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Testosterone Reactivity to Competition and Competitive Endurance in Men and Women
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Abstract

Transient shifts in testosterone occur during competition and are thought to positively influence dominance behavior aimed at enhancing social status. However, individual differences in testosterone reactivity to status contests have not been studied in relation to real-time expressions of competitive behavior among men and women. This study tests the association between changes in endogenous testosterone levels during competition and performance in terms of competitive endurance. Participant sex, social presence, and relative status outcomes (e.g., winning vs. losing) are tested as moderators of this relationship. In two studies, men and women (total $N=398$) competed in the competitive will task (timed weight-holding) either individually or in the presence of an opponent (Study 1) or as a team with and without the presence of a competitor team (Study 2). Results showed a positive relationship between testosterone reactivity and performance for men, particularly those who won or ranked highest among their group – increasing testosterone predicting better performance. For women, the effect was weak overall and only emerged among women in dyads who lost. In Study 2, an exploratory mediation analysis revealed that individual differences in trait dominance predict both testosterone reactivity to competition and task performance, with testosterone reactivity (moderated by sex and status outcome) partially explaining the direct relationship between dominance-related traits and behavior. Our goal was to examine testosterone reactivity in relation to real-time competitive effort and highlight the potential role of this relationship in explaining how individual differences in trait dominance produce competitive behavior.

Introduction

1
2 Originally proposed in the context of territorial behavior in male birds, the challenge
3 hypothesis (Wingfield et al., 1990) guided predictions about the kinds of social encounters that
4 produce increases in , circulating testosterone. These elevations in testosterone appear to promote
5 aggressive behaviors that benefit reproduction by increasing competitive behavior required to
6 gain access to receptive females. Conversely, high testosterone maintained over an extended
7 period is hypothesized to be costly in terms of health and appears to inhibit or reduce the
8 affiliative behavior required for parental care following successful reproduction (Muller, 2017;
9 Wingfield, Lynn, & Soma, 2001). Thus, a key premise of the challenge hypothesis is that an
10 increase in testosterone level in response to a social encounter should be transient and occur only
11 within contexts in which relative social position and, correspondingly, access to a limited
12 resource, is at stake. That is, elements of the social context should play an important role in
13 moderating the relationship between testosterone reactivity and competitive behavior.

14 The challenge hypothesis has been extended to humans to generate predictions about
15 testosterone reactivity to contests for social status observed in men and women (Archer, 2006;
16 Casto & Edwards, 2016a, Geniole & Carré, 2018). This literature supports the notion that short-
17 term elevations in testosterone can adaptively (for the purposes of competitive success) alter
18 competitive and aggressive behavior and underlying neural processes in humans (e.g., Carré et
19 al., 2009; 2013; Goetz et al., 2014; Hermans et al., 2008; Mehta et al., 2015a; Radke et al., 2015;
20 van Wingen et al., 2009; Wagels et al., 2018; for review, Zilioli & Bird, 2017). Consonant with
21 predictions from the challenge hypothesis, the relationship between the testosterone response to
22 competition and dominance-related behavior that would facilitate competitive success appears to
23 be dependent on aspects of the social environment (for review, Carré & Archer, 2018; Geniole &
24 Carré, 2018).

1 For instance, a critical aspect of the competitive social environment that affects
2 testosterone reactivity is the competition outcome, social status gained or lost as a result of
3 implicit or explicit rules of the contest. According to the biosocial model of status (Mazur, 1985,
4 for review Casto and Edwards, 2016a), testosterone should increase following a contest for status
5 for those who experience relative social victory in order to promote subsequent dominance and
6 decrease for those who experience relative social defeat in order to promote subsequent
7 deference. Indeed, research has shown that this designation of a winner or loser (i.e., competition
8 outcome) has been shown to moderate the relationship between testosterone reactivity and
9 subsequent competitive behavior. For example, in men, testosterone change during competition
10 has been found to be positively related with an individual's choice to compete again afterwards
11 (against the same opponent), but only for those who lost (Mehta & Josephs, 2006). Specifically,
12 losers who increased in testosterone were more likely to choose to compete again while losers
13 who decreased in testosterone were more likely to choose the non-competitive alternative. For
14 winners, the direction of change in testosterone was not related to whether men chose to compete
15 again or not. In a separate study, when ask to decide whether or not to compete again against a
16 different opponent, testosterone reactivity to competition, which ranged from decreasing to
17 increasing in direction, positively predicted the likelihood of making the competitive choice only
18 for those who decisively won (Mehta et al., 2015b).

