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Testosterone to cortisol ratio and aggression toward one's partner: Evidence for moderation by provocation

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ABSTRACT

Background: Consistent with the dual-hormone hypothesis, the combination of high testosterone levels and low cortisol levels has been linked to increased dominant and aggressive behaviors. However, recent research indicates that this association is weaker or even reversed following provocation. It is also unclear whether the association between testosterone/cortisol and aggression is similar for men and women and for those with and without attention-deficit/hyperactivity disorder (ADHD).

Methods: Using data from a larger project examining ADHD in the context of romantic relationships, the current study tested the dual-hormone hypothesis in 32 heterosexual young adult couples who engaged in a conflict discussion and a competitive reaction time task in the laboratory. Aggressive behavior was indexed by greater noise blast intensity toward one's partner during the competitive reaction time task. Two potential sources of provocation were examined: 1) affective responses to a conflict discussion task preceding the competitive reaction time task, and 2) whether participants received/did not receive a noise blast before the first two trials of the competitive reaction time task. Salivary testosterone and cortisol were assessed three times throughout the laboratory session, and the ratio of testosterone to cortisol output across the session (T/C AUCg ratio) was calculated.

Results: Consistent with the dual-hormone hypothesis, greater AUCg T/C ratios were associated with greater aggression. Further, T/C ratio–aggression associations were weaker under provoked conditions but did not differ as a function of sex or ADHD status.

Conclusions: Results provide support for the dual-hormone hypothesis and suggest that provocation may be an important moderator of the T/C–aggression relationship.

1. Introduction

Human aggression comes in numerous forms including physical assault, domestic violence, and homicide. Aggression can be broadly defined as "behavior directed towards another individual that is carried out with the proximate (immediate) intent to cause harm" (Bushman and Anderson, 2001, p. 274); and can be further classified as reactive or proactive aggression (Buss, 1962). Reactive forms of aggression generally emerge because of provocation, involve little to no premeditation, and are characterized by the intent to cause harm. In contrast, proactive (i.e., instrumental) aggression involves little to no anger, premeditation, and serves to fulfill a goal beyond harm (e.g., obtaining a valuable item). Considerable work has been carried out to identify predictors of human aggression. Among this body of work is the study of the hormonal underpinnings of human aggression, which has seen a renewed interest with the introduction of the dual-hormone hypothesis (for review, see Mehta and Prasad, 2015).

The dual-hormone hypothesis posits that testosterone and cortisol have joint influences on motivation and behavioral systems that shape dominance and aggression (Batrinos, 2012; Mehta and Prasad, 2015; Montoya et al., 2012; Terburg et al., 2009). Testosterone is the end-product of the hypothalamic-pituitary-gonadal axis, and an anabolic steroid hormone that is robustly associated with aggression in animals (Brain and Haug, 1992). In humans, the direct relationship between testosterone and dominant or aggressive behaviors appears less consistent (Archer et al., 2005). One reason for this inconsistency may be that human social behaviors are subject to more diverse forms of hormonal regulation than animals. Human studies show that the behavioral inhibition system is modulated by cortisol, a catabolic steroid hormone and end-product of the hypothalamic-pituitary-adrenal axis,

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such that low cortisol levels have been tied to callousness and antisocial behavior (Corominas et al., 2012; Shirtcliff et al., 2009). Accordingly, the dual-hormone hypothesis states that testosterone's role in dominant and aggressive behavior depends on cortisol, such that the combination of high testosterone and low cortisol would predict aggressive behavior. To account for the co-regulatory effects of both hormones, testosterone-cortisol ratios may be more useful to the prediction of human aggression than either testosterone or cortisol independently (Terburg et al., 2009).

Thus far, the dual-hormone hypothesis has been supported in the context of dominant leadership behaviors (Mehta and Josephs, 2010), risk-taking (Mehta et al., 2015), and aggression (e.g., Dabbs et al., 1991; Popma et al., 2007). For example, Popma and colleagues (2007) found that cortisol moderated the relationship between testosterone and self-reported overt aggression in delinquent adolescent males, such that the positive association between testosterone and self-reported aggression was stronger among those with lower cortisol. Similarly, Dabbs et al., (1991) reported that the positive relationship between testosterone and violent crimes was larger among young inmates with lower cortisol relative to high cortisol.

Although some evidence supports the dual-hormone hypothesis in the context of aggression, results have not been unequivocal (Denson et al., 2013; Geniole et al., 2011). Prior studies imply that provocation alone may be enough to spark aggression independently of testosterone and cortisol. For example, men who were provoked by social exclusion prior to completing a behavioral aggression task did not show the predicted testosterone x cortisol interaction effect on aggression (Geniole et al., 2011). Support for the dual-hormone hypothesis was only found for socially included men, for whom testosterone was positively associated with aggression when cortisol levels were low. Denson et al. (2013) also found that the dual-hormone hypothesis was not supported by data from women who were provoked. Women in this study were given the opportunity to retaliate against an individual who previously insulted them by administering noise blasts. Contrary to the predictions of the dual-hormone hypothesis, testosterone was positively associated with aggression among women with *high* but not low levels of basal cortisol. Taken together, prior research implies that the interactive effect of testosterone and cortisol on aggressive behaviors may be weaker (or even reversed) when aggression is provoked. Yet only two studies to date have tested predictions of the dual-hormone hypothesis in the context of provoked aggression (using male-only or female-only samples) and have reported divergent findings.

