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The roles of testosterone and cortisol in friendship formation

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ABSTRACT

Although research has investigated the neuroendocrine correlates of romantic relationships, the neuroendocrine correlates of friendship formation are largely unexplored. In two conditions, participants' salivary testosterone and cortisol were measured before and after a high versus low closeness activity with another same-sex participant. In the high closeness task, participants took turns answering questions that fostered increases in self-disclosure. The low closeness task fostered low levels of self-disclosure. Dyadic multilevel models indicated that lower basal testosterone and decreases in testosterone were associated with increased closeness between recently acquainted strangers. Our results suggest that people high in testosterone felt less close to others and desired less closeness. Further, lower basal cortisol and dynamic cortisol decreases were associated with greater closeness and desired closeness in the high closeness condition. Finally, we found that the partners of those who had lower cortisol desired more closeness. These findings suggest that lower testosterone and cortisol are linked to the facilitation of initial social bonds and that these social bonds may, in turn, be associated with changes in these hormones.

1. Introduction

Closeness is crucial to friendships and romantic relationships, and the drive to become close to others has been theorized as a fundamental human motivation or need (Aron and Aron, 1986; Baumeister and Leary, 1995). In terms of the self, closeness represents the degree to which aspects of another are included in one's own identity. This 'inclusion of other in the self' (IOS) can result in an expansion of the self-concept, where both members think of themselves as a cognitive unit (Aron and Aron, 1986; Aron et al., 1991, 1992). Recent approaches to the study of closeness in humans are beginning to examine the biological mechanisms underlying interpersonal closeness, particularly through investigating how hormones such as testosterone and cortisol are linked to social bonds (Ellison and Gray, 2009; van Anders and Gray, 2015).

One hormone that is potentially pivotal in the formation and function of close relationships is testosterone, a steroid hormone regulated by the hypothalamic-pituitary-gonadal (HPG) axis (Gettler et al., 2011; Gray et al., 2006; Edelstein et al., 2011; Perini et al., 2012; van Anders and Goldey, 2010). For instance, higher testosterone appears to facilitate sexual relationships and mating (Gettler et al., 2011; Peters et al., 2008; Slatcher et al., 2011; Welling et al., 2008). Outside of short-term mating contexts, however, higher testosterone may be associated with *inhibited* social connections and lower relationship quality (Edelstein et al., 2014). Indeed, coupled men and women tend to have lower testosterone than singles (Gray et al., 2004; van Anders and Goldey, 2010). Evidence suggests that nurturant behaviors and contexts may contribute to a decline in testosterone (Gettler et al., 2011; Gettler and Oka, 2016; Gray et al., 2004; van Anders et al., 2012; Wingfield et al., 1990). Further, testosterone may impact the quality of an existing romantic relationship. Those with lower testosterone in committed relationships have reported higher relationship satisfaction, and the partners of those with lower testosterone also report higher relationship satisfaction (Edelstein et al., 2014). Additionally, high testosterone individuals have been found to be more avoidant, lonely, and disconnected from others (Turan et al., 2014). These results suggest that higher testosterone may be associated with decreased closeness and desire for closeness.

A majority of research on testosterone and relationships considered thus far indicates that hormones shape social behaviors and interactions. Do social interactions, in turn, shape hormones? For example, cortisol reactivity is a marker of the hypothalamic-pituitary-axis (HPA) response to stress. Cortisol and testosterone both change in response to the social environment. Measuring cortisol and testosterone reactivity increases our understanding

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of how social interactions shape our hormones. Further, individual levels of hormone reactivity are socially relevant physiological markers beyond basal hormone levels. For instance, nurturant responses to babies are associated with reactive decreases in testosterone (van Anders et al., 2012), and interest in babies is inversely related to testosterone reactivity to sexual stimuli (Zilioli et al., 2016). Further, young men's testosterone increases after a brief social interaction with a member of the opposite sex (Roney et al., 2007). Together, these findings suggest that testosterone reactivity may be associated with social relationship processes.

Cortisol reactivity may also play a role in interpersonal relationships. Dyadic closeness and relationship quality tend to decrease under stress (Karney and Bradbury, 1995; Lavee and Ben-Ari, 2007). Further, providing social support to a close other and being socially accepted by peers has been shown to decrease cortisol (Blackhart et al., 2007; Smith et al., 2009). Partners in a relationship may even shape each other's stress response. For instance, evidence indicates that a partner's attachment style in a romantic relationship may influence the other's stress reactivity, as measured via salivary cortisol (Laurent and Powers, 2007; Powers et al., 2006). Together, these results point to a potential association between cortisol reactivity and closeness.

Researchers have begun to posit that hormones, rather than acting in isolation, may be part of a multisystem approach where the joint contributions of hormones produced by the HPG and HPA axes work in concert (Bauer et al., 2002; Laurent et al., 2013). From an evolutionary context, there is empirical support indicating an interaction of the HPG and HPA axes in predicting social behaviors (see Salvador, 2012 for a review). In several species, dominant behaviors are closely related to social hierarchies. Studies investigating the role of these two steroid hormones and dominance have primarily focused on non-human animals, but have begun to be researched in humans. For example, evidence suggests that testosterone and cortisol may interact with each other at both the within-person and within-dyad level (Marceau et al., 2015). The dual-hormone hypothesis posits that testosterone's effect on social behavior is dependent on the steroid hormone cortisol (Mehta and Josephs, 2010; Mehta and Prasad, 2015). A majority of findings related to the dual-hormone hypothesis support the theory that testosterone's role in social behavior may be moderated by cortisol levels. Terburg et al. (2009) propose a neuro-evolutionary model that posits that social aggression is motivated by an imbalance in the levels of cortisol and testosterone.