19 In another study of men, a positive relationship between testosterone reactivity to a
20 competition and subsequent risk-taking behavior was found only among those who won (e.g.,
21 Welker et al., 2019), while a different study found that testosterone reactivity to competition was
22 inversely related to subsequent risk aversion regardless of prior win or loss (Apicella et al. 2014).
23 Carré et al. (2013) found that aggressive behavior following a competition for status was

1 predicted by testosterone reactivity during the competition in both male winners and losers, but
2 winners were more likely to increase in testosterone and displayed greater post-competition
3 aggression than losers. No effects were found for women who were included in this study. In
4 fact, in much of the research discussed above, women were either not included as participants
5 (majority of prior studies) or, women were included, but no significant relationship between
6 testosterone reactivity and the specific status-related behavior was found (Casto & Prasad, 2017).
7 Nonetheless, these studies suggest that a testosterone increase during competition influences
8 subsequent dominant, aggressive, or competitive behaviors dependent on shifts in relative status.
9 However, these kinds of behaviors are also beneficial to status achievement during the
10 competition period itself. Despite the importance of dominance and competitiveness in
11 determining who will win or lose, little is known about how testosterone reactivity during
12 competition relates to ongoing, time-matched status-related behavior such as competitive effort.
13 Indeed, much of the prior research on the winner-loser effect in the laboratory has attempted to
14 control for individual differences in competitive motivation or effort by rigging the competition
15 to be easier for those who “won” and harder for those who “lost” (e.g., Carré et al., 2013; van der
16 Meij et al., 2010; Zilioli & Watson, 2012; for review, Casto & Edwards, 2016). The present
17 research is premised on the notion that the testosterone response to competition is meaningfully
18 tied to, and perhaps even functions to regulate, these individual differences in competitive
19 performance.

20 Given that competition-related changes in testosterone are relatively short-lived (e.g.,
21 Casto & Edwards, 2016b; Henry et al., 2017; Oxford et al., 2010) and androgen effects on tissues
22 including the brain can be relatively rapid (Michels & Hoppe, 2008; Simoncini & Genazzani,
23 2003), it is likely that a testosterone increase during competition could facilitate *ongoing*

1 competitive effort that would enhance the odds of winning. Although testosterone reactivity to
2 competition has been recently linked with time-matched changes in self-reported
3 competitiveness and observer-rated self-assuredness in men (Kordsmeyer & Penke, 2019), the
4 extent to which testosterone reactivity to competition predicts measures of competitive *behavior*
5 expressed during that competition has, to our knowledge, not been tested in humans. That is,
6 despite an abundance of research on testosterone's relationship to dominant and competitive
7 behavior, we still do not know if testosterone reactivity coordinates dominant and competitive
8 behaviors within the contest period – a time when status is actively being contested and
9 testosterone's ability to promote dominance would be most relevant to achieving the contest-
10 related goal.

11 Hormone-behavior interactions are bidirectional in nature and thus, observing
12 competition-associated testosterone change and behavior simultaneously leaves uncertainty
13 about the direction of the relationship. Particularly in regards to rapid mechanisms of hormonal
14 regulation interacting in coordination with sensory-cognitive and neurological processes, causal
15 implications are particularly difficult to disentangle. Thus, the relationship is perhaps best
16 characterized as a rapid feedback loop in which the cascade of physiological changes producing
17 a testosterone increase flow from the awareness that one has entered a competitive contest and
18 ongoing awareness and competitive motivation are, in-turn, affected by these hormonal changes
19 (Casto & Edwards, 2016a, see Fig 5 and related discussion). Additionally, causal patterns within
20 this mechanism are further complicated by numerous intervening factors that can alter the
21 efficiency or sensitivity of the feedback loop such as individual differences in competitive
22 motivation, sensitivity to status threat, the quantity of androgen receptors, and baseline levels of

1 testosterone and cortisol (e.g., Carré & Olmstead, 2015; Eisenegger et al., 2017; Gettler et al.,
2 2017; Vermeer et al., 2016; Zilioli & Watson, 2012).

