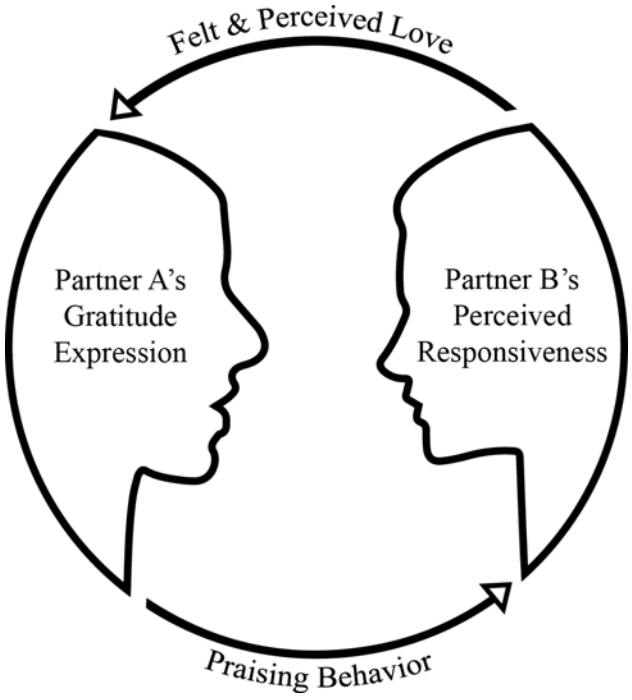

Figure 1. Components of adult human bonding through gratitude: Partner A's expression of gratitude – particularly when it includes praise of Partner B's actions – is associated with Partner B's perception of the expresser's responsiveness (primary outcome), as well as experienced love (secondary outcome; Algoe et al., 2016). In turn, perceived expresser responsiveness is associated with Partner B's future personal and relationship satisfaction (Algoe et al., 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 and 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). As such, we focused our literature search according to the theoretical question at hand (e.g., Williams et al., 1992): Only four studies measure or manipulate oxytocin and subsequently measure *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 positively links plasma oxytocin with self-reported hugging of the partner (Light et al., 2005) and another with the couples' collective behaviors within a live social interaction (Schneiderman et al., 2012).[2]

Here, we are interested in the subjective psychological response to the interaction, to focus 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 studies 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, Heinrichs, Bergmann, Jung, Germann, Schedlowski, et al., 2014, using intranasal oxytocin administration). At first blush, such positive associations may seem to run contrary to well-cited evidence by Taylor and colleagues (2010) regarding associations between oxytocin in (women's) global ratings of interpersonal *distress*. However, we reiterate that the present research question is different: *when 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 attention on the role of oxytocin in the cross-partner *process* of bonding: does oxytocin influence the previously

[2] We acknowledge that this study relied on unextracted samples of oxytocin, a method that has generated criticism (McCullough, Churchland, & Mendez, 2013) and defense (Carter, 2014). In fact, each study reviewed in this section relies 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 the question of oxytocin's role in adult human bonding processes before strong conclusions can be drawn. The current study uses yet another method (procedure and potential strengths are described below) to carefully build on recent findings.

documented positive association between expresser praising behavior and perceived expresser responsiveness (Algoe et al., 2016)? If higher oxytocin levels lead to more favorable situational partner evaluations, such evaluations may not be as contingent on expresser 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., social salience hypothesis; Shamay-Tsoory & Abu-Akel, 2016), which would suggest a *stronger* association between partner praise and benefactor perceptions of responsiveness with higher oxytocin levels. Whichever pattern, we test the hypothesis that the previously documented association between expresser praise and benefactor perceptions of expresser responsiveness is moderated by benefactor oxytocin.

The Current Research

Building on early research (Williams et al., 1992), we advance 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 predict significant positive associations between benefactor's 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 explore associations between oxytocin and the novel outcome of perceived emotions of the expresser, namely perceived expresser gratitude, love, and

general affective reward. Finally, we test the hypothesis that oxytocin moderates the previously observed cross-partner association between expresser praising behavior and the key outcome of benefactor's 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, NC region for a study on "everyday couple interactions." Additional eligibility criteria included: the couple must have been together for at least one year; participants must have not been recently diagnosed with anxiety or depression, nor could they be taking steroid medication; women were pre-menopausal, not currently pregnant or nursing, not pregnant in the prior six months, and had not had an oophorecromy. Most couples were dating (76.7%; with 23.3% reporting that they were married, engaged to be married, 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 to 50), predominantly Caucasian (70.9%) and non-Hispanic (90.7%), with 11.2% self-identifying as being of East Asian descent, 7.4% African-American, 4.7% South Asian, and 5.8% indicating various other racial or ethnic backgrounds.