Finally, the relatively new dual-hormone hypothesis could benefit from being tested in more varied contexts. For example, to the authors' knowledge, no studies have tested the dual-hormone hypothesis among couples. The dual-hormone hypothesis may be a powerful predictor of intimate partner violence, and provocation may be more frequent in the context of intimate relationships. Moreover, predictions of the dual-hormone hypothesis remain untested in individuals with attention-deficit/hyperactivity disorder (ADHD). Young adults with ADHD are more likely to perpetrate interpersonal aggression than adults without ADHD (Fang et al., 2010; Wymbs et al., 2012, 2016), and the dual-hormone hypothesis could help explain this difference.

In summary, the present study aims to test predictions of the dual-hormone hypothesis in a sample of young adult couples with and without ADHD. Based on the dual-hormone hypothesis, we expected that greater ratios of testosterone to cortisol (T/C ratios) would predict greater aggression. In addition, we also explored whether the T/C ratio-aggression association differed by sex and ADHD status. Finally, we tested whether the T/C ratio-aggression association would be weaker following provocation, which was examined in two ways. First, affective responses to the couples' conflict discussions were used as a measure of provocation, with more negative/less positive affect indicating greater provocation. We predicted that the positive relationship between T/C ratio and aggression would be weaker for individuals who expressed greater negative affect and lower positive affect during the conflict discussion task relative to individuals who expressed lower negative affect and greater positive affect during the conflict discussion task. Second, the present study used a standardized aggression task where participants are led to believe that they lose the first trial and receive a white noise blast from their partner. Thus, the order of trial served as an indicator of provocation, such that aggression on the first trial is unprovoked whereas aggression on the second trial is provoked. Accordingly, we hypothesized that the positive relationship between T/C ratio and aggression would be weaker on the second (provoked) trial than on the first (unprovoked) trial.

2. Material and method

2.1. Participants

Heterosexual adult couples ($N_{couples} = 32$) were recruited as part of a larger project examining the dynamics of ADHD in close relationships among emerging young adults (Wymbs, 2018). Emerging young adult (18–25) were targeted because the larger project examined intimate partner violence and this age group reports the highest frequency of intimate partner violence (Black et al., 2011). Participants were recruited using flyers, advertisement via the psychology department research participant pool, as well as a registry of former participants who agreed to be contacted for future studies. Participants were eligible if they were 1) 18–25, 2) heterosexual, 3) in a relationship for at least 3 months, and 4) had never been physically aggressive with their current/prior partners in public or been arrested for assault. In addition, participants were asked to refrain from consuming any caffeine, alcohol or cigarettes, or engaging in vigorous exercise during the four hours preceding the laboratory visit. As part of recruitment, participants underwent screening procedures aimed at confirming ADHD diagnosis. More specifically, participants where considered to have ADHD if: 1) they were diagnosed with ADHD before the age of 13, and 2) presented with elevated symptoms on the ADHD Self-Report Scale Screener (i.e., > 13; Kessler et al., 2005, 2007), 3) exhibited at least four clinically significant DSM-IV symptoms of inattention or hyperactivity/impulsivity either on the Conners Adult ADHD Rating Scale-*Self Report* or on the Conners Adult ADHD Rating Scale-*Partner Report* (Conners et al., 1999), and 4) scored above 2 in at least one domain of functioning on the Impairment Rating Scale (Fabiano et al., 2006).

Two couples where both partners had ADHD, 18 couples where at least one member had ADHD and 12 couples where neither partner had ADHD were included in the present project. This manuscript focuses on a subset of this sample who provide valid cortisol and testosterone data, as well as valid behavioral aggression data (N = 61; 29 couples and 3 individuals unpaired with their partners due to missing data). See Table 1 for descriptive characteristics of the final sample. Among the final sample, 13 individuals reported taking ADHD medication, 8 reported oral contraception, and 1 reported selective serotonin reuptake inhibitor (SSRI) medication. Controlling for use of ADHD medication, oral contraception, or SSRI intake did not influence the present results, and medication use did not moderate any of the results presently reported.

2.2. Procedure

All laboratory sessions began between 10:50 AM and 7:00 PM. Upon arriving at the laboratory, participants provided consent and completed questionnaires assessing self and partner's behavior, coping strategies, conflict resolution strategies, and substance use. Next, partners were moved to separate rooms, seated by a computer, and randomly assigned to complete a six-minute self-control resource depletion or control task. More specifically, all participants watched a 6-minute video (without audio) of a woman being interviewed. During the video, common one-syllable words (e.g., "TREE") were shown at the bottom of the screen (for 10 s each). Participants assigned to the control resource depletion

Table 1
Descriptive characteristics of the final sample.

