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Oxytocin and vulnerable romantic relationships

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ABSTRACT

Oxytocin (OT) has been implicated in the formation and maintenance of various social relationships, including human romantic relationships. Competing models predict, alternatively, positive or negative associations between naturally-occurring OT levels and romantic relationship quality. Empirical tests of these models have been equivocal. We propose a novel hypothesis ('Identify and Invest') that frames OT as an allocator of psychological investment toward valued, vulnerable relationships, and test this proposal in two studies. In one sample of 75 couples, and a second sample of 148 romantically involved individuals, we assess facets of relationships predicting changes in OT across a thought-writing task regarding one's partner. In both studies, participants' OT change across the task corresponded positively with multiple dimensions of high relationship involvement. However, increases in participants' OT also corresponded to their partners reporting *lower* relationship involvement. OT increases, then, reflected *discrepancies* between assessments of self and partner relationship involvement. These findings are robust in a combined analysis of both studies, and do not significantly differ between samples. Collectively, our findings support the 'Identify and Invest' hypothesis in romantic couples, and we argue for its relevance across other types of social bonds.

1. Introduction

Oxytocin (OT) is a neuropeptide hormone involved in diverse aspects of mating and reproduction across mammalian species. Early work emphasized the importance of OT in physiological processes such as uterine contractions and erections (reviewed in Borrow and Cameron, 2012) and milk letdown during nursing (Crowley and Armstrong, 1992). Within psychology, OT's roles in regulating maternal caregiving and infant responsiveness across mammalian species have received extensive attention (e.g., Pedersen and Prange, 1979; Kendrick, 2000; Carter et al., 1992; Fries et al., 2005). A related, more recent literature has emphasized the importance of OT within close social relationships, including mating pair-bonds (van Anders et al., 2011; Carter, 2014). Scholars have found that experimental administration of OT affects pair-bond formation and related processes: e.g., in female prairie voles, the formation of selective partner preferences (Williams et al., 1994); in black-tufted marmosets, huddling with a partner (Smith et al., 2010); in humans, constructive communication between romantic couples during a conflict (Ditzen et al., 2009). These experimental findings are consistent with a perspective in which OT possesses functions for both pair-bond formation *and* maintenance (see Machin and Dunbar, 2011, for an opposing perspective). In multiple lineages, functions that OT plays in maternal-offspring relationships may have been co-opted to regulate pair-bonding (e.g., Crespi, 2015; Numan and Young, 2016).

Administration studies can speak to potential effects of OT. But as scholars explore broad questions regarding OT's function—its "role or manifestation as relevant to social bonds" (van Anders et al., 2011; p. 1267)—an understanding of the circumstances that lead to the *natural production* of OT is also crucial. Environmental contexts prompt hormonal secretion, with certain social ones potent antecedents (Bos et al., 2012). While administration studies provide valuable information, they need not represent ecologically valid scenarios in which individuals naturally produce OT. A complete understanding of function also requires studies of naturally-occurring OT variation.

Recent correlational studies have tested two models of OT's role in human romantic relationships. The first model, "Calm and Connect", predicts positive associations between relationship quality/investment and OT levels, due to the hormone's inhibition of detrimental relationship behaviors (e.g., anxiety, defensiveness) and subsequent stage-setting for warm, nurturing behaviors (e.g., emotional intimacy, physical closeness) (Carter, 1998; Uvnas-Moberg and Petersson, 2005). Several

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findings are consistent with this perspective. For example, Schneiderman et al. (2012) found that 'new lovers' experience high OT levels, which predicts relationship durability months later. Past the initial stages of pair-bond formation, multiple studies also find that circulating levels of OT covary positively with various indices of 'quality' in established bonds (e.g., Light et al., 2005; Grewen et al., 2005; Holt-Lunstad et al., 2008; Holt-Lunstad et al., 2014). Circulating OT within bonded individuals may also be responsive to partners' behaviors: one recent study (Schneiderman et al., 2014) found a positive dyadic association between an individual's OT and his/her partner's reported empathy. The second model, "Tend and Befriend", predicts negative associations between relationship quality and OT. In this model, perceived gaps in romantic relationships (manifesting in stress and/or anxiety) lead to elevated OT, in turn fueling increased 'appetite' or motivation to seek affiliation outside of the threatened relationship (Taylor, 2006; Taylor et al., 2010). Neither model appears to explain the full range of findings. A recent test supported neither model in a large sample of romantic couples (Smith et al., 2013).

We propose a novel way to reconcile conflicting data regarding these past models. Studies that support the Calm and Connect model have tended to ask individuals to report on their own level of relationship involvement (Light et al., 2005; Holt-Lunstad et al., 2014). Research supporting the Tend and Befriend model has asked about the level of relationship involvement or support offered by partners (Taylor et al., 2010). The two sets of findings are not necessarily in conflict.

As a way to reconcile these findings, we propose that, across domains of social relationships, cues of relationship *vulnerability* combine with *emotional engagement* in the relationship to drive increases in OT. In turn, increased OT functions to orient psychological resources toward the vulnerable relationship. Hence, OT, akin to other hormones such as testosterone, functions within a communication system directing the allocation of an individual's psychological and/or physiological resources to certain classes of activities (e.g., Finch and Rose, 1995). For testosterone, evidence supports its role as an allocator of effort toward acquiring new mates (e.g. Gettler et al., 2011). Oxytocin, as a hormone co-opted to function within multiple types of close social relationships (e.g., Crespi, 2015), might function to maintain important social relationships in the face of threats to their security.

Multiple studies examining participants within vulnerable relationships have reported elevated OT, consistent with this proposal. Young adults in new romantic relationships, which may require special investment and attention to foster their success, have higher baseline OT than singles (Schneiderman et al., 2012). Taylor et al. (2010) report higher OT among women who perceive a lack of investment from their partner. Even the widely-recognized role of OT in the mother-infant relationship could be interpreted within this framework, as infants are both highly valued and vulnerable: maternal OT responses bias psychological (as well as physiological) resources toward this relationship (White-Traut et al., 2009; Feldman et al., 2011).

Our proposal resembles the Tend and Befriend model in that both propose that a gulf in relationship investment leads to increased OT. Nonetheless, the two ideas are distinct. Tend and Befriend conceptualizes OT as a modulator of "appetite" (Taylor, 2006; p. 273) for social affiliation in general. Taylor et al. (2010) explicitly conjecture that OT levels "rise in response to [relationship] distress as a signal to affiliate with others" (p. 6). Our proposal argues the opposite: OT motivates interest in the vulnerable pair-bond relationship, rather than other social bonds. In addition, we note that Taylor et al. (2010) argue that OT serves this function for women but not men, for whom they propose vasopressin serves this function. In its original formulation, the Tend and Befriend model applied to women in particular, not men (Taylor et al., 2000).

To test these predictions, we conducted two studies. In Study 1, we asked both partners in romantically involved couples to report on their level of relationship involvement. In Study 2, we recruited romantically involved individuals without their partners, who then provided both self and partner reports of involvement. In both studies, we predicted that there exists a *positive* relationship between an individual's OT and their relationship involvement, but, with an individual's own relationship involvement controlled, an individual's OT is predicted *negatively* by their partner's relationship involvement. Together, these predictions propose that, in the context of romantic relationships, a *discrepancy* between self and partner relationship investment/involvement—specifically, where a partner's investment lags behind one's own—signals vulnerability that triggers an increase in OT.