Design and Procedure

In this observational study, each member of the couple collected a 24-hour urine sample the day before attending the laboratory session together. This 24-hour urine sampling method was selected because it is non-invasive, free from the stress and pain of needle-stick (which may independently affect oxytocin levels; Eliava et al., 2016), and is

a cumulative assessment over the course of 24-hours that 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 and to various stimuli throughout the day (e.g., Eliava et al., 2016; Stuebe, Grewen, & Meltzer-Brody, 2013). Therefore, a urinary mean over 24 hours may more likely reflect participants' overall peripheral levels and serve as a cumulative index of oxytocin (Reyes, Galinsky, Hoffmann, You, Ziegler, & McClintock, 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 (that is, the benefactor who had originally done the kind thing for the expresser) reported on a range of positive emotions, perceptions of the expresser's positive emotions, and perceptions of the expresser's responsiveness to the self. Each video recording was later viewed by four trained judges who coded the expresser's other-praising behavior within the expression. Urine was assayed for oxytocin (OT) and creatinine (CR). Oxytocin is expressed as a ratio of oxytocin to creatinine to adjust for between-person differences in urine concentration. Creatinine is secreted in a steady state by the kidneys and is a direct reflection of urine concentration (Reyes, et al., 2014). Hypotheses and analyses focus 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 hypothesized associations between oxytocin and perceptions, if moderate in size, at 94% power, so all available urine

samples were assayed. Please see Supplementary Online Materials (SOM) for more information about other procedures.

Behavioral Gratitude Task

Using a standard paradigm for observing naturalistic couple conversations, participants were asked to pick something their partner had done for them recently, for which they felt grateful; instructions for this specific task are documented elsewhere (Algoe, Fredrickson, & Gable, 2013; Algoe & Way, 2014; Algoe & Zhaoyang, 2015; Algoe, et al., 2016). Each person selected the event and rated its importance before they were 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 target perceptions of responsiveness, expressers in one condition were asked to focus more on the praiseworthiness of the benefactor's actions (e.g., how thoughtful the benefactor was) whereas in the other condition, they were asked to focus more on how the event benefitted the self (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 collapse across condition but control for this factor in analyses (see SOM for more information as well as Results for report 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 [target] did for [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 is *perceived expresser responsiveness*, with the secondary outcome being *experienced love*. To probe the theoretical specificity of the proposed associations (i.e., 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 explore 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 include "My partner saw the 'real' me", "My partner valued my abilities and opinions", "My partner respected me" (Gable, Gonzaga, & Strachman, 2006). These 10 items were averaged to create the primary outcome of *perceived expresser responsiveness* ($\alpha = .94$). Regarding the emotion terms, analyses will

focus in on the target's experienced "loving," (secondary outcome) as well as perceiving that the expresser experienced "loving" and "grateful" while expressing (exploratory outcomes). To assess affective reward, we computed an average of the 8 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; $\alpha = .72$ and .79, respectively).

Due to a procedural error, these ratings were not obtained from one participant. Evaluation of outliers revealed that, while all dependent measures in Table 1 had some scores greater than 3SD below the mean, three variables in particular showed an obvious gap separating the low outliers from the rest of the distribution as well; because empirically as well as conceptually these extremely low outlying scores do not represent the theoretical space under investigation, they are not included in analyses on the relevant variables. This results in three excluded values for perceived expresser responsiveness, two for experienced reward and one for perceptions of partner's reward.[3] To be conservative, all values are retained 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 >3SD designation to corroborate the cut 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 hours 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, as well as instructions. Each 1 L bottle contained sodium

[3] See SOM for results when these values are included.

metabisulfite powder (~.03 ounces/L), which served as a preservative and prevented oxidation over the 24-hour collection period. The day before the lab session, each participant was to void the bladder upon waking, note the time, then collect all urine produced over the next 24-hour period, storing it in the bottles provided, and keeping it cooled in a refrigerator or the cooler. Participants returned urine in provided coolers. Upon return, total urine volume was combined and measured. Aliquots for oxytocin and creatinine were centrifuged and stored at -80 degrees Centigrade until batch assay for each analyte.