Characteristic	N	%	M	SD
Biological Sex				
Male	32	52.5		
Female	29	47.5		
Race/Ethnicity				
White (non-Hispanic)	56	91.8		
Hispanic	3	4.9		
Mixed Race	2	3.3		
ADHD status				
Diagnosed	22	36.1		
Not Diagnosed	39	63.9		
Age (years)	61		20.27	1.45
Relationship Length (months)[a]	51		19.26	17.24
Testosterone (μg/dL)				
Baseline	61		374.84	256.31
pre-TCRTT	61		352.81	272.74
post-TCRTT	61		339.94	222.78
Cortisol (nmol/L)				
Baseline	61		10.40	8.94
pre-TCRTT	61		9.30	8.65
post-TCRTT	61		9.12	8.52
ln (T/C ratio)				
Baseline	61		−3.65	0.80
pre-TCRTT	61		−3.73	0.86
post-TCRTT	61		−3.74	0.87
ln (T/C AUCg ratio)	61		−3.69	0.82
Average Noise Blast Intensity	61		5.63	2.54
ln (NA/PA ratio)	61		−1.34	0.63
Positive Affect	61		6.23	0.92
Negative Affect	61		1.85	1.10

[a] denotes variables with missing data. ADHD = attention-deficit/hyperactivity disorder; AUCg = area under the curve with respect to ground; NA/PA = negative affect/positive affect; T/C = testosterone/cortisol; TCRTT = Taylor Competitive Reaction Time Test.

condition were instructed to maintain their attention on the woman's face and ignore the words shown at the bottom of the screen (thus depleting control resources by requiring them to stop themselves from attending to novel stimuli; Finkel et al., 2009; Watkins et al., 2013). In contrast, participants assigned to the no control condition were given no instructions and no prior knowledge of the words shown at the bottom of the screen during the video. In the present sample, 14 participants were assigned to the resource depletion condition whereas 47 were assigned to the control condition. This manipulation was used to examine the effect of ADHD status and strained self-control resources on a subsequent couple's conflict discussion task. See Wymbs (2018) for a review of the effect of this manipulation on affective responses to subsequent tasks in the present sample.

Following the six-minute self-control resource depletion task, participants were reunited with their partners and asked to discuss three topics identified as sources of contention in their relationships for 15 min. More specifically, each couple rank ordered the top 5 areas of discord in their relationship from a list of 21 topics often reported as a source of conflict in relationships (Kerig, 1996), and discussed the top 3 topics (5 min per topic). These discussions were video recorded to allow for observational coding. Finally, participants were guided to separate rooms once again and completed a modified version of the 15-minute Taylor Competitive Reaction Time Test (TCRTT) to measure behavioral aggression (Bushman, 1995; Epstein and Taylor, 1967). All procedures were approved by the Ohio University Institutional Review Board.

2.3. Primary measures

2.3.1. Salivary cortisol and testosterone

Saliva samples were collected using Salivette sampling device (Sarstedt, Inc., Newton, N. C.) on three occasions (i.e., immediately prior to the 6-minutes control depletion task, immediately prior to the TCRTT, and immediately following the TCRTT). Research assistants recorded the time at which each saliva samples were obtained. On average, baseline samples (i.e., immediately prior to the 6-minutes control depletion task) were collected approximately 32 min prior to pre-TCRTT samples and 48 min prior to post-TCRTT samples. Samples were stored at −20 °C. All saliva samples were centrifuged and assayed at Ohio University using standard enzyme-linked immunoassay procedures. All samples used to determine cortisol concentrations were assayed in duplicate and averaged, with a mean sensitivity of 0.071 ng/mL (Diagnostic Systems Laboratories, Inc., Webster, TX). Similarly, all samples used to infer testosterone concentrations were assayed in duplicate and averaged, with a mean sensitivity of 1.0 pg/mL (Salimetrics, LLC, State College, PA). Mean intra-assay precision was 7.0% for the cortisol assays and 4.6% for the testosterone assays. Inter-assay precision was 9.8% for testosterone and 10.4% cortisol.

2.3.2. Couples conflict discussion ratings

Video recording of the 15-min conflict discussion task in which couples discussed the three largest areas of conflict in their relationship were subsequently coded by two undergraduate research assistants who were blind to study conditions. Coding was completed using the Interactional Dimensions Coding System: Problem Discussion (IDCS-PD; Kerig and Baucom, 2004). The IDCS- PD is a global coding system in which overall scores for the entire discussion are derived from 14 different elements, including 9 dimensions of individual problem-solving behavior (for which each member of the couple is rated separately) and 5 dimensions of dyadic problem-solving behavior (for which the couple is rated together). Each dimension is scored on a 9-point Likert-type scale, with 1 being extremely uncharacteristic of the interaction and 9 being extremely characteristic of the interaction. IDCS-PD coders scored individual dimensions for the each of the three five-minute segments of the interaction and averaged these scores to determine overall scores for the dimensions. Coders scored the entire discussion as a unit when coding dyadic dimensions. Overall scores and scores for dyadic dimensions were averaged between the two coders (positive affect ICC = .792; negative affect ICC = .881). Affective responses to the conflict discussion task were determined using the ratio of negative affect to positive affect (negative affect to positive affect ratio = ln [negative affect / positive affect]), where larger ratios indicate more negative/less positive responses to the discussion task ($M = -1.34$, $SD = .63$). To examine the independent influence of positive and negative affect, analyses of affective responses to the conflict discussion were repeated using the positive affect ($M = 6.23$, $SD = 0.92$) and negative affect ($M = 1.85$, $SD = 1.10$) separately.