As levels of OT sampled in uncontrolled settings may be influenced by many factors, we created a lab procedure designed to selectively elicit OT responses to relationship features. We asked romantically involved individuals to think about the support they receive, or wish they received, from a relationship partner, and measured pre-post change in OT as a function of this task. Our main prediction concerned the OT change, not baseline OT; however, in each study we also examined mean OT levels across two samples collected one week apart.

2. Study 1

2.1. Method

2.1.1. Participants

We recruited 75 heterosexual couples (mean age = 21.27, SD = 5.37) from a psychology student subject pool to participate in the current study, designed to investigate relationships between several physiological biomarkers and aspects of participants' romantic bonds. All participants reported being in an exclusive romantic relationship with their partner lasting at least one month; the mean reported relationship length was 24 months (SD = 23 months). We obtained mean OT levels (containing at least one 'baseline' measurement) on 149 individuals, and OT change during the lab session on 132 individuals. In several instances, a sample was missing because of insufficient saliva collection, errors in substituting a sample of urine (collected for assaying separate biomarkers), or the participants had to leave the session prior to the second saliva collection. 41% of female participants reported use of hormonal contraceptives at the time of the study. Neither mean OT nor OT change significantly differed as a function of contraceptive use, $t(69) = -0.85$, $p > 0.25$, and $t(56) = 1.76$, $p = 0.084$, respectively. Controlling for contraceptive use did not affect results reported below.

Target sample size was initially 100 couples, based on estimated power to detect a correlation of 0.2 with 80% power in a sample of 200 individuals. We stopped data collection midway through the second semester of recruitment, to permit time to complete most hormone assays by end of the semester. Completed sample size yields ~80% power to detect a correlation of 0.25. Data collection was complete at the time assays were performed.

2.1.2. Procedure

Couples arrived at the laboratory session together, but completed study procedures in separate rooms. After providing informed consent, participants were simultaneously given the first of two sets of questionnaires and materials to provide an initial saliva sample. After completion of both the first questionnaire and sample, participants were given 10 min to perform a thought-writing task. Following the task, participants completed the second questionnaire set. Fifteen minutes into the second questionnaire set (hence, 25 min after initiation of the thought-writing task), a second saliva sample was collected. Participants left the laboratory after completion of the second questionnaire, and returned one week later to drop off a third saliva sample, and to fill out a brief follow-up survey.

Though Horvat-Gordon et al. (2005) argued that saliva does not contain detectable levels of OT, use of newer, and perhaps more sensitive, assay kits suggest that saliva is an acceptable medium for the measurement of OT (e.g., Grewen et al., 2010). The manual for the newest OT

assay from Enzo Life Sciences (ADI-901-153A), which we used, reports a 90% recovery of OT from spiked saliva.

2.1.3. Questionnaires

In the first set of questionnaires, participants provided demographic information, including age, sex, and relationship length. These data were collected to act as covariates in statistical analyses. For instance, given the findings of Schneiderman et al. (2012) that focused on new couples, perhaps relationship length moderates any associations between OT and facets of romantic relationships.

The thought-writing task, designed to elicit OT secretion in individuals, was developed for this study (see Tabak et al., 2011, for a study similarly examining OT reactivity, there with a measure of "interpersonal harm."). Participants were given a piece of paper with the following instructions:

"Please spend a few minutes thinking about your relationship with your partner. Then write about ways that your partner responds to you in ways that show that your partner *truly accepts and connects* with you, or how you *wish* your partner would respond to you in ways that show that your partner truly accepts and connects with you.

In total, you'll have about 10 min for this task. So you have a few minutes to gather your thoughts before writing."

The thought-writing task was designed to prime participants to think about their relationship with their partner in general—the prompt was written so as not to suggest positive *or* negative aspects should be given more weight. As participants provided open-ended responses, the amount of relevant information varied greatly. We designed our study to focus on the prediction of OT based on responses to structured relationship questionnaires (see below). Nevertheless, content of the writing tasks might provide valuable concurrent (or contrasting) information. The content of participants' responses was therefore coded on three dimensions: the extent to which the participant desires a connection from their partner; the extent to which the participant desires a connection with their partner that he/she is not receiving; and the extent to which the participant reports *their partner* desiring a connection. Raters were instructed to rate the last item only if the written responses contained information pertinent to it. One rater rated only 20 of 148 (14%) responses on the third dimension and hence we did not use this item in analyses. Ratings from two independent coders on the first two items correlated highly: 0.63 and 0.77, respectively. Ratings were averaged for all analyses ($\alpha = 0.77, 0.70$ for the two items).

Participants completed a battery of measures regarding their relationship with their partner in the second questionnaire set, after the thought-writing task. Measures included: (a) the Partner-Specific Investment Inventory (PSII; Ellis, 1998); (b) the Perceived Relationship Quality Components Inventory (PRQCI; Fletcher et al., 2000); (c) Tancredy and Fraley's (2006) Attachment bond strength questionnaire, adapted for romantic relationships by Eastwick and Finkel (2012); (d) a 6-item measure of Social Responsiveness, adapted from Canavello and Crocker (2010); (e) a 10-item measure of infatuation with the partner (adapted from unpublished items developed by Helen Fisher and colleagues). We also developed two additional measures for this study: (f) a 12-item measure of desired closeness with the partner (e.g., "I want to be emotionally close, in ways I've never felt before"); a 12-item measure of desired closeness lacking with the partner (e.g., "I want much, much more to be able to know my partner like I've known no one before"). We asked participants to provide both self- and partner-reports on the Relationship-Specific Investment Inventory. We also administered a measure of Relationship Attachment (Simpson et al., 1996) assessing attachment anxiety and avoidance in romantic relationships in general, not specifically the current one. We also asked about relationship length. Partners' reports correlated strongly, $r = 0.97$, $p < 0.0001$; we averaged male and female reports to measure relationship length.

Composite measures of romantic relationship 'involvement' or 'investment' were created through a factor analysis of 19 specific measures: 8 subscales of the RSII: expressive/nurturing, tolerant/permissive/agreeable, future-oriented, giving of time, sexually proceptive, not sexualizing of others, attentive, honest[1]; the 5 subscales of the PRQCI, satisfaction, commitment, trust, passion, and love; social responsiveness; bond strength; infatuation; desired closeness; desired closeness lacking. A scree plot suggested three factors, accounting for 58% of the variance (principal component eigenvalues = 7.43, 2.16, 1.51, 1.17, 1.02, 0.77). Similarly, a parallel analysis (conducted using O'Connor (2000) SPSS script) revealed three components with eigenvalues greater than the mean expected given random data.[2] We extracted (principal axis factoring) and rotated (direct oblimin rotation) three factors, and all were readily interpretable. Table 1 presents factor loadings from the pattern matrix. The first factor, interpreted as Love/Bonding, reflected strong loadings (>0.45) for love, commitment, bond strength, expressive/nurturing, future-oriented, giving of time, and desired closeness. The second factor, Trust/Antagonism, was defined by strong loadings of trust, tolerant/permissive/agreeable, satisfaction, intimacy, and desired closeness lacking. The final factor, sexual passion/responsiveness, was defined by loadings of sexual proceptivity, passion, and attentive. Regression-based factor scores were computed. They covaried moderately ($r = 0.37$–0.46). Therefore, we also extracted a single higher-order factor of 'general' relationship involvement (loadings = 0.66, 0.56, 0.70 for the three components, respectively; 60% of variance explained).[3]

Table 1
Pattern matrix loadings: relationship involvement.