Testosterone may have a differential influence on social behaviors depending on the level of cortisol. For example, testosterone is negatively associated with empathy when basal cortisol is low, but positively associated with empathy when basal cortisol is high (Zilioli et al., 2015). In contrast, a recent study found that males with higher testosterone and lower cortisol were more popular and more likely to act as social connectors (Ponzi et al., 2016). Given the prior associations found among testosterone and relationship satisfaction, emotional support, and nurturance, it is worth exploring whether testosterone and cortisol might jointly predict interpersonal closeness.

A laboratory-based approach to understanding the social neuroendocrinology of friendship formation

Growing evidence suggests that testosterone and cortisol are associated with behavior and functioning in social relationships. So far, the evidence suggests that high testosterone facilitates initial sexual and romantic relationships, yet is associated with lower long-term relationship satisfaction. Given the prior findings on links among testosterone and relationship processes, it is worth exploring its role in relationship formation. A systematic starting point is to investigate the role of testosterone during friendship formation. In friendships, testosterone may play a facilitative role, as it does with early-stage romantic love. Alternatively, given the potential inhibitory role testosterone plays in trust, empathy, and relationship satisfaction, (e.g. Bos et al., 2010; Edelstein et al., 2014; Hermans et al., 2006) testosterone may be associated with less closeness in friendly dyadic social interactions. Further, cortisol potentially affects and is potentially affected by interpersonal relationships. One study looked at the association between friendship formation and hormones. Across three laboratory-based intergroup friendship meetings, cortisol was measured before and after a friendship formation activity. Cortisol levels decreased (Page-Gould et al., 2008), indicating the potential for a hormonal response to a laboratory-based closeness induction task. To our knowledge, very few studies to date have examined the role of testosterone or cortisol in interpersonal closeness outside of a romantic context. Further, there is little research on dyadic effects of testosterone or cortisol (i.e., partner effects of one person's hormone levels associated with the feelings of closeness felt by the other person in a dyad) in interpersonal relationships. Researchers have found that testosterone's influence on social behaviors such as empathy may depend on concentrations of cortisol (Zilioli et al., 2015). The present study will examine such hormonal effects in the context of friendship formation.

The research described below investigated how testosterone and cortisol are related to closeness and the desire for closeness during friendship formation. A central aim of the present research was to explore the association of basal testosterone and cortisol and testosterone and cortisol changes with closeness and desire for closeness in same-sex dyadic social interactions and whether these interactions occurred as actor effects or partner effects (these effects consider the role each member plays in a dyad and the interaction of the two members in a dyad). Second, we investigated how a closeness induction paradigm modulates testosterone and cortisol changes. Third, we conducted an exploratory analysis to see how testosterone and cortisol might jointly predict closeness. To achieve these aims, we assessed testosterone and cortisol before and after a lab-based high or low closeness induction task.

2. Method

2.1. Participants and design

Participants were recruited individually from the Introductory Psychology subject pool at a private university in the Northeast U.S. and received course credit for participation. Participants either completed a high closeness task (26 dyads, $N = 52$) or a low closeness task (32 Dyads, $N = 64$).[1] It is important to note that participants were not randomly assigned to each task. Instead, the high-closeness data were collected first, followed by the low closeness data collected in the following months (the low-closeness condition was added later as a comparison group for the high-closeness condition). The sample was relatively diverse, with participants identifying as 52.6% Caucasian, 16.4% African American, 16.4% Hispanic, 5.2% Mixed Race/Ethnicity, and 2.5% Asian (79.3% Female; $M_{age} = 19.70$, $SD = 1.88$).

[1] An additional 26 dyads were not eligible for inclusion in the present data analysis. Some were excluded due to missing testosterone data or saliva not being collected in both dyad members (22 dyads), or participants knowing each other prior to the study (4 dyads). Exclusion from the study was not associated with participant gender ($\chi^2(1) = 2.05$, $p = 0.152$) or being in one of the three prominent racial/ethnic groups in our study (Caucasian, African American, and Hispanic; $\chi^2(2) = 0.44$, $p = 0.804$). However, included participants happened to be slightly younger ($M = 19.70$, $SD = 1.88$) than ineligible participants ($M = 20.38$, $SD = 2.34$; $t(162) = -2.02$, $p = 0.045$).

2.2. Procedure

After providing informed consent, participants were asked to drink a few sips of water in order to facilitate a clean sample of saliva. Participants were also asked prior to the study to refrain from eating for one hour before coming to the lab. Participants taking steroid medications were excluded from the study. Participants were asked to indicate caffeine and nicotine use, exercise, and oral contraceptives use. Oral contraceptive use was not significantly associated with women's testosterone ($ps \leq .083$). Controlling for oral contraceptive use did not alter the significance of any analyses with testosterone. All experimental sessions were conducted between noon and 5:00 p.m. to reduce diurnal fluctuations in testosterone and cortisol (Granger et al., 1999; Schultheiss and Stanton, 2009). Additionally, participants arrived at the lab expecting to have a conversation with a same-sex stranger. The Institutional Review Board approved all procedures.

2.2.1. High closeness task

Participants completed the "Fast Friends" procedure for 40 minutes as outlined in Aron and Aron (1997). Partners in the activity took turns reading and answering a series of 36 questions that progressively escalate in their levels of self-disclosure to experimentally generate interpersonal closeness. Example questions occurring at the beginning of the task include, "Given the choice of anyone in the world, whom would you want as a dinner guest?" Towards the end of the task, participants asked each other questions inviting a higher level of personal disclosure (e.g., "If you were to die this evening with no opportunity to communicate with anyone, what would you most regret not having told someone?"). Closeness is typically achieved as partners take turns answering questions in increasing levels of self-disclosure. An advantage to this paradigm is the elimination of familiarity as a confound of closeness and the isolation of closeness as a variable. This guided self-disclosure reliably results in the two partners reporting closeness levels similar to those seen in their closest relationship (Aron and Aron, 1997).