2.3.3. Behavioral aggression

Behavioral aggression was measured using a modified version of the Taylor Competitive Reaction Time Test (TCRTT; Bushman, 1995; Epstein and Taylor, 1967). Participants were seated at a computer and told that they would play a "reaction time game" against their partner. More specifically, participants were told that their partner and themselves will be simultaneously shown a stimulus on the screen and should press a key as soon as they saw the stimulus. To win a trial, participants were told that they should press the key before their partner. Additionally, prior to each trial, participants were prompted to set the duration and intensity of a noise blast (i.e., white noise) to be administered to their partner as "punishment" in the reaction time game. More specifically, participants were told that if they win a trial, their partner would hear the noise blast they had set, whereas if they lost a trial, the participants would hear the noise blast that their partner had set. In fact, participants were playing against a computer, and the sequence of wins, losses, and their "partner's" noise blast settings (i.e., duration and intensity) were predetermined. Participants selected noise blast duration by clicking on a scale ranging from 0 to 10 (corresponding to 0.5–2.0s). Similarly, participants selected noise blast intensity by clicking on a scale ranging from 0 to 10 (corresponding to

50–100 decibels). Consistent with prior work using the TCRTT (Anderson and Dill, 2000), participants completed a total of 25 trials and won 13. The first trail was always a loss to ensure that duration/intensity ratings corresponding to the first trial were indicative of *unprovoked aggression* whereas duration/intensity ratings corresponding to the second trial were indicative of *provoked aggression*. Only the first two trials of the TCRTT were recorded. Prior work suggests that noise intensity is a more valid measure of aggression than duration (Ferguson et al., 2008). As such, noise intensity levels across the first and second trial were averaged to yield an overall behavioral aggression measure ($M = 5.64$, $SD = 2.54$). Additionally, noise intensity levels of the first ($M = 4.49$, $SD = 2.56$), and second ($M = 6.79$, $SD = 3.43$) trials of the TCRTT were used to infer unprovoked and provoked behavioral aggression, respectively. For completeness, analyses of noise blast duration are reported in the appendix.

2.4. Analytic plan

Temporal changes in cortisol levels, testosterone levels, and Testosterone/Cortisol ratios (T/C ratios) were modeled using 3-level mixed linear models where sampling occasions were nested within individuals and individuals were nested within couples (i.e., level 1 = sampling occasions; level 2 = individuals; level 3 = couples). Time was coded as hours since the first saliva sample. Individual level intercepts and linear slopes relating time to hormone levels were modeled as random effects using an unstructured covariance matrix. Furthermore, couple level intercepts were modeled as random effects to account for the dyadic nature of the data (Kenny et al., 2006). Salivary cortisol and testosterone concentrations were log-transformed prior to analyses to render level 1 residuals normally distributed. Furthermore, T/C ratios were also log-transformed prior to analyses to ease interpretation and comparison with other work (Sollberger and Ehlert, 2016); log transforming a ratio ensure that the strength of its relationship with a given variable is independent of the order in which it was computed (i.e., A/B v. B/A).

Preliminary analyses revealed that salivary testosterone and cortisol showed a steady linear decline throughout the experiment ($b = -0.125$, $F(1,54.75) = 11.44$, $p = .001$, $b = -0.249$, $F(1,58.39) = 12.30$, $p = .001$ respectively) suggesting no reactivity to study procedures. Furthermore, T/C ratios did not vary as a function of time ($b = .122$, $F(1,58.33) = 2.72$, $p = .10$). As such, cortisol and testosterone levels across the entire visit were computed as Area Under the Curve relative to ground (AUCg) using the trapezoidal method (Pruessner, Kirschbaum, Meinlschmid, & Hellhammer, 2003), and the ratio of testosterone to cortisol secreted over the entire visit was computed as follows: T/C AUCg ratio = ln(Testosterone AUCg / Cortisol AUCg).

Behavioral aggression (e.g., average noise blast intensity on the TCRTT) was predicted using two-level mixed models where individuals were nested within couples (i.e., where level 1 = individuals; level 2 = couples). Once again, couple level intercepts were modeled as random effects to account for the dyadic nature of the data. T/C AUCg ratio was entered as a level 1 fixed effect to test the joint influence of testosterone and cortisol on behavioral aggression. Negative affect to positive affect ratio (NA/PA ratio) and the interaction of NA/PA ratio by T/C AUCg ratio were also entered as a level 1 fixed effects to assess the degree to which provocation during the conflict discussion task moderated the relationship between T/C ratio and aggression. Finally, analyses predicting average noise blast intensity on the TCRTT as a function of T/C AUCg ratio were repeated while substituting average noise blast intensity with either noise blast intensity to the first or second trial of the TCRTT. In doing so, we aimed to compare the effect T/C ratio on a measure of unprovoked aggression (first trial) to the effect of T/C ratio on a measure of provoked aggression (second trial).