3 Nonetheless, a growing body of research experimentally manipulating testosterone levels
4 by intranasal, oral, or transdermal administration suggests that, in certain contexts, elevated
5 testosterone causally promotes the emergence of competitive and aggressive behavior (for recent
6 reviews; Casto & Mehta, 2019; Geniole & Carré, 2018). For example, in one study, women
7 given supplemental testosterone were more likely to choose to compete again than women given
8 a placebo, but only following a social victory and only if they were high in trait dominance
9 (Mehta et al., 2015a). Exogenously administered testosterone has been shown to elevate men's
10 perceptions of their own physical dominance (Welling et al., 2016), an effect that would likely
11 increase competitive efforts. Additional research shows that testosterone can rapidly activate
12 areas in the brain involved in experiences of pleasure and reward and resulting motivated
13 behavior (Vermeer, et al., 2016; Welker et al., 2015) which is consonant with reports that
14 testosterone reactivity is associated with task enjoyment (Geniole et al., 2019; Mehta et al.,
15 2015b). Although the relationship between testosterone and competitive behavior is
16 bidirectional, prior work justifies the prediction that testosterone reactivity is a driving force
17 underlying competitive striving.

18 In line with previous research about the role of social context in moderating
19 testosterone's effect on behavior (Carré & Archer, 2018), a particularly salient aspect of the
20 competition environment is the physical presence of an opponent or opponents. While models
21 about the dynamic relationship between testosterone and competition (e.g., the challenge
22 hypothesis) typically assume that emergence of this relationship requires an actual social
23 *encounter*, it is unclear whether this is indeed the case. That is, the physical presence of an

1 opponent could motivate competitive efforts and may even be an essential eliciting condition for
2 hormone-behavior relationships in competitive contexts (Roney, 2016). Despite this notion,
3 many laboratory studies of testosterone reactivity to competition merely give the illusion of the
4 physical presence of an opponent such as telling the participant that a competitor is in a nearby
5 room or showing an avatar image of a person while the ‘competitor’ actions are computer
6 generated (for review, Casto & Edwards, 2016a). It is possible that this design feature
7 inadvertently eliminates elements of the social context provided by the physical presence of an
8 opponent that contribute to testosterone reactivity and competitive motivation, a prediction that
9 has not been previously tested and that we test in this research.

10 Another notable omission from prior research regarding social context is the intervening
11 role of group membership and the social presence of opponent groups, a context that is likely to
12 reflect the inter-group condition under which testosterone mechanisms for regulating competitive
13 behavior evolved. For social species including humans and some non-human primates, contests
14 for status often take place within the context of social groups where placement among the social
15 hierarchy is at stake (Cummins, 2006; Hill et al., 2008; Sapolsky et al., 2005; Zink et al., 2008).
16 Further, between-group dominance contests – coalitional competitions – are common among
17 human and non-human primate species (Crofoot & Wrangham, 2010). In these instances, group
18 membership is likely to influence testosterone reactivity to competition and competitive
19 behavior, as members of groups must balance individual dominance striving with the more
20 cooperative behavior required for coalition formation and maintenance (Diekhof et al., 2014;
21 Flinn et al., 2012; Reimers & Diekhof, 2015; Tauer & Harackiewicz, 2004). This prediction is
22 supported by a few studies that have found that, among men, testosterone reactivity to
23 competition is affected by whether the contest is within or between group, with attenuated

1 responses found for the former (Wagner et al., 2002, Oxford et al., 2010, Flinn et al., 2012; see
2 Mehta et al., 2009 for similar effects with baseline testosterone). Moreover, in between-group
3 competitions, men who ranked the highest among their group showed a greater testosterone
4 increase over the course of competition, but only if their group won (Oxford et al., 2010).
5 Although never before tested in the laboratory, the physical presence of a competitor group could
6 effectively shift focus from within-group status conflict (beating one's own groupmates) to
7 between-group status conflict (beating members of the other group), potentially altering the ratio
8 of dominance/cooperativeness required for success and related testosterone reactivity.