Measure	Factor loadings		
	Love/bonding	Trust/antagon.	Sex. passion/resp.
PSII-expressive/nurturing	**0.576**	0.310	0.115
PSII-tolerant/permissive	−0.115	**0.696**	0.041
PSII-future-oriented	**0.750**	0.017	−0.024
PSII-giving of time	**0.668**	0.157	−0.027
PSII-sexually proceptive	−0.109	0.011	**0.707**
PSII-not sexualization of others	0.282	0.063	0.236
PSII-attentive	0.254	−0.146	**0.470**
PSII-honest	0.321	0.243	0.257
PRQCI-satisfaction	0.273	**0.633**	0.132
PRQCI-commitment	**0.809**	0.145	0.045
PRQCI-intimacy	0.306	**0.451**	0.339
PRQCI-trust	0.194	**0.766**	0.157
PRQCI-passion	0.152	0.406	**0.550**
PRQCI-love	**0.880**	0.050	−0.050
Bond strength	**0.812**	−0.011	−0.040
Social responsiveness	0.326	0.256	0.327
Infatuation	0.434	−0.191	0.341
Desired closeness	**0.675**	−0.090	−0.063
Desired closeness lacking	−0.028	**−0.465**	−0.014

Notes. Loadings >0.45 in **bold**. $N = 146$.

2.1.4. Hormonal assays

For each of the three saliva samples, participants were instructed to provide approximately 5 mL of passive drool into two separate test tubes. The second saliva sample, collected 25 min after initiation of the writing task, was designed to capture any changes in OT that occurred during the writing task (the 25 minute delay reflects the time necessary for changes in endogenous OT to be reflected in saliva [e.g., White-Traut et al., 2009], plus the amount of time typically needed for

[1] We did not include three subscales: physically protective (as investment in this regard is highly sex-specific); monetarily investing (as large investments in this regard are uncommon in student populations), and good relationship with partner's family (as much variance is accounted for by where partner's family resides). All other measures in our questionnaire packet pertinent to relationship quality were included in the factor analysis.

[2] Two of the three eigenvalues were greater than the corresponding eigenvalue in 95% of all simulations in the parallel analysis, and the third was >90%.

[3] Not surprisingly, this general factor correlated extremely highly with the first principal component extracted from all 19 measures, $r = 0.96$.

a participant to produce 5 mL of saliva). Samples given during the laboratory procedure were provided at various times in the day, and follow-up samples were all provided when the participant woke up the morning before the session. All samples were collected and immediately frozen at −20 °C until the time of assay. Prior to assay, samples were thawed, mixed by vortexing, then centrifuged for 15 min to break up and precipitate mucins. A 1.5 mL portion of supernatant saliva was then dried down using a vacuum concentrator at 4 °C and reconstituted with 250 μL of assay buffer immediately prior to assay, resulting in a 6:1 concentration.

OT concentrations were measured using an ELISA kit from Enzo Life Sciences (ADI-901-153A; Farmington, NY). All assays were performed in duplicate. Enzo reports a 15 pg/mL sensitivity for this assay. Enzo does not report a correlation between saliva and serum for OT, though a previous study found a correlation of 0.59 in an earlier assay kit (Grewen et al., 2010). Mean intra-assay coefficients of variation (CVs) were 8.7% for men, and 14.6% for women. The mean inter-assay CV was 14.5% for men, and 14.6% for women. Skewness statistics indicated highly skewed distributions for OT values in both men and women (3.39 and 6.72, respectively). Therefore, log-transformed OT values were used in all analyses involving mean values. One assay, containing only 4 female samples, produced an invalid standard curve, and, as there was no sample remaining, the results were excluded.

The assay instructions for OT recommend an extraction step, which is designed to eliminate interfering substances from the sample matrix that might interfere with antibody binding. McCullough et al. (2013) argue that extraction is necessary, as unextracted samples can lead to OT measurements orders of magnitude higher than, and uncorrelated with, traditionally extracted samples. However, recent evidence indicates extraction eliminates the vast majority of OT in the bloodstream is that is sequestered by binding proteins (Carter, 2014), perhaps making unextracted measurements a better estimate of circulating OT levels. Additionally, interference from the sample matrix may be trivial for saliva samples once they are dried and reconstituted with sample buffer. Some notable previous studies, including key ones on which we build, have assayed OT in unextracted samples (e.g., Schneiderman et al., 2012; Taylor et al., 2010). The question of whether to extract or not extract is an unresolved issue within the field of OT research. Prior to participant assays, we performed a pilot assay on extracted samples from 4 individuals not participating in the study. Extracted samples led to unreliable results: concentrations were near or below the minimum detection limit of the assay, CVs greatly exceeded 15%, and assays of control samples (containing a known concentration of OT) yielded invalid values. We note that many published validations and critiques of OT assay methods have been based on a previous version of the Enzo Life Sciences antibody, one with higher sensitivity but lower specificity, making extraction more viable and necessary. Two recent validations determined that intranasal OT produced reliable increases in OT from unextracted saliva collected 30–90 min after administration (Daughters et al., 2015), continuing for up to 7 h (van IJzendoorn et al., 2012). All assays for participants were thus performed on unextracted samples.

During the process of performing OT assays on women's samples, the assay manufacturer changed the detection antibody used in the assay kits. As a result, 44 of women's samples (all provided in the initial questionnaire session) were measured with a newer assay antibody (as were all men's samples), though the majority of the women's samples were measured with the old antibody. The two different antibodies yielded highly different means and standard deviations for women's initial OT measurements, $t(62) = 9.40$, $p < 0.001$. However, using this same breakdown of women to compare OT measurements at other time points (i.e., when the same antibody was used) showed similar means (second sample: $t(71) = 0.21$, $p = 0.84$; third sample: $t(59) = 0.39$, $p = 0.70$), indicating that true values for women in these two groups were similar, with differences arising from the use of different assay kits. Thus, the 44 values from the new antibody were transformed to match the scale of the initial OT measurements from the old antibody; that is, they were converted to *z*-scores and then converted using the mean and standard deviation from samples assayed with the original antibody. These transformed values were used in all analyses. One consequence of this transformation, where men and women were effectively measured on different scales, is a very large sex difference in average OT values, $t(147) = 6.63$, $p < 0.001$; though some of this difference may be real, most of it is, again, likely an artifact of the different assay antibodies. To prevent this from biasing subsequent analyses, both OT variables (the baseline average and the change) were transformed into *z*-scores within sex, which eliminated the main effect for sex. We note that our major effects are paralleled in the male and female samples, and given that all male samples were assessed with the same antibody, this suggests that the statistical transformation of female values has not biased our result.

2.2. Results

2.2.1. OT change as a function of thinking about the relationship

We predicted that individuals' own relationship involvement would positively predict change in OT as a function of thinking about their relationship, whereas partners' relationship involvement would negatively predict change. To address this prediction, we performed a series of mixed model analyses (SPSS 22.0) on individuals nested within couples, to model independent effects while accounting for non-independence between members of a couple (Kenny et al., 2006).[4] OT change (the difference between second and first OT measurements) was the dependent measure. We first performed an analysis using overall relationship involvement measures as predictors, then subsequently performed separate mixed model analysis for each individual relationship involvement component (which were exploratory analyses to further interpret any effects of the overall measure). Self- and partner-relationship involvement were entered as covariates in all models, and were the primary variables of interest. Once again, while our predictions concerned responses to the structured questionnaire measures, we also performed a set of analyses substituting coded responses on the writing task for relationship questionnaire measures. Initial analyses did not include relationship length as a covariate. We also assessed robustness of results by including relationship length as a predictor, however, and report these analyses, given the possible effects of relationship length on OT (e.g., Schneiderman et al., 2012). Exclusion of relationship length did not substantively affect results (see Supplementary Online Materials). Sex was entered as a fixed factor, and sex x relationship investment interactions were tested in each analysis. Degrees of freedom for test statistics were determined using Satterthwaite approximation, reported to the nearest whole number.