2.2.2. Low closeness task

Participants completed a series of tasks for 40 minutes, the same time period as the high closeness task, adapted from Steele (1999) that included face-to-face dyadic social interaction with the goal of achieving a lower level of closeness than that of the high closeness task. First, participants were instructed to give each other a series of directions to varying points around campus. They were then asked which series of directions was easiest and hardest for them, and how they felt their partner was at giving directions. Participants then played a geography game. The instructions of the geography game were to take turns thinking of places that began with the same first letter in the alphabet. Lastly, participants in the study took turns reading a passage aloud and answering questions related to reading comprehension. The goal of these activities was to provide a dyadic face-to-face social interaction that does not promote a high level of closeness.

2.2.3. Post-interaction questionnaires

Testosterone (and potentially cortisol) may be associated with not only how close individuals feel to others, but also how close individuals wish to become with others (Edelstein et al., 2014; Turan et al., 2014). Because of this, we investigated both self-reported feelings of closeness and desired closeness during the interactions. Closeness and desired closeness were measured following the social interaction. The measure of closeness was obtained using the Inclusion of Other in the Self scale (IOS: Aron et al., 1992). The IOS scale is a pictorial 7-point Likert scale. The scale depicts two increasingly overlapping circles. Greater overlap between the circles represents greater closeness. For desired closeness, participants were given the instruction to circle the picture that best described their relationship with their partner in the experience and also asked to circle the picture that best described their desired level of overlap with their partner in the experience.

2.2.4. Saliva collection and hormone assays

2.2.4.1. Saliva collection.

Participants provided saliva samples before and after the closeness (high or low) task. The first saliva sample (T1) was collected ten minutes after signing informed consent. The second saliva sample (T2) was collected 20 min after the completion of the task. Salivary testosterone and cortisol concentrations at each time point reflect levels approximately 20 min prior to the sample collection (Granger et al., 1999; Schultheiss and Stanton, 2009). Saliva collection was performed using Salimetrics Oral Swab (Salimetrics, LLC). Swabs were placed under the tongue for 90 s for saliva collection. Samples were sealed in a cryogenic vial and stored in a −20C freezer.

2.2.4.2. Hormone assays.

The saliva samples from the *high closeness condition* were shipped on dry ice to Salimetrics Inc. (Carlsbad, CA). The samples were analyzed for testosterone and cortisol concentrations using Salimetrics Assay kits (Granger et al., 1999, 2004). All samples were assayed in duplicate. Intra-assays CVs were low for testosterone (Avg CV = 5.8%) and cortisol samples (Avg CV = 4.9%), whereas inter-assays CVs were slightly higher for testosterone (Avg CV = 13.6%) compared to cortisol samples (Avg CV = 6.9%).

The saliva samples from the *low closeness condition* were shipped on dry ice to University of Trier (Trier, Germany). The samples were analyzed for testosterone and cortisol concentrations using commercially available kits from Salimetrics Inc. All samples were assayed in duplicate. Intra-assay and inter-assay CVs were low for testosterone (Avg CV = 8.12% and 9.83%, respectively) and cortisol (Avg CV = 9.26% and 6.00%, respectively).

2.2.5. Statistical analyses

Because the pairs in our data violated the independence assumption of typical parametric test, multilevel linear modeling (MLM) was employed to conduct dyadic analysis. We followed the recommendations of Kenny et al. (2006). To show the degree of interdependence, we computed the intraclass correlations (*ICC*s) determined from null, intercepts-only models using a compound symmetry covariance structure for our primary dependent outcome. In particular, the *ICC*s were greater than zero for post-test IOS measures of closeness ($ICC = 0.40$) and desired closeness ($ICC = 0.15$), thus supporting our use of MLM. Unless otherwise specified, our analyses consisted of 2-level MLMs (person-level effects nested within dyads), used an unstructured covariance structure, and had means comparisons performed using type III F-tests.

Given the dyadic nature of our interpersonal interaction methods, it was necessary to consider the hormones of both partners when investigating how they may affect closeness (e.g., Edelstein et al., 2014). Thus, our analyses also tested actor and partner effects, as indicated by the Actor-Partner Interdependence Model (Cook and Kenny, 2005). Specifically, actor effects indicate effects of a predictor on an outcome within the same participant (i.e., a participant's hormones predicting closeness in the very same participant). On the other hand, partner effects are more interpersonal in nature, corresponding to the effect of a variable on an outcome within a different participant (i.e., a participant's hormones predicting his/her partner's degree of closeness). Dual-hormone interactions were assessed by standardizing the predictor variables to center them on zero and multiplying their values to calculate interaction terms.

Table 1
Actor and Partner effects of Basal Testosterone and Testosterone Changes Predicting Closeness.