9 The present research was designed to explore the relationship between individual
10 differences in testosterone reactivity to competition and the competitive persistence expressed
11 during that competition. In two studies, participants competed in the *competitive will task*, in
12 which performance was determined by the level of competitive endurance a participant
13 expressed during a contest for time. Additionally, we experimentally manipulated the social
14 presence of one or more opponents. Although the task was 'physical' in that it involved holding
15 a weight, there was undoubtedly a strong psychological component in that a participant had to
16 endure substantial discomfort to outcompete others. To validate task performance as a
17 representation of psychological motivation, we provide evidence in the present research for a
18 positive association between performance time and self-reported individual differences in
19 competitiveness, dominance motivation, and task-specific motivation. Additionally, we show
20 that physical qualities associated with strength (i.e., height, weight, body mass index) do not
21 correlate with performance and further, that the relationship between the psychological factors
22 discussed above and performance after controlling for height, weight, and body mass index.
23 Combined, these analyses suggest that trait-level characteristics related to status motivation

1 represent underlying psychological motivations that are expressed behaviorally, at least in part,
2 as competitive endurance above and beyond physical strength. Critically, in this task, all
3 participants competed against an unknown set of other participants for a small monetary grand
4 prize given to those who performed the best overall (distributed after all subjects participated).
5 Thus, we expected that when an opponent or opponents were present, shifts in relative status as a
6 result of having performed better (a relative win) or worse (a relative loss) would occur during
7 the competition as relative winners would continue competing against the unknown standard of
8 'best overall performance among all the participants.' Thus, generally, we predicted that
9 testosterone reactivity across the task would interact with the relative win/loss to predict
10 competitive endurance since the status gained for winners would occur before the end of the
11 competition.

12 Specifically, Study 1 was designed to test the relationship between testosterone reactivity
13 and competitive endurance in men and women competing in dyads as well competing
14 individually against an unseen group of individuals. For participants who competed in dyads, we
15 also tested the moderating effects of relative social victory or defeat compared to one's
16 opponent. We predict that testosterone reactivity will be positively associated with competitive
17 endurance such that greater increases in testosterone will relate to a relatively longer
18 performance times and likewise, greater decreases in testosterone will relate to relatively shorter
19 performance times. Further, for those who competed in the presence of an opponent, we
20 predicted that the positive relationship between testosterone reactivity and competitive endurance
21 would emerge only for those who experience relative social victory within that context.

22 Study 2 was designed to examine the relationship between testosterone reactivity and
23 competitive endurance among men and women competing in teams, one team against another, or

1 competing against unseen opponent teams. As in Study 1, we also tested the moderating effects
2 of relative performance-based rank among the other participants present. We predict that larger
3 increases in testosterone over the course of competition will be associated with longer
4 competitive endurance while larger decreases in testosterone would be associated with shorter
5 competitive endurance, for those who experienced relative social victory (ranked highest among
6 the group). Both studies included men and women so that sex of the participants could be tested
7 as potential moderator of the relationship between testosterone reactivity and competitive
8 behavior. Although prior research, discussed above, would suggest that this relationship should
9 only emerge among men (within specific contexts), with substantially less prior research on
10 women, this prediction is made with the caveat that little is known about how these variables
11 should relate in women (Casto & Prasad, 2017).

12 **Study 1 Method**

13 **Participants**

14 A sample of 190 undergraduates (131 women and 59 men, with a mean age of 19 years,
15 $SD = 1.1$, range = 18 to 25) from Emory University participated in the study. Participants were
16 recruited from the psychology department subject pool composed of undergraduates enrolled in
17 either of two introductory psychology courses, each of which has a research participation option
18 as a condition for satisfactory completion of the course. To minimize potential cultural
19 influences, only U.S. citizens whose native language was English were permitted to sign up for
20 the study. The study was approved by the university's Institutional Review Board (IRB).

21 **Competitive Will Task**

22 A physical task was employed to determine individual differences in competitive
23 endurance. Participants held a weight (a common dumbbell used for resistance training, 11lb. for

1 women, 2 lbs. for men) at arm's length and shoulder height for as long as they felt they could in
2 competition against other participants. The weight differential between men and women was
3 decided based on pilot studies generating equivalent mean performance times for women and
4 men with a 1:2 weight ratio. Whether competing individually or in dyads, participants were told
5 "The competition has to do with who has the most competitive will – who can endure the
6 discomfort of holding up their arm the longest in order to attempt to be a winner." Participants'
7 shoulder height was marked with a line on an index card taped to the wall and each participant
8 was instructed to hold their arm at that height, dropping it once they "no longer wished to
9 compete or could no longer physically keep their arm above the line, whichever came first."
10 Performance time was recorded and revealed (by showing the timer) to a participant only after
11 dropping arm to signal his/her end to the competition. Participants were stopped by the
12 experimenter if they reached the 13-minute maximum (mean performance time was 4 minutes,
13 SD = 1 minute and 15 seconds).