Prior work suggests that cortisol and testosterone levels differ between men and women (Dabbs, 1990; Kirschbaum et al., 1999), and follow a circadian rhythm (Chida and Steptoe, 2009; Dabbs, 1990). As such, biological sex (coded as male = 0; females = 1), and the time of day during which the experimental session began (coded as hours passed between midnight and the first saliva sample) were included as covariates. Finally, the present analyses also included sex and ADHD status as potential moderators.

3. Results

3.1. Preliminary analyses

3.1.1. Tests of proposed covariates

Testing for sex difference revealed that males displayed significantly greater testosterone AUCg ($t(59) = 10.91$, $p < .001$) and greater ln T/C ratios ($t(59) = 5.01$, $p < .001$) than females. However, sex did not predict cortisol AUCg, and was unrelated to average noise blast intensity, noise blast intensity to the first trial, or noise blast intensity to the second trial (all $ps > .11$). As a result, biological sex was retained as a covariate measure and examined as a moderator.

Individuals with ADHD displayed significantly greater testosterone AUCg ($t(59) = 3.05$, $p = .003$) and marginally greater ln T/C ratios ($t(59) = 5.01$, $p = .076$) than individual without ADHD. However, ADHD status did not predict cortisol AUCg, and was unrelated to average noise blast intensity, noise blast intensity to the first trial, or noise blast intensity to the second trial (all $ps > .22$). Sex and ADHD status were independent in the present data ($\chi^2(1, N = 61) = 1.724$, $p = .19$).

Finally, experimental sessions which started later were associated with marginally larger T/C AUCg ratios ($b = .107$, $F(1,59) = 3.86$, $p = .054$). However, session start time did not predict testosterone AUCg, cortisol AUCg, and was unrelated to average noise blast intensity, noise blast intensity to the first trial, or noise blast intensity to the second trial (all $ps > .11$).

3.1.2. Effects of the self-control resource depletion task

Study condition (self control or no self-control) did not predict average noise blast intensity, noise blast intensity to the first trial, or noise blast intensity to the second trial, testosterone AUCg, cortisol AUCg, or AUCg T/C ratios (all ps > .29).

3.2. Testosterone to cortisol ratio and behavioral aggression

Controlling for sex, AUCg T/C ratios were associated with greater noise blast intensity across trials of the TCRTT ($b = 1.02$, $F(1,58) = 4.96$, $p = .030$). This association was more strongly driven by the first trial (unprovoked aggression) ($b = 1.07$, $F(1,58) = 5.24$, $p = .026$) relative to the second trial (provoked aggression) of the TCRTT ($b = .98$, $F(1,58) = 2.42$, $p = .12$). Controlling for time of day, study condition, or ADHD status did not alter this finding. Furthermore, the association between AUCg T/C ratios and average noise intensity was not moderated by sex, time of day, study condition, or ADHD status (all $ps > .05$).

3.3. Moderation by affective responses to the conflict discussion

3.3.1. Negative affect to positive affect ratio

The interaction of NA/PA ratio and T/C ratio significantly predicted average noise blast intensity ($b = -1.72$, $F(1,56) = 6.45$, $p = .014$), controlling for sex. Tests of simple slopes revealed that, at low (−1 SD) and average (mean) levels of NA/PA ratio, T/C ratio was positively associated with average noise blast intensity ($b = 2.04$, $F(1,56) = 11.59$, $p = .001$, and $b = .94$, $F(1,56) = 4.23$, $p = .044$, respectively). In contrast, T/C ratio was unrelated to average noise blast intensity at high (+1 SD) levels of NA/PA ratio ($b = -0.16$, $F(1,56) = .059$, $p = .80$). A graphical representation of this interaction is depicted in Fig. 1a. Removing sex from the test of this interaction did