Actor Effects		Across both conditions			High Closeness Task			Low Closeness Task		
Outcome	Predictor	*B*	*SE*	*p*	*B*	*SE*	*p*	*B*	*SE*	*p*
IOS	Basal T	−1.04	0.35	0.004	−1.34	0.55	0.019	−0.57	0.43	0.198
	T Reactivity	−1.31	0.59	0.029	−1.68	0.97	0.092	−1.04	0.74	0.169
IOS-Desired	Basal T	−0.48	0.19	0.013	−0.70	0.30	0.024	−0.34	0.24	0.168
	T Reactivity	−1.42	0.60	0.021	−1.94	0.97	0.052	−0.97	0.79	0.229
Partner Effects		**Across both conditions**			**High Closeness Task**			**Low Closeness Task**		
Outcome	Predictor	*B*	*SE*	*p*	*B*	*SE*	*p*	*B*	*SE*	*p*
IOS	Basal T	0.08	0.36	0.828	−0.09	0.55	0.867	0.38	0.42	0.371
	T Reactivity	−1.03	0.60	0.092	−0.27	0.93	0.772	−1.53	0.74	0.046
IOS-Desired	Basal T	0.12	0.35	0.733	0.06	0.55	0.913	0.35	0.43	0.42
	T Reactivity	0.00	0.58	0.997	0.93	0.93	0.326	−0.58	0.71	0.421

Note: Separate models were conducted for actor and partner effects. *B* weights represent unstandardized effects from multilevel modeling.
Basal T = Basal Testosterone, T Reactivity = Testosterone changes, controlling for basal testosterone.

As often is the case with hormones, testosterone and cortisol were positively skewed. Thus, we corrected our hormonal data with a natural log transformation. All inferential statistics were derived from natural log transformations, but we present the data, when appropriate, using untransformed raw values. Changes in hormones were assessed by differences between natural log-transformed hormone values. Specifically, we subtracted pre-manipulation hormonal concentrations from post-manipulation hormonal concentrations.

3. Results

3.1. Preliminary analyses

First, we examined whether our closeness tasks produced different levels of closeness. As expected, participants completing the high closeness task reported greater closeness ($F(1,55.85) = 21.47$, $p < 0.001$) and desired closeness ($F(1,56.18) = 11.16$, $p = 0.001$) than participants completing the low closeness task. The summary of these mean differences are presented in Fig. 1.

Consistent with well-known sex differences in testosterone, our preliminary mixed analysis indicated that men had higher basal and post-test testosterone than women ($Fs \geq 32.05$, $ps \leq 0.001$). However, our mixed analysis did not reveal significant sex differences in cortisol ($Fs \leq 2.16$, $ps \geq 0.147$). Although we aimed to examine changes in hormones after the social interaction, our analyses unexpectedly revealed that participants in the high closeness condition had higher testosterone concentration measurements at baseline ($M = 109.20$ pg/mL, $SD = 8.84$) than those in the low closeness condition ($M = 80.39$ pg/mL, $SD = 8.20$; $F(1,54.02) = 6.22$, $p = 0.016$).[2] Because these sex and condition differences presented difficulties in interpreting the effects of testosterone, we controlled for sex and closeness task where appropriate.

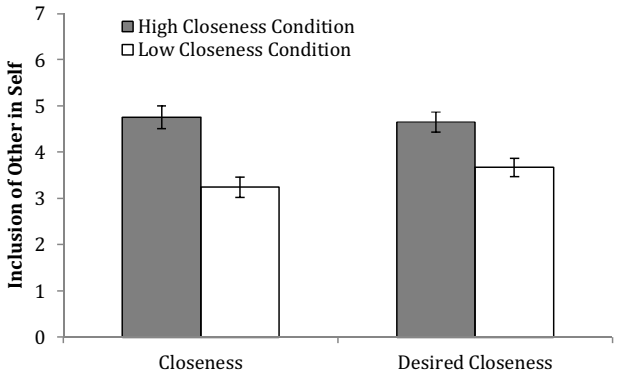

Fig. 1. Differences in Closeness Between the High Closeness and Low Closeness Conditions. Note: Error bars represent standard deviations of the mean.

3.2. Aim 1: Hormones and interpersonal closeness

To test the effects of basal testosterone and cortisol and testosterone and cortisol dynamics on friendship formation, we conducted multilevel dyadic models regressing our two closeness measures on basal hormone and hormone changes for actor and partner effects. We conducted these analyses across both tasks (controlling for gender and closeness task), which provides greater statistical power and heterogeneity in our sample, but then also with each type of task separately (controlling for gender), which increases sample homogeneity but decreases statistical power. The results of these analyses, which we summarize below, are presented in Tables 1 and 2.

3.2.1. Basal Testosterone and closeness

Collapsing data across the two conditions, our multilevel models showed that basal testosterone was associated with decreased closeness in participants. We first examined actor effects of basal testosterone. Specifically, there was an *actor* effect of basal testosterone being negatively associated with IOS closeness ($B = -1.04$, $t(89.30) = -2.97$, $p = 0.004$) and desired closeness ($B = -0.48$, $t(86.23) = -2.54$, $p = 0.013$). This overall pattern was similar when examining the actor effects of basal testosterone separately within the conditions, with basal testosterone having slightly stronger magnitude of associations with perceived and desired closeness in the high closeness condition ($ps \leq 0.024$) than in the low closeness condition ($ps \leq 0.198$). For partner effects of basal testosterone, there were no associations with the closeness outcomes collapsed across both conditions ($ps \geq 0.733$), or within each condition ($ps \geq 0.371$). Collectively, these results suggest that higher basal testosterone is associated with one's own decreased feelings of closeness during the friendship formation process.

3.2.2. Testosterone reactivity and closeness

We then examined the effects of testosterone reactivity in our models (see Table 1). Across both conditions, *actor*

[2] This was not likely due to any systematic differences in numbers of men and women within the low closeness (78.1% women) and high closeness (80.8% women) conditions, as there was no association between closeness task and gender ($\chi^2(1) = 0.122$, $p = 0.727$).

Table 2
Actor and Partner Effects of Basal Cortisol and Cortisol Changes Predicting Closeness.