2.2.1.1. Main effect of thought-writing task. We predicted that OT changes across the thought-writing task would be conditional upon relationship features. However, we also analyzed whether our manipulation increased participants' OT levels on average. Participants' OT did increase slightly on average (mean change: 1.53 pg/mL), but this increase was not significantly different from zero, $t(131) = 0.90$, $p = 0.37$.

2.2.1.2. Overall relationship involvement. In accord with our predictions, individuals' own relationship involvement strongly positively predicted OT change, $F(1,118) = 9.28$, $p = 0.003$, $\gamma = 0.32$. At the same time, partners' relationship involvement strongly negatively predicted individuals' OT change, $F(1,117) = 7.37$, $p = 0.008$, $\gamma = -0.28$. Neither sex interaction was significant: ($F[1,105] = 1.86$, $p = 0.18$ for self involvement; $F[1,104] = 1.33$, $p = 0.25$ for partner involvement; we detected no difference in effects as a function of sex.[5]

[4] These analyses are also known, variously, as hierarchical linear models (HLM), multilevel models (MLM), or dyadic data analyses (see Kenny et al., 2006).

[5] Using as a general measure the first principal component of all 19 measures resulted yielded very similar results: $F(1,117) = 9.10$, $p = 0.003$, $\beta = 0.29$ for self-involvement, $F(1,117) = 6.34$, $p = 0.013$, $\beta = -0.23$, for partner-involvement.

Table 2
Associations of relationship involvement with OT change as a function of relationship thoughts.

Effect	Overall			Love/bond			Trust/antag.			Sex. passion/resp.		
	b	*F*	*p*	*b*	*F*	*p*	*b*	*F*	*p*	*b*	*F*	*p*
Sex	0.06	0.17		0.15	0.72		−0.07	0.19		−0.05	0.09	
Relationship length	−0.00	0.00		−0.01	0.02		−0.03	0.07		0.00	0.00	
Self rel. involve.	**0.32**	**9.28**	**0.003**	**0.31**	**6.01**	**0.016**	0.13	1.44	0.232	**0.27**	**7.38**	**0.008**
Partner rel. involve.	−**0.29**	**7.37**	**0.008**	*−0.21*	*3.48*	*0.064*	−0.04	0.19		−**0.34**	**10.91**	**0.001**
Sex × self rel. involve.	−0.30	1.86	0.176	−0.31	1.52	0.221	−0.18	0.53		−0.22	1.14	
Sex × partner rel. involve.	−0.25	1.33		−0.19	0.68		−0.35	2.42	0.123	0.00	0.00	

Notes. All numerator df = 1. Denominator df ranges from 61 to 118. See SOM for details. All $p < 0.25$ reported; $p < 0.05$ in bold, $p < 0.10$ italics. OT change, relationship length, self-relationship involvement and partner-relationship involvement all *z*-scored. Hence, effects of these predictors are akin to standardized weights. Sex dummy-coded −0.5 female, 0.5 male.

2.2.1.3. Individual components of relationship involvement. In exploratory analyses of individual components, effects were strongest for sexual passion/responsiveness: self-sexual passion/responsiveness positively predicted OT change, $F(1,117) = 7.38$, $p = 0.007$, $\gamma = 0.27$, whereas partner-sexual passion/responsiveness negatively predicted OT change, $F(1,116) = 10.90$, $p = 0.001$, $\gamma = -0.34$. OT change was predicted positively by self-love/bonding, $F(1,117) = 6.01$, $p = 0.016$, $\gamma = 0.31$; there was a trend in a negative direction for partner love/bonding, $F(1,118) = 3.48$, $p = 0.064$, $\gamma = -0.21$. Neither self- nor partner-trust/antagonism predicted the OT change, $p > 0.25$. See Table 2. As with the general factor, sex did not moderate the effects of self or partner reports of any individual factor.

2.2.1.4. Simplified model. In the models above, self and partner relationship involvement received non-zero, opposite weights in the statistical model predicting OT change. One can reduce and simplify the statistical model by constraining self and partner reports to be equal in magnitude, but opposite in sign – i.e., enter as a predictor a single variable reflecting self-partner discrepancy in relationship involvement (see Grebe et al., 2013). The effect of this signed difference on overall involvement was highly significant, $F(1,68) = 12.25$, $p = 0.001$, $\gamma = 0.30$ (Fig. 1A). Among individual components, significant positive effects on OT change were found for the self-partner difference on sexual passion/responsiveness, $F(1,63) = 19.98$, $p < 0.001$, $\gamma = 0.34$ (Fig. 1D), and love/bonding, $F(1,71) = 5.11$, $p = 0.027$, $\gamma = 0.21$ (Fig. 1B). The difference on trust/antagonism failed to reach significance, $F(1,65) = 0.30$, $p > 0.25$, $\gamma = 0.05$ (Fig. 1C). When two outlying values for overall involvement and sexual passion/responsiveness (Fig. 1A,D) were winsorized, effects remained highly significant, $F(1,70/68) = 10.27, 13.91$, $p = 0.002$, <0.001.[6]

We quantified effects of the signed difference in overall involvement on OT change by estimating mean OT change one standard deviation above the mean difference and one standard deviation below the mean difference. For the former – individuals considerably more involved than their partners – mean OT change was estimated to be 7.21 pg/mL, a 19% increase over baseline (35.81 pg/mL); $t(119) = 2.92$, $p = 0.004$. For the latter – individuals whose partners were considerably more involved than they were – mean OT change was estimated to be −4.70 pg/mL, a 13% decline from baseline; $t(120) = 1.84$, $p = 0.068$.[7]

2.2.1.5. Correlations between relationship involvement across partners. We predicted and find that self-and partner-relationship involvement predicts OT changes, independent of the other. By no means, of course, does this imply that self- and partner-relationship involvement is not positively correlated. In fact, for overall involvement and the three specific components, self- and partner-scores did positively covary, $r = 0.27, 0.26, 0.43, 0.33$, respectively, all $p < 0.028$.

2.2.2. Writing task content

Self-reports of overall relationship involvement correlated strongly and positively with ratings of participants desiring connection in the writing task, $r(144) = 0.56$, $p < 0.001$, and negatively with participants desiring connection they weren't receiving, $r(144) = -0.42$, $p < 0.001$. ('Desiring connection,' then, covaried negatively with 'desiring connection not received', $r(146) = -0.46$, $p < 0.001$.) In a mixed model using 'desiring connection' in place of overall relationship involvement (but still including partner reports of overall involvement), the association of this writing task dimension fell just short of significantly predicting the OT change, $F(1,111) = 3.35$, $p = 0.070$, $\gamma = 0.19$. In a model substituting 'Desiring connection not received' for overall relationship involvement, 'Desiring connection not received' did not predict the OT change, $F(1,111) = 0.21$, $p = 0.641$, $\gamma = -0.04$. As this variable apparently reflects somewhat poor connection with the partner, it is not clear than an association should be expected.