Urinary oxytocin and creatinine assays. Urinary oxytocin was assayed using a commercial ELISA kit with extraction (Enzo Life Sciences, Farmingdale, NY) purchased in May 2013. The addition of the extraction procedure, which reduces matrix interference and concentrates the sample, 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). Lower level of detection for oxytocin was 1.2 pg/ml after extraction; extraction efficiency was 99%; intra- and inter-assay coefficients of variation were 4.8% and 8%, respectively.

Oxytocin of the targets was the focus of the current investigation. One did not provide urine and two participants' oxytocin values were so high that they were above the level of detection by the assay and we did not receive values from the analyst. These three participants are 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 windsorized to 1.2 for analysis. Creatinine was assayed by 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 Cr). This ratio was log-transformed to normalize the positively skewed distribution for statistical analyses.

Observed expresser praising behavior. The expressers used many positively-valenced statements, only some of which were other-praising (see Algoe et al., 2016 for full description of the procedure and code). Four trained judges watched the videos with sound on to document the other-praising behavior, using a five-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); ICC = .866.

Results

Descriptive Statistics

See Table 1 for means and standard deviations for each dependent and independent variable. See SOM for table of correlations among measured variables.

Table 1. Means and standard deviations of study variables

	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 OT (pg/mg Cr)	1.03 – 16.88	4.93	2.91
Urinary OT (pg/mg Cr) – log-trans	0.01 – 1.23	0.63	0.24

Note. Outliers were excluded when presenting the range, means, and standard deviations of the relevant variables used in analyses; see Method for more information. Urinary OT (oxytocin) metric is Oxytocin pg/mg CR; non-transformed values are provided for reference; log-transformed (log-trans) values were used in analyses.

Oxytocin and Psychological Responses

To test the main effects of target's 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 the first column of Table 2 for standardized regression coefficients and confidence intervals for the effect of urinary oxytocin on each outcome. From these models, 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 conclusions of any of these analyses. Controlling for relationship satisfaction did not change conclusions about primary, secondary, or discriminant outcomes, however, target's perceptions that the expresser felt grateful (β = .17, p = .078, CI[-.11, 1.95]) and loving (β= .17, p = .064, CI [-.04, 1.31]) were no longer significantly associated with oxytocin in these analyses.

Table 2. Standardized regression coefficients and 95% confidence intervals from models regarding the benefactor's psychological responses to the conversation

	Oxytocin (pg/mg Cr)	Condition	Gender
	β, [95%CI]	*β,* [95%CI]	*β,* [95%CI]
Perceived partner responsiveness	.28, [.211, 1.177]**	-.08, [-.307, .118]	.17, [-.031, .438]
Experienced love	.34, [.456, 1.691]**	-.03, [-.315, .225]	.07, [-.196, .398]
Experienced reward	.10, [-.072, .991]	-.09, [-.432, .145]	.16, [-.072, .560]
Perceived expresser gratitude	.22, [.136, 2.183]*	-.20, [-.951, -.054]	-.04, [-.594, .394]
Perceived expresser love	.27, [.248, 1.691]**	.01, [-.303, .328]	.11, [-.153, .541]
Perceived expresser reward	.07, [-.514, 1.093]	-.02, [-.320, .382]	.06, [-.265, .505]

Note. Total *df* in these models ranged from 117-120. Condition and gender were included as covariates in all analyses. *$p < .05$, **$p < .01$

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

Target Oxytocin X Expresser Other-Praising Behavior

Previous research documented the cross-partner effect of expresser's other-praising behavior on the key outcome of the target's perception of expresser responsiveness (Algoe et al., 2016), and here we test whether this effect was moderated

[4] Controlling for gender, condition significantly interacted with circulating oxytocin to predict perception of expresser's affective reward from the interaction ($B = -1.53$, $p = .039$, CI[-2.97, -.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 targets with higher oxytocin were more likely to perceive this affective reward ($B = .95$, $p = .065$, CI[-.06, 1.96]). Given the unexpected nature of the finding and marginally significant trend, we do not interpret this further.

by target's oxytocin. (See SOM 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 above: expresser other-praising behavior and the interaction term computed by multiplying expresser other-praising behavior with target's 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 5000 samples, and to test simple slopes within the interaction, if the overall interaction was significant. The interaction term was significant: B = -.58, t(107) = -2.11, p = .037, 95%CI [-1.12, -.04]. See Figure 2 for depiction of the interaction, using values at, above, and below 1 SD beyond 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 those with high oxytocin, perceptions of expresser responsiveness did not depend on the expresser's behavior in that specific interaction: B = .07, t(107) = 0.83, p = .410, 95%CI [-.10, .23]. However, for those 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 those targets with average and low levels of oxytocin, the simple effect was statistically significant: B = .21, t(107) = 3.50, p = .001, 95%CI [.09, .32], for those with average, and B = .35, t(107) = 3.71, p < .001, 95%CI [.16, .53] for those with low levels of oxytocin.