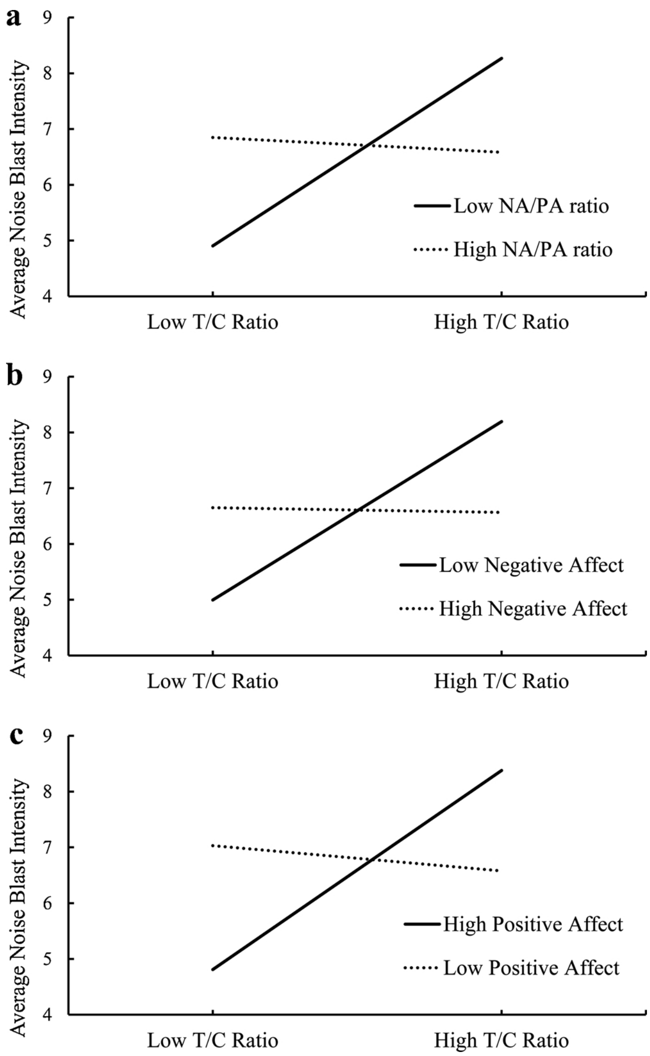

Fig. 1. Predicted average noise blast intensity on the Taylor Competitive Reaction Time Task as a function of testosterone to cortisol ratio (T/C ratio) and the ratio of negative affect to positive affect (panel a), negative affect (panel b) and positive affect (panel c) displayed during the couple's conflict discussion task. High and low levels refer to +1 and −1 SD, respectively.

not influence the present findings (NA/PA ratio x T/C ratio interaction: $b = -1.80$, $F(1,57) = 6.67$, $p = .012$). On its own, NA/PA ratio was unrelated to average noise blast intensity, first trial intensity, second trial intensity, or AUCg T/C ratios (all $ps > .12$). Furthermore, interactions of sex x NA/PA ratio x T/C ratio, ADHD status x NA/PA ratio x T/C ratio, and study condition x NA/PA ratio x T/C ratio were non-significant (all $ps > .44$).

3.3.2. Negative affect

A negative affect x T/C ratio interaction significantly predicted average noise blast intensity ($b = -0.90$, $F(1,56) = 5.33$, $p = .025$), controlling for sex. Tests of simple slopes revealed that, at low (−1 SD) and average (mean) levels of negative affect, T/C ratio was positively associated with average noise blast intensity ($b = 1.94$, $F(1,56) = 10.58$, $p = .004$, and $b = .94$, $F(1,56) = 4.20$, $p = .045$, respectively). In contrast, T/C ratio was unrelated to average noise blast intensity at high (+1 SD) levels of negative affect ($b = -0.05$, $F(1,56) = .006$, $p = .94$). A graphical representation of this interaction is depicted in Fig. 1b. Removing sex from the test of this interaction did not influence the present findings (negative affect x T/C ratio interaction: $b = -0.97$, $F(1,57) = 5.90$, $p = .018$). On its own, negative affect was unrelated to average noise blast intensity, first trial intensity, second trial intensity, or AUCg T/C ratios (all $ps > .15$). Furthermore, interactions of sex x negative affect x T/C ratio, ADHD status x negative affect x T/C ratio, and study condition x negative affect x T/C ratio were non-significant (all $ps > .44$).

3.3.3. Positive affect

Finally, a positive affect x T/C ratio interaction significantly predicted average noise blast intensity ($b = 1.32$, $F(1,57) = 5.65$, $p = .021$), controlling for sex. Tests of simple slopes revealed that, at high (+1 SD) and average (mean) levels of positive affect, T/C ratio was positively associated with average noise blast intensity ($b = 2.16$, $F(1,56) = 10.89$, $p = .002$, and $b = .94$, $F(1,56) = 4.32$, $p = .042$, respectively), whereas T/C ratio was unrelated to average noise blast intensity at low (−1 SD) levels of positive affect ($b = -0.27$, $F(1,56) = .149$, $p = .70$). A graphical representation of this interaction is depicted in Fig. 1c. Removing sex from the test of this interaction did not influence the present findings (positive affect x T/C ratio interaction: $b = 1.31$, $F(1,57) = 5.19$, $p = .026$). On its own, positive affect was unrelated to average noise blast intensity, first trial intensity, second trial intensity, or AUCg T/C ratios (all $ps > .17$). Furthermore, interactions of sex x positive affect x T/C ratio, ADHD status x positive affect x T/C ratio, and study condition x positive affect x T/C ratio were non-significant (all $ps > .16$).

4. Discussion

The primary aim of the present study was to test the dual-hormone hypothesis in a sample of heterosexual young adult couples with and without ADHD. To do so, we measured levels of salivary testosterone and cortisol throughout a laboratory visit during which participants administer white noise blasts to their "partner" following a conflict discussion task. Consistent with the dual-hormone hypothesis (Mehta and Prasad, 2015), we found that greater testosterone to cortisol (T/C) ratios were associated with greater noise blast intensity across recorded trials, indicating greater behavioral aggression. Moreover, the relationship between noise blast intensity and T/C ratio was not moderated by biological sex or ADHD status. This finding adds to the body of literature linking high testosterone and low cortisol to greater aggressive behavior in humans (Dabbs et al., 1991; Popma et al., 2007) and extends it by examining a non-delinquent and non-offending sample of young adult couples.