2.2.3. Predictors of average OT level

We also examined whether self- or partner-relationship involvement predicted mean OT levels. Unlike for the OT change, we did not make specific predictions for analyses concerning baseline levels, as these levels may have been biased by a number of extraneous factors. These analyses, like those for individual relationship involvement factors, were exploratory. Initial levels in the lab session were averaged, for each individual, with morning levels one week later. The correlation between log-transformed values across time was statistically robust for men, $r(68) = 0.51$, $p < 0.001$, but not women, $r(50) = 0.08$, $p > 0.25$. There was no significant effect for either self or partner responses predicting average OT: $F(1,134) = 0.32$, $p > 0.25$, $\gamma = 0.06$ for self-relationship involvement; $F(1,134) = 0.00$, $p > 0.25$, $\gamma = -0.01$ for partner− relationship involvement. Similarly, we detected no associations between specific components of relationship involvement and mean OT levels. Mean OT levels diminished with relationship length, $F(1,67) = 4.69$, $p = 0.034$, $\gamma = -0.20$. See SOM for full results.

[6] We emphasize that these discrepancy scores are *signed*. Hence, high levels of own relationship involvement paired with relatively low levels of partner involvement are associated with greater OT increases as a function of the thought listing task. Low levels of own relationship involvement paired with relatively high levels of partner involvement are associated with smaller OT increases (or even OT decreases) as a function of the thought listing task.

As noted in our methods section, the manufacturer changed antibodies after we had already assayed a subset of women's samples. All of men's samples, however, were assayed using the same antibody kit. To address whether results held within our sample of men alone, we performed sex-specific analyses. For men, self-partner discrepancy on the overall measure, $F(1,64) = 5.75$, $p < 0.019$, $\beta = 0.31$, and sexual passion/responsiveness, $F(1,64) = 6.54$, $p < 0.013$, $\beta = 0.31$, significantly predicted change in OT; for love/bonding, the association fell short of statistical significance, $F(1,64) = 2.94$, $p < 0.091$, $\beta = 0.26$. For women, results were similar: Overall: $F(1,54) = 5.94$, $p < 0.018$, $\beta = 0.32$; sexual passion/responsiveness: $F(1,54) = 10.24$, $p < 0.002$, $\beta = 0.38$; love/bonding: $F(1,54) = 2.47$, $p < 0.121$, $\beta = 0.21$. The primary results we report are robust even within the sample of men, for whom all assays were performed using the same antibody kit.

[7] For these analyses, we scaled OT levels by the new assay, performed on all men. Percentage changes, however, are identical if levels are scaled on the old assay, which applied to the majority of women.

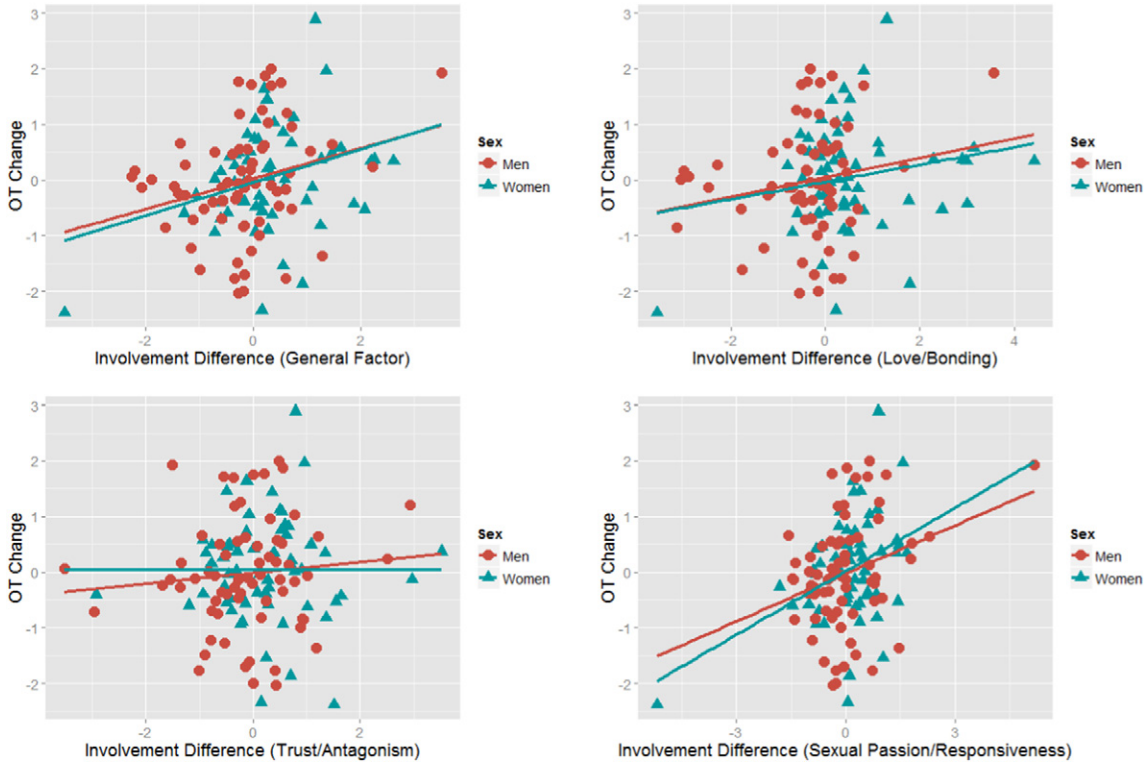

Fig. 1. Factors of relationship involvement difference on OT change. Values on both axes *z*-scored.

3. Study 2

3.1. Methods

3.1.1. Participants

Participants were 148 individuals (116 women; mean age = 23; SD = 2.84) recruited on a university campus in Norway. All participants reported being in an exclusive romantic relationship with their partner lasting at least one month; the mean reported relationship length was 28 months (SD = 26 months; median = 19). (Relationship length was reported to be the impossible value of 375 months – ~31 years – by one individual, age 21. The mean was substituted for this value for all analyses.) Participants were recruited though various channels associated with the university, including student newspapers, faculty blogs, and Facebook posts; in addition, participants were recruited through a story in a major city newspaper. 79% of female participants reported use of hormonal contraceptives at the time of the study. Neither mean OT nor OT change significantly differed as a function of contraceptive use, $t(111) = -0.15$, $p = 0.882$, and $t(110) = 0.56$, $p = 0.574$, respectively. Controlling for contraceptive use did not affect results reported below.

3.1.2. Procedures

Procedures were similar to those of Study 1, with two notable exceptions imposed by logistical constraints pertaining to how participants were recruited and compensated for participation. Like procedures in Study 1, (a) after providing informed consent, participants completed a series of questionnaires, largely pertaining to health, during which an initial saliva sample (~5 mL) was collected in two test tubes through passive drool; (b) they then were asked to engage in the same 10-minute thought-listing task as participants in Study 1; hence, they were asked to think about and list "ways that your partner responds to you in ways that show that your partner *truly accepts and connects* with you, or how you *wish* your partner would respond to you in ways that show that your partner truly accepts and connects with you"; (c) they then completed a second packet of questionnaires, including a series that pertained to their investment in the relationship; (d) 15 min into the second set of questionnaires (hence, 25 min after the onset of the thought-listing task), they provided a second saliva sample (~5 mL) through passive drool in two tubes; (e) they returned a third saliva sample (~5 mL, two tubes), collected upon awakening, one week later. Immediately after receipt, all saliva samples were frozen at −20 °C. Saliva samples were shipped on dry ice to the Hominid Reproductive Endocrinology Lab, Department of Anthropology, University of New Mexico. Prior to assay, samples were thawed, mixed by vortexing, then centrifuged for 15 min to break up and precipitate mucins. As in Study 1, a 1.5 mL portion of supernatant saliva was dried down using a vacuum concentrator at 4 °C and reconstituted with 250 μL of assay buffer immediately prior to assay, resulting in a 6:1 concentration. OT concentrations were measured using an ELISA kit from Enzo Life Sciences (ADI-901-153A; Farmington, NY), with assays performed in duplicate. Mean intra-assay and inter-assay coefficients of variation (CVs) were 7.1% and 14.7%, respectively.