All conclusions hold when controlling 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 Cr values greater than about 5.72 in our sample.

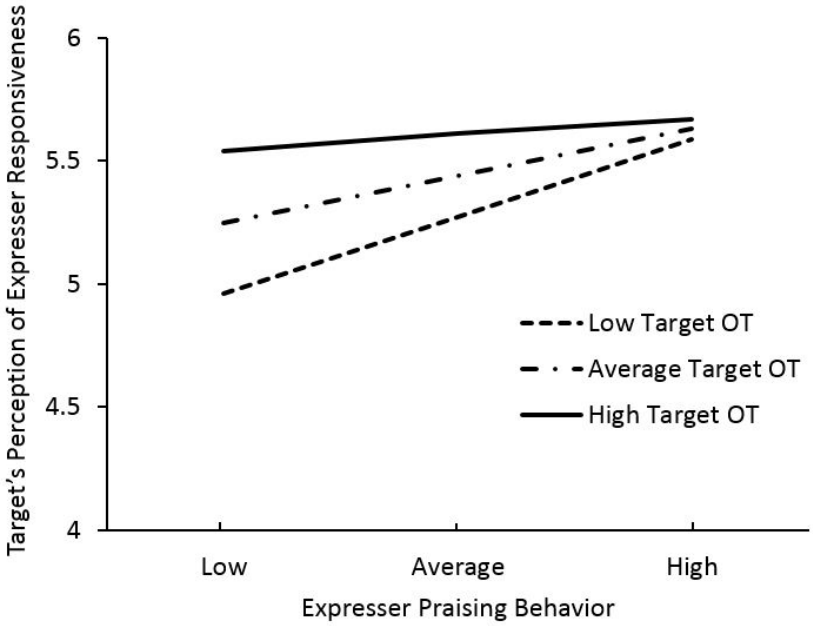

Figure 2. Effect of expresser's praising behavior on target's perception of expresser responsiveness, moderated by target's circulating oxytocin at low (-1 SD), average, and high (+1 SD) values.

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-hours, their partner's behavior when expressing gratitude was not associated with perceptions of expresser 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 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 viewing photos of male and female strangers, raises the possibility that the current dissociated effects among "good"

outcomes of perceived responsiveness and affective reward seen here and in Algoe & Way (2014) will generalize beyond the close relationship context (Theodoridou, Rowe, Penton-Voak, & Rogers, 2009).

The pattern of the interaction between target oxytocin and expresser praise predicting perceived responsiveness (and love, presented in the SOM) 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 does appear more consistent with the pattern of effects presented in the SOM 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 (see three explanations thoughtfully reviewed in Bartz et al., 2011, for example), 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 testing for gender differences -- would benefit from increased sample sizes to further increase the reliability of estimates and confidence in conclusions.

Though we await replication, we see the current data as promising initial evidence for the co-evolved proximal mechanisms through which oxytocin facilitates potentially life-enhancing connections (Holt-Lunstad et al., 2010), and a useful jumping-off point for future research targeting oxytocin's role, not only in attenuating negative and physically

distressing responses (e.g., Ditzen, Schaer, Gabriel, Bodenmann, Ehlert, & Heinrichs, 2009), but in growth processes as well (Lestanova, Bacova, Kiss, Havranek, Strbak, & Bakos, 2015).

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Author Contributions

S. B. Algoe developed the study concept and design. K. Grewen contributed to the development of the method for collecting 24-hr urine, oversaw data collection, and storage or urine as well as assay of oxytocin and creatinine. L. E. Kurtz contributed to data collection. S. B. Algoe analyzed the data, drafted the manuscript, and L. E. Kurtz and K. Grewen provided critical revisions. All authors approved the final version of the manuscript for submission.

Supplementary Online Material: Oxytocin and Social Bonds

Design and additional procedural details

After each member of the couple was independently screened via online questionnaire, both members of the couple individually completed an online questionnaire, collected a 24-hour urine sample, then attended this lab session together with the partner. At the laboratory session, we also collected saliva and resting measures of psychophysiology, and couples completed a series of tasks. Consistent with the resource-intensive nature of this type of research, data were collected for multiple purposes (see Finkel, Eastwick, & Reis, 2015); please contact the first author for more details about measures.