Actor Effects		Across both conditions			High Closeness Task			Low Closeness Task		
Outcome	Predictor	*B*	*SE*	*p*	*B*	*SE*	*p*	*B*	*SE*	*p*
IOS	Basal C	−0.07	0.24	0.773	−1.42	0.35	<0.001	0.29	0.31	0.925
	C Reactivity	−0.25	0.33	0.456	−1.50	0.50	0.005	0.33	0.44	0.749
IOS-Desired	Basal C	−0.23	0.24	0.344	−1.51	0.36	<0.001	0.05	0.30	0.860
	C Reactivity	−0.22	0.32	0.494	−1.63	0.50	0.002	0.33	0.40	0.415
Partner Effects		**Across both conditions**			**High Closeness Task**			**Low Closeness Task**		
Outcome	Predictor	*B*	*SE*	*p*	*B*	*SE*	*p*	*B*	*SE*	*p*
IOS	Basal C	−0.04	0.24	0.857	−0.16	0.43	0.716	0.04	0.31	0.900
	C Reactivity	−0.44	0.33	0.183	−0.56	0.52	0.295	−0.42	0.44	0.346
IOS-Desired	Basal C	−0.15	0.24	0.545	−0.97	0.37	0.014	−0.01	0.31	0.965
	C Reactivity	−0.46	0.33	0.166	−1.68	0.51	0.002	−0.03	0.40	0.934

Note: Separate models were conducted for actor and partner effects. *B* weights represent unstandardized effects from multilevel modeling.
Basal C = Basal Cortisol, C Reactivity = Cortisol changes, controlling for basal Cortisol.

testosterone changes were negatively associated with perceived closeness ($B = -1.31$, $t(82.28) = -2.22$, $p = 0.029$) and desired closeness ($B = -1.42$, $t(89.84) = -2.35$, $p = 0.021$). Similar to the previous analyses, we investigated these effects separately within both the high and low closeness conditions. Specifically, we found that the trends of actor effects of testosterone reactivity on closeness and desired closeness were more pronounced in the high closeness condition ($ps \leq 0.092$) compared to the low closeness condition ($ps \leq 0.229$). For partner effects, there were no significant associations between testosterone reactivity and any of the closeness variables, either within condition or across both conditions, with one exception. Partners of those that experienced larger increases in testosterone in the low closeness condition reported less closeness ($B = -1.53$, $t(34.16) = -2.08$, $p = 0.046$).

3.2.3. Basal Cortisol and closeness

We also investigated whether basal cortisol was associated with closeness across all of our data (controlling for condition and gender) and then separately within each condition (see Table 2). Basal cortisol was not associated with actor or partner closeness or desired closeness across all data or within the low closeness condition. However, in the high closeness condition, basal cortisol was negatively associated with actor closeness ($B = -1.42$, $t(34.97) = -4.02$, $p < 0.001$), actor desired closeness ($B = -1.51$, $t(33.61) = -4.25$, $p < 0.001$), and with partner desired closeness ($B = -0.97$, $t(33.79) = -2.59$, $p = 0.014$), but not associated with partner closeness ($B = -0.16$, $t(40.99) = -0.37$, $p = 0.716$). Overall, these results suggest that when individuals self-disclose, lower cortisol is associated with feeling closer to others, desiring closeness, and other's desiring closeness in the high closeness condition.

3.2.4. Cortisol reactivity and closeness

We then examined if cortisol changes were associated with our closeness outcomes across all of our data (controlling for condition and gender) and then separately within the high or low closeness conditions (see Table 2). Cortisol changes were not associated with actor or partner closeness or desired closeness across all data or within the low closeness condition. In the high closeness condition, cortisol changes were negatively associated with actor closeness ($B = -1.50$, $t(38.67) = -2.98$, $p = 0.005$), actor desired closeness ($B = -1.62$, $t(38.41) = -3.26$, $p = 0.002$), partner desired closeness ($B = -1.68$, $t(32.15) = -3.32$, $p = 0.002$), but not the extent to which partners' felt close ($B = -0.56$, $t(29.78) = -1.06$, $p = 0.295$). These results suggest that decreases in cortisol across time are associated with increases in feelings of closeness to others, desiring closeness, and other's desiring closeness during high levels of self-disclosure (high closeness condition).

3.3. Aim 2: Associations between friendship formation and hormone changes

Our second aim was to examine whether the closeness-induction paradigm would modulate hormonal responses. For testosterone, we conducted 3-level dyadic MLMs, with time of salivary collection (before the interaction vs. after) nested within individuals, which were in turn nested within dyads. Specifically, our models regressed testosterone concentrations on time of collection (pre vs. post), task (high vs. low closeness), and their interaction effect to test systematic differences in hormonal changes, depending on the level of closeness induction. The conditional means of testosterone raw values (controlling for gender) are plotted by time and interaction condition in Fig. 2. In this model, there was an unexpected effect of condition on testosterone concentrations ($F(1,54.02) = 19.60$, $p < 0.001$), characterized by elevated testosterone among those in the high closeness task ($M = 107.72$ pg/mL, $SE = 5.71$) compared to the low closeness task ($M = 73.80$ pg/mL, $SE = 5.30$). A main effect of time also showed that testosterone levels decreased across time in both conditions (Mdiff = −7.26 pg/mL, $SE = 2.18$; $F(1,48.21) = 17.17$, $p < 0.001$). Importantly, however, there was a significant time X condition ($F(1,48.22) = 4.33$, $p = 0.043$). This interaction was characterized by a significant decrease in testosterone from pre to post ($M_{diff} = -9.93$ pg/mL, $SE = 3.09$) in the low closeness task participants (simple effect $F(1,52.04) = 19.37$, $p < 0.001$). However, there was no significant decrease in testosterone in those completing the high closeness task (simple effect $F(1,44.69) = 2.13$, $p = 0.152$).