The two notable exceptions were the following:

First, participants did not bring their romantic partners to the lab. Hence, participants did not participate as couples; for each couple, just one member participated. We used this modified procedure because we could not offer participants compensation for participating as couples sufficient to recruit a sample of ~200 individuals (the target sample size). As a result, we obtained reports of partners' relationship investment from the participant herself or himself, rather than from the partner.

Second, we did not administer the full battery of relationship involvement measures we administered in Study 1. For self-involvement, we administered (a) the Relationship-Specific Investment Inventory (Ellis, 1998); (b) a measure of Attachment Bond Strength (adapted from Tancredy and Fraley, 2006); (c) a measure of infatuation with partner (see Study 1 Method); (d) measures of what individuals want from their relationship and what they get from their relationship. All measures were used in Study 1. For partner's involvement, we administered a partner-report version of the Relationship-Specific Investment Inventory (Ellis, 1998). We used that set of measures because Ellis

Table 3
Principal component loadings, relationship involvement: Study 2.

Measure	Loadings	
	Self	Partner
PSII-expressive/nurturing	**0.656**	**0.782**
PSII-tolerant/permissive	0.304	**0.724**
PSII-future-oriented	**0.592**	**0.510**
PSII-giving of time	**0.760**	**0.678**
PSII-sexually proceptive	0.388	0.442
PSII-not sexualization of others	0.308	**0.502**
PSII-attentive	0.404	**−0.598**
PSII-honest	**0.561**	**0.606**
Bond strength	**0.746**	
Infatuation	**0.587**	
Desired closeness	**0.584**	
Desired closeness lacking	−0.311	

Notes. Loadings >0.45 in **bold**. $N = 146$.

(1998) developed and validated a partner-report version of it. In his study, participants reports of their partners' involvement covaried substantially with partners' self-reports, mean r for subscales = 0.46. All questionnaires were administered in Norwegian (translated and back-translated to ensure comparability in meaning).

We extracted a first principal component from the set of measures within each battery used in Study 1, which explained 38% of the variance in both self- and partner-reports. Loadings are presented in Table 3. As can be seen, loadings for shared measures are very similar. Tucker's coefficient of factor congruence based on these shared measures was 0.959, indicating that the two dimensions, one representing self-involvement and the other representing partner-involvement (as perceived by self) are near-identical (Lorenzo-Seva and ten Berge, 2006). Moreover, coefficients of factor congruence with the first principal component extracted from the set of relationship involvement measures in Study 1 (based on shared measures) were 0.991 and 0.969 for self- and partner-reports, respectively. Hence, the dimensions of relationship involvement assessed in the two studies are near-identical, despite the sets of measures only partially overlapping. Principal component scores (scaled as *z*-scores) were computed for both self- and partner-measures, and used as our primary measures of self- and partner-relationship involvement.[8]

To provide the most powerful test of whether our primary finding in Study 1 reproduced in Study 2, we regressed OT change on sex (centered at "mean" of sex, where female = 0 and male = 1),[9] the difference between self- and partner-relationship involvement, relationship length (logged), and the self-partner relationship involvement x sex interaction. We followed up with an analysis that regressed OT change on self- and partner-relationship involvement entered as separate scores.

3.2. Results

3.2.1. Descriptive statistics: OT change

OT change scores were computed and used as our primary outcome measure. The second saliva sample was missing for one participant. Examination of OT change scores for the remaining 147 participants revealed one extreme outlier, whose value was 113.63; the second most extreme value was 68.50. The outlier was 5.2 SD from the mean (5.8 SD based on scores excluding the outlier). This outlying score may well have resulted from mismatching of first and second saliva samples for this individual. In any case, it is very unlikely to reflect a true value. Hence, we excluded it in all analyses. Mean OT values for all valid scores were 46.6 (SD = 25.7) and 49.1 (SD = 26.0) pg/mL for initial and post-thought-listing samples, respectively. OT change averaged 2.53 pg/mL (SD = 19.1). Women's average OT concentration was 46.89 pg/mL (SD = 22.91), and men's was 42.55 pg/mL (SD = 16.97).

3.2.2. Prediction of OT change from relationship involvement

Did the primary empirical finding in Study 1 reproduce in Study 2? *Yes*. Consistent with Study 1, the discrepancy between self- and partner involvement significantly predicted OT change, $F(1,140) = 4.40$, $p = 0.038$, $\beta = 0.18$. See Table 4. Neither relationship length nor the involvement discrepancy × sex interaction was significant. Exclusion of these effects from the model did not substantively affect results ($\beta = 0.17$, $p = 0.048$).

We quantified effects of signed difference between self- and partner involvement on OT change by estimating mean OT change one standard deviation above the mean discrepancy and one standard deviation below the mean discrepancy. For individuals considerably more involved than their partners (1 SD above the mean), mean OT change was estimated to be 6.01 pg/mL, a 13% increase over baseline (46.19 pg/mL); $t(140) = 2.62$, $p = 0.010$. For individuals whose partners were considerably more involved than they were (1 SD below the mean), mean OT change was estimated to be −1.04 pg/mL, a non-significant 2% decline from baseline; $t(140) = -0.44$, $p = 0.66$.

When self- and partner-relationship involvement were entered separately, a significant negative effect of partner-involvement emerged, $F(1,138) = 4.95$, $p = 0.028$, $\beta = -0.30$, just as in Study 1. See Table 4. The effect for self-involvement was positive but fell short of being statistically significant, $F(1,138) = 3.14$, $p = 0.079$, $\beta = 0.25$. Exclusion of the one individual for whom we substituted mean relationship length strengthened findings very slightly: for self- and partner, respectively, $\beta = 0.27, -0.30$, respectively, $p = 0.064, 0.025$. Exclusion of relationship length and the interactions with sex altogether changed results minimally: for self- and partner, $\beta = 0.21, -0.27$, respectively, $p = 0.111, 0.040$.

3.2.3. Predictors of average OT level

As in Study 1, initial OT levels in the lab session were averaged, for each individual, with morning levels one week later. The correlation between log-transformed values across time was comparable for men, $r(24) = 0.31$, $p = 0.128$, and women, $r(104) = 0.22$, $p = 0.021$; collectively, $r(129) = 0.27$, $p = 0.002$. As in Study 1, there was no significant

Table 4
Associations of relationship involvement with OT change as a function of relationship thoughts: Study 2.

Effect	*b*	*F*	*p*	*b*	*F*	*p*
Sex	0.00	0.00		−0.02	0.06	
Relationship length	−0.05	0.38		−0.06	0.49	
Self-partner involvement discrepancy	**0.18**	**4.40**	**0.038**			
Sex × S-P discrepancy	−0.02	0.14				
Self involvement				*0.25*	*3.14*	*0.079*
Partner involvement				**−0.30**	**4.95**	**0.028**
Sex × self involvement				−0.06	0.23	
Sex × partner involvement				−0.01	0.00	

Notes. Results reported in left set of columns are from analyses entering self-partner discrepancy in relationship involvement as predictor. Results reported in right set of columns are from analyses entering self relationship involvement and partner relationship involvement as separate predictors. df = 1140 and 1138, respectively. All $p < 0.25$ reported; $p < 0.05$ in bold, $p < 0.10$ italics. OT change, sex, relationship length (log-transformed), self-relationship involvement and partner-relationship involvement all *z*-scored. Hence, regression coefficients of these predictors are akin to standardized weights.