In the original study (Algoe, Kurtz, & Hilaire, 2016), prior to the conversation, without the target's knowledge, the expresser was randomly assigned to one of two sets of instructions about what to emphasize during the expression of gratitude, either "the praiseworthiness of your partner's actions" or "the positive outcome you personally received in the situation." Because that publication documents that the manipulation did not affect perceptions of expresser responsiveness, we did not have predictions that the proposed effects in the current study would be moderated by condition. Therefore, we collapse across condition but control for this factor in analyses. (However, the moderated analysis we report in the manuscript, using praising behavior as a continuous – rather than manipulated – variable is conceptually the same.)

Of the variables in the present investigation, target's oxytocin– the independent variable - has not been reported elsewhere. Expresser's praising behavior, target's perception of expresser responsiveness, target's experienced positive emotions, and target's perception of expresser's aggregated positive emotions were each reported in Algoe, Kurtz, & Hilaire, 2016 (Study 2, Sample A). However, the multiple studies in that manuscript addressed a different research question. Specifically, that manuscript established the association between expresser praising behavior and target's perception of expresser responsiveness as well as positive emotions. The current hypothesis concerns oxytocin and had not yet been tested. Specifically, here, we test whether several outcomes are associated with oxytocin (main effects) and whether the association between praising behavior and target's perception of expression of responsiveness is moderated by target's oxytocin. Supplementary exploratory analyses (reported below) report results of this moderation test for the target's positive emotions.

Additional Analyses

1. Supplementary Table 1. Correlations among all measured variables used in analyses

Measures	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.
1. Perceived expresser responsiveness	--										
2. Experienced love	.57**	--									
3. Experienced reward	.62**	.46**	--								
4. Perceived expresser gratitude	.42**	.36**	.40**	--							
5. Perceived expresser love	.57**	.55**	.49**	.38**	--						
6. Perceived expresser reward	.51**	.46**	.77**	.44**	.58**	--					
7. Expresser's other-praising behavior	.24**	.26**	.23*	.15	.25**	.33**	--				
8. Urinary OT (pg/mg Cr) – log-trans	.20*	.28**	.03	.24**	.23*	.03	-.03	--			
9. Relationship satisfaction	.42**	.28**	.35**	.21*	.38**	.32**	.12	.18*	--		
10. Live together	.17	.00	.13	.02	.02	-.05	-.10	.06	.14	--	
11. Relationship status	.20*	.19*	.14	.04	.04	-.01	.08	.11	.18*	.53**	--
12. Conversation duration	.16	.10	.15	.10	.19*	.23**	.31**	-.09	.05	-.11	-.10

Note. As noted in the manuscript, three variables – perceived expresser responsiveness, target's experienced reward and perceptions of expresser reward – originally contained outliers and they were removed for these analyses. Live together: 1 = yes, 0 = no; Relationship status: 1 = cohabiting, engaged, married, 0 = dating exclusively

*$p < .05$, **$p < .01$

2. Results of exploratory moderation tests on two outcomes examined in Algoe, Kurtz, & Hilaire (2016).

The moderation analysis in the manuscript focused on the primary outcome of perceived partner responsiveness because it is the outcome from these interactions that has been the focus of theory about gratitude's role in social life (i.e., the "relational currency" through which gratitude is proposed to operate; Algoe, 2012) and has been supported by evidence that this response to being a target of an expression of gratitude forecasts the target's future positive evaluation of the relationship (Algoe et al., 2013; Algoe & Zhaoyang, 2015). However, it was also prompted by recent evidence to support the hypothesis that gratitude expressions with *greater expresser use of praising behavior* would be associated with greater target perceptions of expresser responsiveness (i.e., that the target feels understood, validated, and cared for by the expresser; Algoe et al., 2016).

Of interest, that recent publication also tested a question about a secondary outcome – whether praising is also more likely to simply make the target feel good. Indeed, in that research, expresser's other-praising behavior was significantly positively associated with both the theoretically specific experience of love as well as with more general affective reward (Algoe et al., 2016). Theoretically, such outcomes may generate additional paths through which relationships are fortified, per Fredrickson's broaden-and-build theory of positive emotions (Fredrickson, 2013), and Gonzaga and other researchers' focus on love as a commitment device (e.g., Fletcher, Simpson, Campbell, & Overall, 2015; Gonzaga, Keltner, Londahl, & Smith, 2001; Gonzaga, Turner, Keltner, Campos, & Altemus, 2006). As such, it is important to continue to examine their role in this particular interpersonal process.