The present study also tested the moderating effect of provocation on the relationship between T/C ratio and behavioral aggression. The present study inferred the presence of provocation using affective responses to a conflict discussion task. Consistent with our hypotheses, we found that the association between T/C ratio and noise blast intensity was moderated by affective responses to the conflict discussion task such that larger T/C ratios predicted greater noise blast intensity for low (and average) but not high Negative Affect to Positive Affect (NA/PA) ratios. In addition, the present study was able to examine the order of TCRTT trials to infer the presence of provocation. More specifically, participants freely set the intensity of noise blasts to be administered to their partner during the first and second trial. However, they were led to believe that they lost the first trial and thus received a punitive noise blast from their partner before setting the intensity of the second trial. As such we hypothesized that the relationship between T/C ratio and noise blast intensity would be greater on the first (unprovoked) trial relative to the second (provoked) trial of the TCRTT. Consistent with our hypothesis, we found that the relationship between T/C ratio and noise blast intensity was significant for the first but not the second trial of the TCRTT.

The moderating effect of provocation on the relationship between T/C ratio and behavioral aggression found in the current study is consistent with past studies. More specifically, Geniole et al., (2011) found that the interaction of testosterone and cortisol did not predict aggression for men who were provoked by social exclusion on a game of

Cyberball. In contrast, men who were not provoked through social exclusion did show a positive association between aggression and testosterone when cortisol was low (Geniole et al., 2011). Of interest, the present findings were not fully consistent with previous work suggesting that provocation can reverse the aggression-T/C ratio relationship (Denson et al., 2013). In this prior study, researchers asked women to give a 2-minute speech after which they received insulting feedback. After receiving this feedback participants were given the opportunity to administer noise blast to the person who had previously insulted them. Denson et al. (2013) found that greater testosterone levels predicted greater aggression among women with *high* but not low levels of basal cortisol, thus suggesting a reversal of the dual-hormone hypothesis in the context of provoked aggression. The present finding partially supports this study because while the aggression-T/C ratio association was non-significant for participants who reported more negative/less positive affective responses to the conflict discussion, the slope relating aggression to T/C ratio began to trend in the negative direction. In other words, lower T/C ratio was associated with greater aggression (albeit non-significantly) in individuals who were especially provoked during the conflict discussion task. Thus, it is possible that under more intense provocation (e.g., insult) the aggression—T/C ratio association may be reversed.

In summary, the present study makes an important contribution to the literature by comparing the association between T/C ratio and aggression across different forms of aggression. The dual-hormone hypothesis was developed to better understand behaviors aimed at increasing social status or dominance. In the context of acute threat or provocation, higher cortisol levels may motivate defensive behavior, as exhibited by prototypical fight-or-flight responses which are marked by increases in cortisol (Kalin, 1999). Such defensive behavior may result in reactive aggression, to help the aggressor survive or escape the threat. In contrast, proactive (unprovoked) aggression may serve the purpose of increasing status or dominance over others. Therefore, the dual-hormone hypothesis may be best suited for understanding a broad range of behaviors aimed at asserting dominance or status rather than aggression per se. Nevertheless, our results corroborate other studies (Geniole et al., 2011) in suggesting that the dual-hormone hypothesis could predict human aggressive behaviors if such behaviors are instrumental to asserting dominance or status. In the context of romantic relationships, T-C ratios may be more useful in understanding intimate partner violence that is aimed at asserting dominance in the relationship (as opposed to defensive aggression). Future studies could further address this issue by testing the dual-hormone hypothesis in the context of varied forms of instrumental aggressive behaviors (including some that do/do not serve to assert status and dominance).

The present study also adds to the literature by examining the effects of sex and ADHD status on testosterone, cortisol and aggression. Biological sex did not moderate the association between aggression, cortisol and testosterone. Our findings are in line with several other studies that have reported dual-hormone influences on risk-taking behavior in adults and externalizing psychopathology in adolescents and youth (for review, see Mehta and Prasad, 2015). With respect to ADHD status, we found that individuals with ADHD had higher testosterone levels than those without ADHD but observed no differences in cortisol or aggressive behavior. We are not aware of any previous investigations that have examined the dual-hormone hypothesis among adults with ADHD. However, prior studies do indicate that cortisol and testosterone levels may be altered among individuals with ADHD. For instance, drawing from primarily child samples, ADHD status has been linked with lower resting cortisol levels and lower cortisol stress reactivity (for reviews, see Corominas et al., 2012; Scassellati et al., 2012). Less work has examined current testosterone levels among individuals with ADHD. In a study by Chance et al. (2000), testosterone levels were elevated in a subset of boys (aged 9–11) of whom 92% were diagnosed with ADHD. Given the paucity of research on the interrelationships between testosterone, cortisol, and ADHD (particularly among adult samples) and the relatively small number of individuals with ADHD in the current sample ($n = 22$), it is premature to draw any firm conclusions about the lack of findings in the present study. However, since some work has shown elevated rates of interpersonal aggression among adults with ADHD (Fang et al., 2010; Wymbs et al., 2012, 2016), it may be useful to examine what role, if any, testosterone and cortisol may play in understanding or predicting aggression in this particular population.