We also explored whether gender moderated these effects, as other research has found that gender moderates whether interactions—specifically, competition—affect testosterone responses (Carré et al., 2013). When added to the above model as a moderator, gender did not moderate the effects of time, closeness task, or the time X condition interaction on testosterone ($Fs \leq 1.58$, $ps \geq 0.215$).

For cortisol, we conducted another 3-level MLM regressing cortisol concentrations on the condition, time, and the condition X time interaction, controlling for gender. This analysis revealed only a significant main effect of time ($F(1,56.26) = 80.15$, $p < 0.001$), reflecting the tendency for cortisol levels to decrease from before the task ($M = 217.91$ ng/dL, $SE = 16.36$) to after ($M = 149.61$, $SE = 11.30$; see Fig. 2). The condition main effect ($F(1,56.09) = 0.72$, $p = 0.400$) and condition X time interaction ($F(1,56.26) = 0.31$,

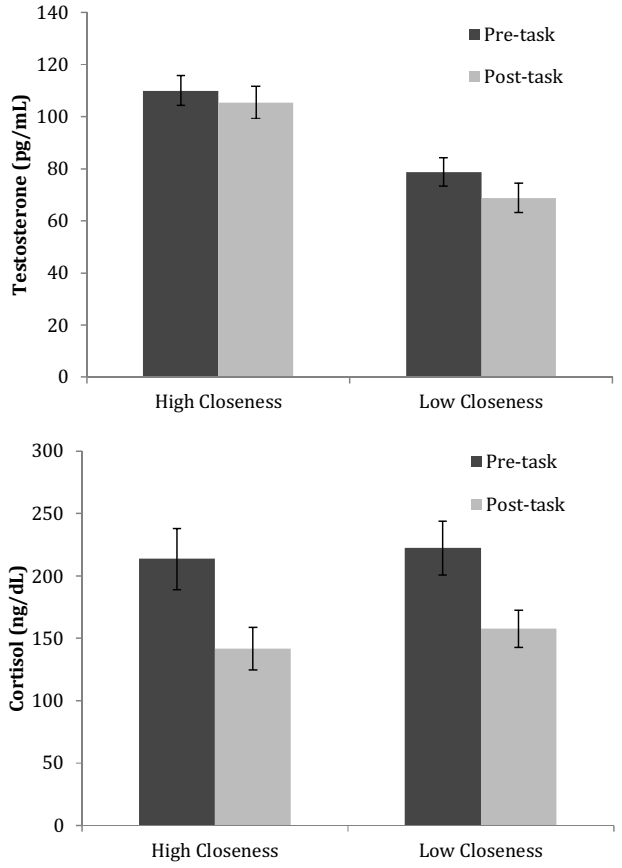

Fig. 2. Differences in testosterone and cortisol before and after the social interactions in each condition. Note: Error bars represent standard errors.

$p = 0.579$) were nonsignificant, and controlling for gender did not alter the significance of any results.

3.4. Aim 3 (Exploratory): Dual-hormone interactions predicting closeness

Because researchers have been increasingly examining hormonal interactions using a multi-systems approach, (Bauer et al., 2002; Marceau et al., 2015; Mehta and Prasad, 2015), we explored whether basal testosterone and cortisol, as well as changes in testosterone and cortisol, were associated with our closeness measures, controlling for gender and closeness condition. We additionally examined whether these interactions occurred as actor effects or partner effects. There were no significant basal testosterone by basal cortisol interactions predicting the closeness measures as actor effects ($|t|$s ≤ 0.98, $ps \geq 0.329$) or partner effects ($|t|$s ≤ 0.18, $ps \geq 0.858$). Additionally, there were no testosterone change X cortisol change interactions predicting the closeness measures as actor effects ($|t|$s ≤ 0.34, $ps \geq .732$).

On the other hand, changes in testosterone and cortisol significantly interacted to predict our closeness measures as a partner effect. However, there was no clear pattern of simple slopes (see supplemental results, plotted at ± 1 *SD*s) within these interactions and the pattern was not consistent with those previously found investigating changes in testosterone and cortisol (e.g., Mehta et al., 2015). First, within the interaction of cortisol and testosterone changes predicting perceived closeness ($b = 0.28$, $t(83.86) = 2.03$, $p = 0.045$), the trend between testosterone changes and closeness ($b = -0.36$, $t(83.86) = -1.53$, $p = 0.133$) was more negative when cortisol changes were low, than when cortisol changes were high ($b = -0.08$, $t(83.86) = -0.37$, $p = 0.713$). Second, within the interaction of cortisol and testosterone changes predicting desired closeness ($b = 0.34$, $t(87.49) = 2.51$, $p = 0.014$), there was a positive association between testosterone changes and desired closeness when cortisol was high ($b = 0.44$, $t(87.49) = 2.17$, $p = 0.034$), but no association when cortisol was low ($b = -0.24$, $t(87.49) = 1.07$, $p = 0.290$). Future work is needed to replicate these inconsistent exploratory findings.

4. Discussion

There is a growing body of evidence suggesting that hormone levels play an integral role in relationship processes and that social relationships may in turn shape hormone levels. Our study contributes to a new line of inquiry examining the dyadic effects of testosterone and cortisol in humans. In particular, the current research investigated how both basal testosterone and cortisol and testosterone and cortisol changes over the course of a same-sex dyadic interaction were associated with feelings of closeness. We found that those who had lower testosterone and cortisol at baseline and showed greater decreases in these hormones felt closer to their interaction partner, on average.