In the present investigation, however, we are especially focused on the potential influence of *oxytocin* on subjective psychological outcomes from the expression. Therefore, predictions for moderation of the expresser behavior-target emotion link are less clear. One study – using genotyping of the *CD38* gene - provides indirect evidence that oxytocin is associated with experienced *love* but not with *general affective reward* after being the target of an expression of gratitude (Algoe & Way, 2014).

Here, to build on this nascent body of work, we conduct exploratory tests of whether the previously documented associations between expresser praise and (a) experienced loving as well as (b) affective reward after the interaction (Algoe et al., 2016) are moderated by the target's oxytocin. The models used here are analogous to the primary model in the manuscript that uses perceived expresser responsiveness as the outcome. All conclusions hold when controlling for conversation duration, whether the couple lived together, whether they were dating versus committed to the long term, and relationship satisfaction.

(a) Experienced love

The interaction between target oxytocin and expresser praising behavior was significant: B = -.81, t(109) = -2.41, p = .018, 95%CI [-1.48, -.14]. The pattern of effects here was similar to that observed for perceived expresser responsiveness (see manuscript Figure 1). It appears that high levels of circulating oxytocin, indexed by 24-hr urine concentration, facilitated experiences of love: for those with high oxytocin, experienced love did not depend on the partner's behavior in that specific interaction: B = .07, t(109) = 0.72, p > .250, 95%CI [-.13, .27]. However, for those with average or low levels of oxytocin, the expresser's behavior mattered: only those whose partners made use of other-praising behavior felt greater love as a result of the interaction. For those with average and low levels of oxytocin, the simple effect was statistically significant: B = .27, t(109) = 3.78, p < .001, 95%CI [.13, .40], for those with average, and B = .46, t(109) = 4.06, p < .001, 95%CI [.23, .68] for those with low levels of oxytocin.

(b) Experienced general positive emotions (i.e., the average post-interaction rating of: satisfied, warm, admiring, peaceful, open, amused, proud, and inspired)

The interaction between target oxytocin and expresser praising behavior was significant: B = .83, t(108) = 2.17, p = .032, 95%CI [-.07, 1.59]. The pattern of effects here was different than that observed for perceived expresser responsiveness (see Supplementary Figure 1). It appears that low levels of circulating oxytocin, indexed by 24-hr urine concentration, left targets unfazed by the expresser's behavior: for those with low levels of oxytocin, experienced affective reward did not depend on the partner's behavior in that specific interaction: B = -.01, t(108) = -0.08, p > .250, 95%CI [-.26, .25]. However, for those with average or high levels of oxytocin, the expresser's behavior mattered: those whose partners made use of other-praising behavior experienced greater affective reward from the interaction. For those with average and high levels of oxytocin, the simple effect was statistically significant: B = .19, t(108) = 2.37, p = .020, 95%CI [.03, .34], for those with average, and B = .38, t(108) = 3.45, p < .001, 95%CI [.16, .60] for those with high levels of oxytocin.