Strength of the present study include three measurements of cortisol and testosterone per participant, as well a standardized behavioral measure of aggression. The present study was also able to examine the dynamics of provocation and aggression within couples. As such, we addressed limitations of prior work by including both men and women and extended prior work on the dual-hormone hypothesis by examining provocation from one's partner (as opposed to a stranger). However, some limitations of the present study are worth noting. Affective responses to the conflict discussion task and the presence of a noise blast preceding the first two trial of the TCRTT are somewhat novel operationalizations of provocation. In contrast, prior work used social isolation (Geniole et al., 2011) and insults (Denson et al., 2013) to operationalize provocation. While affective responses to a conflict discussion could be considered more face valid and clinically significant (given that couples are likely to engage in conflict discussions in daily life), replication using the present measures of provocation along with others (e.g., social exclusion) is important for bolstering the present conclusions. While sex was consistently used as a covariate in analyses of cortisol and testosterone, a more thorough approach would have been to also control for menstrual cycle (or examine menstrual cycle as a moderator). Similarly, we reported that experimental session start time did not predict total levels of testosterone or cortisol. However, diurnal rhythms of cortisol and testosterone may still have had an influence on the present results. This could be addressed in a replication study by more closely controlling the time of laboratory sessions. Although the present study was able to support predictions of the dual-hormone hypothesis in an unconventional sample (i.e., adults with and without ADHD), replicating the present results in other populations and/or using a larger sample size is warranted. Finally, while the TCRTT is commonly used as a measure of behavioral aggression in the psychological literature, future studies could benefit from including other measures of aggression along with the TCRTT.

An important limitation of the present study is that the present data was acquired as part of a larger project aiming to study ADHD within the context of intimate relationships. The present result should therefore be considered preliminary. While measures collected as part of this larger project provided novel (and perhaps more naturalistic) tests of potential sources of provocation, the present study lacks a priori provocation manipulations. It is important to replicate the present findings with a study specifically designed to directly test the moderating effect of provocation on the association between testosterone, cortisol and aggression.

5. Conclusions

The current study supports the dual-hormone hypothesis, such that higher T/C ratios predicted greater aggressive behavior among couples. This effect was consistent across men and women and for those with and without ADHD. Furthermore, consistent with recent studies, the present results imply that the association between T/C ratio and aggression is weaker (and may trends in the opposite direction) following provocation. In relation to the broader literature, our findings may imply that the dual-hormone hypothesis will predict human aggression only to the extent that the aggressive behavior in question serves to assert dominance or attain status.

Conflicts ofInterest and source of funding

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Appendix A

The following section reports results of analyses predicting average noise blast duration ($M = 2.86$, $SD = 1.81$) and noise blast duration during the first ($M = 2.39$, $SD = 2.14$) and second ($M = 3.34$, $SD = 2.06$) trials.

Preliminary analyses

Sex, ADHD status, experimental session start time, and study condition were unrelated to average noise blast duration, noise blast duration to the first trial, or noise blast duration to the second trial (all *ps* > .09).

Testosterone to cortisol ratio and noise blast duration

Controlling for sex, AUCg T/C ratios were associated with marginally greater noise blast duration across trials of the TCRTT ($b = .62$, $F(1,57.91) = 3.46$, $p = .068$). However, this association was non-significant when controlling for time of day, study condition, and ADHD status ($p = .13$).

Moderation by affective responses to the conflict discussion

The interaction of NA/PA ratio and T/C ratio was unrelated to average noise blast duration ($p = .23$), controlling for sex. On its own, NA/PA ratio was unrelated to average noise blast duration, first trial duration or second trial duration (all *ps* > .68). Furthermore, interactions of sex x NA/PA ratio x T/C ratio, and ADHD status x NA/PA ratio x T/C ratio were non-significant (all *ps* > .74).

The interaction of negative affect and T/C ratio was unrelated to average noise blast duration ($p = .29$), controlling for sex. On its own, negative affect was unrelated to average noise blast duration, first trial duration or second trial duration (all *ps* > .67). Furthermore, interactions of sex x NA/PA ratio x T/C ratio, and ADHD status x NA/PA ratio x T/C ratio were non-significant (all *ps* > .77).

The interaction of positive affect and T/C ratio was unrelated to average noise blast duration ($p = .21$), controlling for sex. On its own, positive affect was unrelated to average noise blast duration, first trial duration or second trial duration (all *ps* > .33). Furthermore, interactions of sex x NA/PA ratio x T/C ratio, and ADHD status x NA/PA ratio x T/C ratio were non-significant (all *ps* > .58).

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