A key strength of the current study was the investigation of actor and partner effects in these hormones. According to the Actor-Partner Interdependence Model (Cook and Kenny, 2005), the presence of actor effects indicates that one's basal testosterone levels as well as testosterone change predict one's own feelings of closeness during the friendship formation process. Partner effects were not present, indicating that a participant's testosterone level did not predict their partner's degree of closeness, with one exception: Partners of those who experienced larger decreases in testosterone in the low closeness condition reported greater closeness. In sum, these results demonstrate that those with lower basal testosterone and greater testosterone decreases felt closer to others and desired more closeness, and that actor effects drove these associations. Altogether, these results suggest that not only do testosterone levels correlate with closeness, they may also respond to the social environment.

Previous work suggests that higher basal testosterone may be associated with decreased satisfaction in romantic relationships (Edelstein et al., 2014). The present study supports this general concept and extends these findings to indicate that testosterone may be associated with lower levels of closeness during friendship formation. The current study also found that testosterone decreased more within individuals that became relatively closer. This effect lends support to the theory that a nurturant social context may serve as a feedback loop where the social environment influences hormone levels (van Anders et al., 2012; Wingfield et al., 1990).

In support of this theory, our study and the results of others' research suggest that low testosterone is associated with stronger social bonds. Research in this emerging field collectively paints a complex and intriguing picture of how testosterone is linked to prosocial behavior. On the one hand, higher testosterone has been associated with aggressive tendencies and decreased trust and empathy (e.g., Bos et al., 2010; Hermans et al., 2006). On the other hand, when status may be obtained from an interaction, exogenous administration of testosterone appears to promote the prosocial behaviors of generosity and reciprocity (Boksem et al., 2013; Zak et al., 2009). These results suggest that when status is threatened, testosterone may promote aggression, dominance, and potentially antisocial behavior (Mazur and Booth, 1998; Mehta et al., 2008). When social status is obtained by prosociality, testosterone may enhance those behaviors (Boksem et al., 2013; Zak et al., 2009). Testosterone is potentially less beneficial once higher sta-

tus is established, and prestige may have a potentially inhibiting effect on testosterone. High prestige men tend to have lower basal testosterone (Johnson et al., 2007). Further, those who seek status through prestige, or sharing expertise, tend to be more liked than those who seek status via dominance and aggression (Cheng et al., 2013). Together, these findings suggest that testosterone's effect on behavior may be context-specific. In a friendship context, where status is likely not as important (when compared to more competitive contexts), our results suggest testosterone is associated with decreased closeness. Given that emotional closeness may underlie empathy (Müller et al., 2013), the present findings lend support to the concept that testosterone may inhibit prosociality in a friendship context. More research is needed to clarify how testosterone and prosociality are related.

The present findings lend support to the idea that testosterone is associated with decreased closeness in friendship formation. However, the current results may not generalize to other contexts of social bonding, such as initiating romantic relationships or caregiving. For example, work by Slatcher et al. (2011) suggests that both elevated dominance and testosterone may contribute to greater success at gaining the attention of potential mates. These and other findings suggest testosterone may facilitate sexual relationships in humans and nonhuman animals (Beehner et al., 2006; Slatcher et al., 2011; Wingfield et al., 1990). Recent work also suggests that testosterone is positively associated with centrality and popularity in social networks when cortisol is low (Ponzi et al., 2016). This work raises the possibility that testosterone may be instrumental in initiating freely elected social bonds, beyond just those formed in a laboratory. Future work is needed to examine the roles of testosterone and cortisol in dyadic contexts other than laboratory-based friendship formation.

We also investigated whether basal cortisol was associated with closeness and desired closeness during friendship formation, examining both actor and partner effects. In the high closeness condition, those with higher cortisol displayed reduced closeness and reduced desired closeness. Further, we found partner effects for cortisol and closeness in that those with higher basal cortisol had partners who desired to be less close to them. Basal cortisol was not associated with actor or partner closeness or desired closeness across all data or within the low closeness condition. Altogether, these findings suggest that when individuals self-disclose in a high closeness laboratory task, lower cortisol is associated with feeling closer to others, desiring closeness, and others desiring closeness in the high closeness condition.

We also found that cortisol reactivity was associated with closeness as both an actor and partner effect. Results indicated that individuals who showed more decreased levels of cortisol—those who may have been less stressed during the interaction or became less stressed over time—felt greater closeness with their partners and believed that their partners desired to be closer to them. The causality of these associations is unclear: Do lower cortisol levels or decreases in cortisol lead to greater closeness? Or rather, does becoming close drive changes in cortisol? The latter is less likely, given that there were no condition X time interaction effects for cortisol. Our results also suggest that higher cortisol is associated with less closeness in laboratory-based social interaction. Researchers have begun to examine the influence of cortisol on social behavior in a naturalistic setting. For example, female caregivers with higher basal cortisol displayed lower-quality caregiver behavior (de Schipper et al., 2009). Our findings support recent research on the importance of cortisol reactivity in close dyadic social interactions. For example, women with avoidant attachment, and the partners of insecurely attached women, display greater cortisol reactivity to conflict discussions (Beck et al., 2013; Powers et al., 2006), indicating that cortisol reactivity is associated with both actor and partner effects in a dyadic interaction. Cortisol reactivity during social interactions holds potential health implications. For instance, an immune response may follow an HPA-axis response (Sapolsky et al., 2000), indicating potential negative health consequences of cortisol reactivity in a friendly social interaction. In addition, our results indicate that lower cortisol levels during friendship formation are associated with increased closeness for the actor and the partner. Given the positive health benefits associated with close relationships (i.e. Holt-Lunstad et al., 2010; Robles et al., 2014), and increased social support (i.e. Uchino, 2009), it seems worthwhile to further examine the physiology of new social bonds. Further, partner effects in close relationships point to the importance of considering how one's partner in a relationship affects the individual's hormones and health (Edelstein et al., 2014).