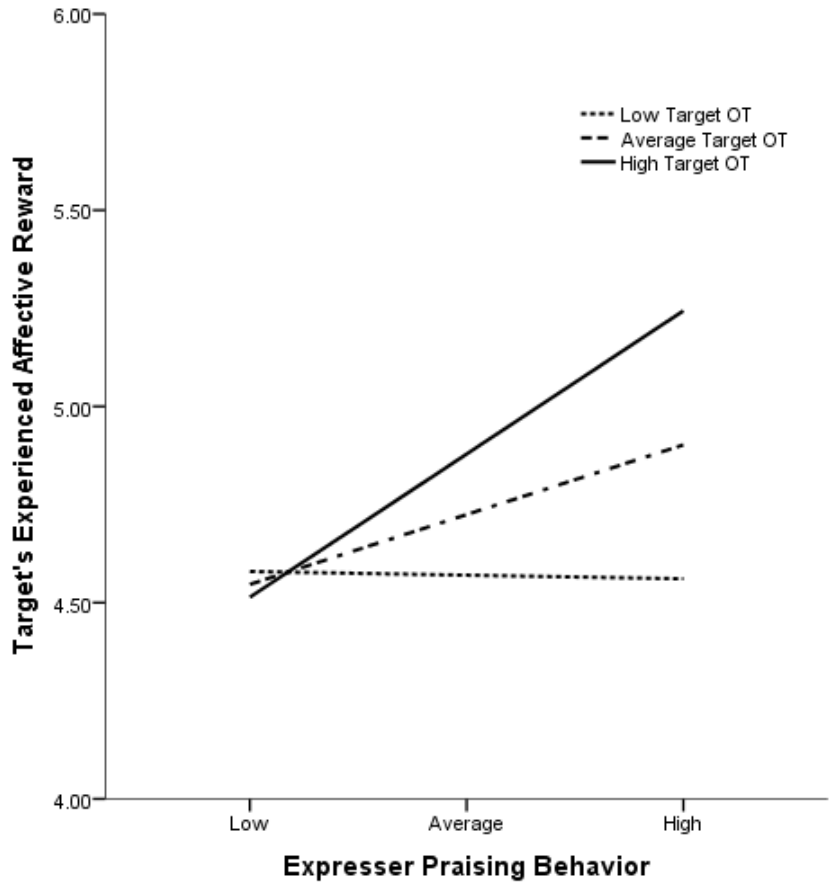

Figure 1. Effect of expresser's praising behavior on target's experienced affective reward, moderated by target's circulating oxytocin at low (-1 SD), average, and high (+1 SD) values.

In summary, target-experienced love followed the same pattern as perceived expresser responsiveness reported in the manuscript. One interpretation of those results is that greater oxytocin serves as rose-colored glasses to color "bonding-centric" subjective psychological experiences and buffer against relatively lower-quality partner behavior within the one-time expression of gratitude. General affective reward, however, followed the opposite pattern: people with low oxytocin levels were unfazed by use of praising behavior and generally did not experience these interactions as rewarding, whereas greater oxytocin levels were associated with greater responsivity to praise in the context of this social interaction. One interpretation of this pattern of effects is that oxytocin also helps people *extract more reward* from high-quality social interactions (see Isgett, Kok, Baczkowski, Algoe, Grewen, & Fredrickson [2017] for a similar point, as well as Shamay-Tsoory & Abu-Akel [2016]). Of course, such rewards likely have downstream effects for the individual and the dyad. If replicated, this dissociated pattern of effects suggests two different but complementary processes through which oxytocin influences social bonds.

3. **Results of exploratory moderation tests on novel exploratory outcomes: perceptions of expresser emotions.**

Inferences targets made about the expresser's emotions during the interaction were exploratory outcomes: does the predicted effect of oxytocin's influence on one's own experiences extend to the perceived experiences of the partner? Here, to be complete, we further explore whether these associations are systematically contingent on expresser behavior. In theory, greater praising behavior within an expression of gratitude may be associated with greater perceived gratitude (Algoe & Haidt, 2009) so the significant association between target oxytocin and perceptions of gratitude documented in the manuscript may be moderated by expresser praise in the same way as the perception of expresser responsiveness was. Expressed love is not the central focus of the interaction, though perceived love of the expresser likely tracks closely with perceived expresser gratitude as well as one's own experience of love, so may follow a similar pattern as those two variables. Perceived general affective reward may follow a similar pattern as experienced general affective reward. The results of analogous tests to those conducted for perceived responsiveness in the manuscript are presented in Supplementary Table 2. All conclusions hold when controlling for conversation duration, whether the couple lived together, whether they were dating versus committed to the long term, and relationship satisfaction.

Supplementary Table 2. Standardized regression coefficients and 95% confidence intervals around the interaction term and simple effects of expresser praising on each outcome at three levels of oxytocin

	Interaction term *B,* [95%CI]	**@lowOT** *B,* [95%CI]	**@avgOT** *B,* [95%CI]	**@highOT** *B,* [95%CI]
Perceived expresser gratitude	-1.04 [-2.19, .11]	.58 [.20, .97]**	.33 [.09, .57]**	.08 [-.25, .42]
Perceived expresser love	-0.05 [-.85, .75]	.31 [.04, .57]*	.29 [.13, .46]***	.28 [.05, .52]*
Perceived expresser reward	0.80 [-.06, 1.67]	.11 [-.18, .40]	.30 [.12, .48]***	.49 [.24, .74]***

Note. @lowOT = simple effect when oxytocin is < 1SD below the mean; @avgOT = simple effect at mean levels of oxytocin; @highOT = simple effect when oxytocin is > 1SD above the mean; * $p < .05$, ** $p < .01$, *** $p \leq .001$

(a) Perceived expresser gratitude

The interaction between target oxytocin and expresser praising behavior was not statistically significant, though trending toward it: t (108) = -1.80, p = .075. As the coefficients in Table S2 clarify, similar to the results for perceived responsiveness, targets with high circulating oxytocin perceived greater gratitude in the expresser regardless of the expresser's behavior, but for those who had average and low levels of oxytocin, their perceptions of expresser gratitude was significantly contingent on expresser praising behavior.