[8] A parallel test indicated 4 factors for self-reports and 3 factors for reports on partners' involvement. But, as in Study 1, extracted components covaried with one another, such that the first principal component reported above captures a general factor running through subcomponents. Because self- and partner-factors were not directly comparable, unlike in Study 1, but (as noted above) the first principal component is comparable, we focus exclusively on this general relationship involvement factor.

[9] This procedure estimates the main effect of self-partner discrepancy in relationship involvement as a weighted mean of the effect for males and females when interactions with sex are included, as opposed to an unweighted mean main effect. The latter weights more heavily the effect for males, which is much less stably estimated, given a large discrepancy in sample size (just 33 men vs. 113 women). No interactions with sex were detected (see Table 4), and coding of sex makes no difference when interactions are excluded.

effect of relationship involvement differences predicting average OT: $F(1,42) = 0.29$, $p = 0.589$, $\beta = 0.06$.

4. Combined analysis

The results of Study 2 reproduce the primary empirical pattern that emerged from Study 1; in both studies, the discrepancy between self- and partner-relationship involvement predicted change in OT, such that OT levels increased in response to a task in which participants thought about their relationships for those individuals who were highly involved in their romantic relationships relative to the involvement (or, in Study 2, perceived involvement) of their partners. At the same time, in Study 2, a significant effect was detected only for partners' involvement. Does that mean that the studies, taken as a whole, provide evidence only for a negative association between OT change and partners' involvement, and not for a positive association between OT change in self-involvement? No. Even well-powered studies (power = 80%) yield significant associations only 80% of the time. Moreover, the association between self-involvement and OT change in Study 2 was in a predicted direction, with $p = 0.079$.

To assess the extent to which the results of the two studies, considered collectively, provide support for predicted associations, we conducted analyses on the combined studies. In these analyses, we (a) represented self- and partner-involvement with our measures in each study, represented as *z*-scores; again, these measures should be comparable (see factor congruence coefficients reported above); (b) controlled for study. We entered relationship involvement × sex and relationship involvement × study interactions as well. Analyses were run as multilevel regressions, which controlled for dependency of self- and partner-reports in Study 1.

Results are presented in Table 5. Three key findings emerged:

First, as expected, a robust self-partner discrepancy in relationship involvement effect emerged, $F(1,225.2) = 5.38$, $p = 0.021$, $\gamma = 0.20$. (Not reported in Table 5, but emerging from a separate analysis.)[10]

Second, when self- and partner-relationship involvement were entered separately, both main effects emerged: For self, $F(1,260.2) = 11.25$, $p = 0.001$, $\gamma = 0.29$; for partner, $F(1,260.5) = 11.91$, $p = 0.001$, $\gamma = -0.29$. Indeed, associations for self- and partner-relationship involvement were opposite in sign and nearly identical in magnitude.

Third, in no instance did either study or sex moderate associations of self- and partner-relationship involvement with OT change. For sex interactions, all $p > 0.3$. For study interactions, all $p > 0.6$. Notably, then, we detected no differences in associations as a function of the precise measures of relationship involvement we administered, who provided reports on partner involvement (self vs. partner), population sampled (college students in the U.S. or Norway), or sex. Future studies may explore additional possible moderating effects.

Finally, to assess whether results are driven by relatively new relationships and not well-established ones, we added interaction effects involving logged relationship length. Neither the relationship length × self-involvement nor the relationship length × partner-involvement interaction emerged as significant or noteworthy: $F(1,183.0) = 0.42$, $p > 0.5$, $\gamma = -0.04$, $F(1,182.9) = 0.39$, $p > 0.5$, $\gamma = -0.04$, respectively.

5. Discussion

In two independent samples—one of couples and one of individuals in committed relationships—short-term changes in OT elicited by thoughts about the relationship robustly covaried with reports of both partners' relationship involvement. Consistent with our predictions, increases in OT across a thought-writing task were predicted by high levels of individuals' own relationship involvement, but also by low levels of partners' relationship involvement. Accordingly, the *difference or discrepancy* between self and partner involvement was a significant predictor of OT change in both studies. This pattern was upheld in both male and female subjects.

In Study 1, when analyzing coded content from the writing task in place of factors derived from relationship questionnaires, we find results that trend in the same direction as our primary analyses—reports of 'desiring connection' positively predict an OT response—however, they are non-significant. We emphasize that structured relationship questionnaires, not the actual content of the writing task, were the measures intended to predict OT changes. Queries into specific aspects of the relationship offer a more controlled and, very likely, accurate assessment of romantic relationships than subjective ratings of a short open-ended thought-listing.

Unlike the majority of published findings on OT and human social bonding, we did not find significant associations between baseline OT and either partner's relationship involvement in either study. Participants' baseline OT, as measured by levels upon arriving for the laboratory session, might be influenced by a number of activities (e.g., stressful events, arguing about a conflict, having sexual contact, but also demands to attend to important tasks independent of the relationship). While we cannot eliminate the possibility that extraneous factors biased OT responsivity in our sample as well, we see this as less likely: the one key event intervening between the first and second OT measurements was the thought-writing manipulation that focused the participant's attention on the relationship under consideration. For this reason, the OT change may represent a stronger test of how relationship factors affect OT responses and may more closely mimic the OT response experienced in response to the partners themselves. Similarly, Tabak et al. (2011) found significant associations between an OT response, but not baseline OT, and reactions to a manipulation designed to evoke feelings of interpersonal harm.

Paradigms from other studies designed to elicit an OT response have relied upon manipulations such as recording a video message to an interpersonal transgressor (Tabak et al., 2011), sexual self-stimulation (de Jong et al., 2015), a 'warm touch' intervention for married couples (Holt-Lunstad et al., 2008), or an emotional induction task based on personal relationships (Turner et al., 1999). Our findings suggest thinking about one's relationship with his or her partner can also lead to an OT response, but contingent upon the vulnerability of the relationship. Further research may assess the conditions under which thinking itself can evoke an OT response. Additionally, future studies utilizing more targeted thought-listing tasks may be able to reveal whether priming

Table 5
Associations of relationship involvement with OT change as a function of relationship thoughts: combined analyses, Study 1 and Study 2.

Effect	γ	*F*	*p*	γ	*F*	*p*
Study	−0.02	0.04		0.00	0.00	
Sex	−0.00	0.00		−0.01	0.04	
Relationship length	−0.03	0.27		−0.03	0.24	
Self involvement	**0.29**	**11.25**	**0.001**	**0.26**	**9.36**	**0.003**
Partner involvement	**−0.29**	**11.91**	**0.001**	**−0.30**	**12.55**	**<0.001**
Study × self involvement	−0.08	0.23				
Study × partner involvement	−0.08	0.21				
Sex × self involvement	−0.08	0.96				
Sex × partner involvement	−0.07	0.67				
Rel. length × self involvement				−0.04	0.42	
Rel. length × partner involvement				−0.04	0.39	

Notes. All numerator df = 1. Denominator df ranges from 127.4 to 260.9. All $p < 0.25$ reported; $p < 0.05$ in bold. OT change, sex, relationship length, self-relationship involvement (log-transformed) and partner-relationship involvement all *z*-scored. Hence, effects of these predictors are akin to standardized weights. Study effect-coded −0.5 Study 1, 0.5 Study 2. Sex nested within couple in multilevel analyses (applicable to Study 1).

[10] We re-ran this analysis dropping 40 women from Study 1 on whom pre- and post-thought-listing task OT was assayed using different assay kits. The self-partner discrepancy in relationship involvement effect remained robust, $F(1,202.5) = 13.47$, $p = 0.0003$, $\gamma = 0.27$.

certain kinds of thoughts about relationships lead to differing OT responses.