Our results also indicate that those with lower cortisol levels had partners with a greater desire to be close to them. This supports a recent finding using a social network analysis that indicated that males with lower cortisol were more popular and more likely to act as social connectors (Ponzi et al., 2016). On the flip side, those who go to bed feeling lonely experience higher cortisol awakening response the next morning (Doane and Adam, 2010). Together, these findings suggest that social interactions may play a key role in shaping our hormone responses and that our hormones may shape our social interactions. Future research is needed to examine these possibilities and test the directionality of the association between cortisol and closeness.

In terms of a multisystem approach and the dual-hormone hypothesis, we did not find that testosterone and cortisol jointly predicted closeness as an actor effect. However, we found partner effects in that changes in testosterone and cortisol significantly interacted to predict partners' closeness, but in no consistent manner. Future research is needed to replicate these exploratory findings and determine if testosterone and cortisol changes are differentially associated with how close others feel and want to feel toward the person experiencing the hormonal changes.

This work is not without limitations. First, the laboratory closeness manipulation was successful and participants became significantly closer in the high closeness task versus the low closeness task. However, comparing the differences in closeness between the two tasks suggested these tasks may be better categorized as high and moderate closeness, rather than high and low closeness. Anecdotally, a few participants reported that they made a new friend following the low closeness task.

Although, like the present study, previous research has examined pre/post changes in hormones (see Brown et al., 2009; Carré et al., 2013; Edwards and Casto, 2013; Mehta and Josephs, 2006; Mehta et al., 2015; Norman et al., 2015; Page-Gould et al., 2008), future work could measure testosterone and cortisol changes through multiple points during the interaction. This would elucidate subtle variability in hormonal changes during friendship formation and their associations with closeness.

Our two conditions had systematic differences in participants' basal testosterone levels, which hindered the ability to make comparisons in the changes and differences in hormonal correlates across these conditions. It was clear from our analyses that this was not attributable to gender differences between these samples. Although we used the same enzyme immunoassay kits for both conditions, it is possible that these hormonal differences across the two conditions were due to different assay techniques used by the two labs to which the saliva samples were shipped. It is necessary in the future to test experimental manipulations of closeness with minimal possibility for systematic bias between different tasks.

Findings from the present study are correlational in nature and rely on basal hormones and dynamic hormone reactivity. To establish whether testosterone and cortisol causally influence friendship formation, future studies should examine the effect of exogenous administration of these hormones on closeness. In addition, col-

lecting more samples within the period (e.g., samples targeting testosterone and cortisol during the middle of the manipulation) could elucidate the process and timing involved in these effects.

Future research also needs to investigate the mediating and moderating psychological mechanisms explaining how hormones are related to closeness. Previous research indicates administration of testosterone decreases empathy, mimicry, and trust (Boksem et al., 2013; Bos et al., 2010; Hermans et al., 2006). Given that these interpersonal processes are critical to making social connections and forming close relationships, they are plausible mediators of the effects we reported in the current study. Another potential mediator could be self-disclosure, or the act of revealing one's thoughts, feelings, and facts about the self to another (Laurenceau et al., 1998). For example, prior work has shown that women with higher levels of testosterone are more likely to view post-sex communication and self-disclosure as being higher risk and offering lower benefits, potentially suggesting a mechanism contributing to the relationship between high testosterone and low relationship satisfaction (Denes et al., 2016; Edelstein et al., 2014). Considering the role of personality, extraversion has been implicated as a moderator of the link between women's testosterone and romantic relationship status (Costa et al., 2015). Investigating these potential mediators and moderators may provide an understanding of the mechanisms underlying the neuroendocrinology of friendship formation.

5. Conclusion

Based on our results and the emerging findings of others, hormones such as testosterone and cortisol may be associated with closeness in romantic relationships as well as friendships. Further, these hormones may influence social processes in the early stages of the formation of close relationships. Thus, in the context of other hormonal mechanisms and biomarkers associated with closeness (e.g., oxytocin, vasopressin; see van Anders and Gray, 2015 for a review), decreased testosterone and cortisol may be mechanisms of social facilitation. Although many of the existing studies present a correlational snapshot of associations between hormones and social intimacy, there is a growing need to extend this work into longitudinal studies and pharmacological manipulations of hormones. The potential for reciprocal, bidirectional effects between hormones and closeness demand a more nuanced approach to account for how hormones may contribute to the formation, maintenance, and potential destruction of social bonds. Further, incorporating a multisystems approach, where both the HPG and HPA axes are examined in concert, may be important as researchers consider the role of potential joint contributions of testosterone and cortisol on social behavior. Future exploration of mediating factors could further delineate the role of hormones in dyadic social interactions. This research may elucidate the neuroendocrinology of closeness and the biological mechanisms of the formation of social bonds.

Conflicts of interest

None.

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Contributors

The contributors to this manuscript are Sarah Ketay, Keith M. Welker, and Richard B. Slatcher. Sarah Ketay was involved in the conception and design of the study, acquisition of data, interpretation of data, and in drafting the article and revising it critically for important intellectual content. Keith Welker was involved in analysis and interpretation of data and drafting the article and revising it critically for important intellectual content. Rich Slatcher was involved in data analysis and interpretation and drafting the article and revising it critically for important intellectual content.

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Appendix A. Supplementary data

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