(b) Perceived expresser love

The interaction between target oxytocin and expresser praising behavior was not significant: $t(109) = -0.13$, $p > .250$. As the coefficients in Table S2 clarify, other-praising behavior was significantly positively associated with perceived love regardless of the target's oxytocin levels.

(c) Perceived expresser affective reward (i.e., the average post-interaction rating of: satisfied, warm, admiring, peaceful, open, amused, proud, and inspired)

The interaction between target oxytocin and expresser praising behavior was not statistically significant, though trending toward it: $t(108) = 0.80$, $p = .068$. As the coefficients in Table S2 clarify, similar to results of experienced reward reported above, targets with low circulating oxytocin did not have perceptions of the partner's reward that were contingent on the person's behavior (in fact, similar to the pattern of effects in Supplementary Figure 1, they perceived relatively low reward experienced by the expresser in the interaction). However, they perceived greater reward experienced by the expresser to the extent the expresser used greater other-praising behavior.

4. Analyses including conceptually distinct composite score outcomes

As indicated in the manuscript, a few participants provided scores on composite variables (i.e., perceived expresser responsiveness, experienced reward, perceived reward) that were demonstrably lower than all other participants by two criteria: greater than 3SD below the mean and with a gap separating them from the rest of the distribution. In this context, such responses are both anti-normative and do not fall into the theoretical context we are evaluating. Nonetheless, it is interesting to consider whether conclusions change by including these different participants in analyses. Here, we present results of all analyses presented in the manuscript, this time including the three extremely low scores on perceived responsiveness as well as two on experienced reward and one on perceptions of partner's reward.

Supplementary Table 3. Standardized regression coefficients and 95% confidence intervals from models regarding three of the benefactor's psychological responses to the conversation including low outliers

	Condition	Gender	Oxytocin (pg/mg Cr)
	β, [95%CI]	*β,* [95%CI]	*β,* [95%CI]
Perceived partner responsiveness	-.03, [-.330, .225]	.10, [-.149, .462]	.22, [.080, 1.350]*
Experienced reward	.08, [-.472, .191]	.10, [-.189, .541]	.16, [-.169, 1.349]
Perceived expresser reward	-.02, [-.399, .340]	-.05, [-.313, .501]	.11, [-.397, 1.295]

* $p < .05$

The main effect of oxytocin on perceived partner responsiveness remained statistically significant in the primary analysis (see Supplementary Table 3), as well as when controlling for conversation duration, whether the couple lived together, and whether they were dating versus committed to the long term (*p*s < .05). When controlling for relationship satisfaction, the effect of oxytocin on perceived partner responsiveness was reduced to non-significance: β = .11, $p = .216$, 95%CI [-.21, .91].

The overall interaction term reduced in size in the primary analysis to become non-significant when the three outlying perceived responsiveness scores were included in the distribution: $B = -.52$, $t(109) = -1.57$, $p = .120$, 95%CI [-1.17, .136]. It remained that way when controlling for conversation duration, whether the couple lived together, and whether they were dating versus committed to the long term (*p*s ≤ .148). When controlling for relationship satisfaction, however, the interaction term was significant: $B = -.61$, $t(107) = -2.05$, $p = .042$, 95%CI [-1.19, -.021].

Of interest, regardless of the model, the same simple effects pattern observed in the manuscript analysis held, such that the effect is strongest (and significant) for those with low oxytocin (*p*s < .001) and weaker or non-existent for those with high oxytocin (*ps* ranged from .030 to .176, average was .069).

Regarding the main effects of experienced and perceived expresser reward reported in the manuscript, oxytocin continued to be unassociated with these outcomes when including scores from all participants ($p = .126$ and .295 for experienced and perceived reward, respectively), and this conclusion did not change when controlling for conversation duration, whether the couple lived together, whether they were dating versus committed to the long term, or relationship satisfaction (experienced reward *ps* ranged from .109 to .504, $M = .222$; perceived reward *ps* ranged from .245 to .724, $M = .390$).

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