Finally, given the current climate regarding the reproducibility of published findings in general (e.g., Open Science Collaboration, 2015), and within OT research particularly (e.g., Nave et al., 2015; Lane et al., 2016), we see the successful reproduction of our main finding across two samples from different cultures as a strength worth noting. Our findings are by no means the final word, even with a successful reproduction—indeed, one lesson emerging from the 'reproducibility crisis' is that findings should be scrutinized, even after passing peer review. However, the most high-powered tests of our hypotheses, in the combined analyses, provide strong evidence consistent with our predictions.

5.1. "Identify and Invest"

Our proposal builds upon two established models for socio-relational causes of OT production within romantic relationships – the "Calm and Connect" and "Tend and Befriend" models – and show how findings supportive of each can be reconciled. Aspects of relationship quality or investment might be either positively or negatively related to OT, depending on whose assessments of the relationship are used. Rather than predicting OT to be a response to either strong feelings of bonding with a partner (e.g., Schneiderman et al., 2012) *or* a partner's perceived disengagement (e.g., Taylor et al., 2010), we predicted the hormone would be produced in *both* scenarios. One's own emotional engagement, along with the vulnerability of the relationship, jointly form the circumstances predicting strong OT responses. In the parlance of dyadic mixed model analyses, we predicted and found positive actor effects but negative partner effects on OT.

Provisionally, to distinguish our proposal from previous models, we refer to our proposal as the "Identify and Invest" model. The model argues that OT does not instigate affiliative motivations in general. Rather, it proposes that OT-associated interpersonal motives are "tagged" with the identity of particular targets of special importance – hence the term "Identify" – and lead individuals to invest in relationships with the targets – hence the term "Invest."

Naturally, any understanding of the psychological effects of OT in romantic relationships should speak to how it operates in other contexts – perhaps most notably, mother-infant relationships. The Identify and Invest hypothesis does so. From mothers' point of view, these relationships are vulnerable not because infants might abandon mothers, but because infants' well-being is highly dependent on maternal attention. In the face of threats to infants, it makes little sense that mothers should be motivated to affiliate with others in general. Rather, mothers should pay particular attention to the reactions and needs of a specific social entity – specifically, their infants.

OT levels may be especially elevated in new romantic relationships because both partners are uncertain of where the other stands. As relationships stabilize, OT levels should subside. Indeed, one prediction of the Identify and Invest hypothesis is that the highest levels of OT among romantically involved individuals should *not* be experienced by partners who are both strongly bonded to each other. In our current study, OT levels were lower in couples who had been in their relationship longer. The Identify and Invest hypothesis may also explain findings suggesting that anxiously attached individuals—people highly dependent on relationship partners whose love they often perceive to be fragile—tend to have chronically high levels of OT (e.g., Marazziti et al., 2006; Weisman et al., 2013).

Might different models of what leads to OT be applicable to different sets of circumstances? Perhaps. We propose, then, that future work should consider the possibility that the Identify and Invest model explains why particular circumstances lead to the production of OT, along with the possibilities that the Calm and Connect or Tend and Befriend models offer an appropriate explanation.

5.2. The psychological functions of OT

The current study cannot directly speak to how OT affects psychological processes in relationships. Our perspective is compatible, however, with arguments that, at least in part, OT functions to modulate reward systems (Bethlehem et al., 2014; Numan and Stolzenberg, 2009) – in particular, in ways that enhance sensitivity to contingencies involving specific targets' actions. In light of known contexts in which OT is especially elevated (breastfeeding mothers, romantically involved individuals), it makes sense that, to the extent that OT enhances attentiveness to social stimuli (Striepens et al., 2012), it does so in circumstances in which it is naturally produced not in highly general ways, but with respect to specific individuals or social goals. Once again, the effects of OT should be, in some fashion, "tagged" to specific relationships (e.g., mothers should process social information pertinent to care and protection of infants, not social goals in general). Future research may address these processes in contexts in which OT responses are elicited.

5.3. The role of specific domains of involvement

In exploratory analyses of Study 1, the contrast between partners' sexual passion was found to be particularly predictive of change in OT. By contrast, partners' trust did not predict OT change. It may be that aspects of a romantic bond linked to sexuality are especially relevant for OT responsivity, due to OT's conserved role in sexual functioning across species (Borrow and Cameron, 2012). We did not have a comparable factor in Study 2 to use as a test of this idea; future research may address whether these findings are robust.

5.4. Comments on an extraction step prior to hormone assays

Out of necessity, samples were not extracted prior to assay. Recent findings defend the use of unextracted samples (Carter, 2014). In addition, the assay instructions recommend extraction 'to avoid matrix interference without being too dilute to measure'. Our procedure of drying down and reconstituting the saliva samples achieved this without an extraction step. Enzo reports only two other substances are known to cross-react substantially with the OT assay, mesotocin (7%) and vasotocin (7.5%), neuropeptides related to OT but not produced by humans. All other structurally similar substances, including vasopressin and many active metabolites of OT (Carter, 2014), have low cross reactivity (<0.02%). McCullough et al. (2013) argue that unextracted samples yield mere noise. Yet the reliable and systematic associations we find from unextracted samples, which others do as well (e.g., Taylor et al., 2010; Schneiderman et al., 2012), strongly suggest otherwise. Notably, short-term increases in OT in another study, measured via extracted samples, corresponded to greater anxiety toward an imaginary transgressor (Tabak et al., 2011). This finding is consistent with our perspective, though OT samples were processed differently. If a substance other than OT drives systematic findings, that substance remains unknown, but would be of interest.

5.5. Peripheral vs. central OT

OT is a hormone, with receptor sites distributed throughout the body. Like many hormones, it has neuromodulatory properties, in that it is projected centrally and affects neurotransmitter systems in particular brain regions (Numan and Stolzenberg, 2009). Our studies examined changes in peripheral levels of OT only. We cannot know that corresponding changes in central projections of OT occurred as well. This limitation is not distinctive to our studies. All studies that have examined OT levels in relation to relationship features have measured peripheral levels only. Moreover, within a general framework for understanding hormonal influences, it makes sense that there is some correlation between central and peripheral actions; hormones generally function to

coordinate multiple attunements of distinct systems (both peripheral and neural) simultaneously. At the same time, it is important to acknowledge that, until we know more about how closely neural and peripheral secretions are coordinated, our findings speak directly only to peripheral secretions.

6. Conclusions

An extensive body of findings points to OT playing a role in physiological scaffolding that renders close social relationships "close" – psychologically impactful. The current studies investigated features of romantic pair-bonds that predict naturally-occurring increases in OT levels. OT responsivity was indeed related to investment in romantic pair-bonds, but most potently when psychological investment is not reciprocated by the partner—i.e., in vulnerable relationships. We observed this effect in two studies, and in a combined analysis. The Identify and Invest Hypothesis yields predictions to be tested by future research, not only in the area of romantic relationships, but also within mother-infant relationships and friendships. More broadly, research on OT may help elucidate the evolutionary pathways giving rise to close social relationships across multiple domains (e.g. van Anders et al., 2011).

Author contributions

N.M.G. and S.W.G. developed the original study concept. All authors contributed to the studies' designs. N.M.G., T.V.G., A.A.K., L.E.O.K., and S.W.G. performed data collection. N.M.G., M.E.T., and S.W.G. performed hormone assays, data analysis and initial interpretation. N.M.G. and S.W.G. drafted the manuscript, and all other authors provided critical revisions. All authors approved the final version of the manuscript for submission.

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