14 Participants were informed that a \$20 cash prize would be offered to the one male and
15 female participant¹ who held their arm up the longest of all the other men and women
16 participants who participated during that semester (data was collected across two semesters).
17 Regardless of the presence or absence of an opponent, all participants were competing against
18 each other for the same cash prize. For those competing in dyads, relative "winners" and "losers"
19 were determined according to who dropped his or her arm first. However, because the
20 competition was for an overall prize, winners could continue to compete against unknown others

¹ Separate cash prizes were given to men and women in Study #1 in an attempt to reduce performance effects due to socialized factors (e.g., perceptions of physical inferiority and backlash for competitive behavior) in mixed-sex dyads. "Opponent" in this research is someone else competing at the same time, a person who the participant can reference when making relative judgements about status position, i.e., relative winner vs. loser. In Study #2, discussed below, cash prizes were not separate for men and women because of the larger number of participants competing at the same time.

1 for the best possible performance and resulting cash reward. Participants were not given any
2 reference times for other participants' performances or any feedback about how well how their
3 performance ranked overall. Prize winners were privately contacted at the end of the semester
4 via email.

5 "Performance" in this task was operationalized as the time in seconds that a participant
6 held up his or her arm before quitting the contest. For participants who competed in dyads, a
7 second outcome variable, performance time over or under one's partner, was created to assess
8 the relationship between testosterone reactivity and relative performance. This variable was
9 calculated by subtracting the partner's time from each participants' total performance time
10 resulting in positive values for relative winners and negative values for relative losers. This
11 second outcome measure allowed us to test whether testosterone reactivity was particularly likely
12 to predict post-victory competitive behavior (in line with previous research, e.g., Carré et al.,
13 2013; Mehta et al., 2015b; Trainor et al., 2004)

14 **Construct validation.** We used this task because a similar physical endurance task was
15 employed by Crust and Clough (2005) to provide criterion validity for a measure of mental
16 toughness, a multidimensional concept from sport psychology having to do with competitive
17 confidence, resilience, persistence, and control. Mental toughness is considered to be one of the
18 most important psychological predictors of competitive success (Crust, 2007). In Crust and
19 Clough (2005), total mental toughness score was positively related to "weight-holding
20 endurance" measured in units of time ($r = .34$) (p. 193). To provide additional evidence of
21 validity for the competitive will task, participants in the present study completed a series of
22 questionnaires designed to determine individual differences in constructs related to status
23 motivation – competitiveness (Competitiveness Index – CI, Houston et al., 2002), social power

1 (Power and Dominance System Scales – PDSS, Murphy, 2016), social achievement goal
2 orientation (Social Achievement Goal Orientation Survey, revised – SAGOS, Horst et al., 2007),
3 and academic achievement motivation (Academic Motivation Scale – AMS, Vallerand et al.,
4 1992) – which we correlated with task performance.

5 Among the 190 participants in this study who completed these measures and participated
6 in the competitive will task, performance was significantly and positively related to subscales for
7 CI enjoys competition ($r = .22, p = .002$), PDSS dominance motivation ($r = .21, p = .004$), and
8 AMS intrinsic motivation ($r = .23, p = .002$) demonstrating good convergent validity (full
9 correlation matrix shown in supplementary data). Task performance was not significantly related
10 to CI contentiousness, PDSS felt power, PDSS attention to power cues, AMS extrinsic
11 motivation, AMS amotivation, or any of the SAGOS scales (performance and mastery approach
12 and avoidance in social goals). Additional competitiveness questions administered alongside
13 these scales, “I do not give up easily in competition” ($r = .23, p = .001$) and “I am a competitive
14 person” ($r = .21, p = .009$) also demonstrated a positive correlation with performance. Finally,
15 task performance also significantly and positively correlated with responses to the task-specific
16 pre-competition question “How motivated are you to win?” ($r = .25, p = .001$) and post-
17 competition questions “I tried really hard to win the competition” ($r = .45, p < .001$) and “I really
18 wanted to win the competition” ($r = .32, p < .001$). When separating by sex, observed
19 relationships were generally the same across men and women, but correlation coefficients were
20 consistently larger among women participants. All p-values for each correlation were considered
21 significant after adjusting the “statistical significance” set point for alpha based on false
22 detection rate from conducting multiple tests (Benjamini & Hochberg, 1995).

1 Given the potentially confounding nature of competitive endurance and physical strength
2 in the competitive will task, we tested the relationship between task performance and physical
3 qualities associated with strength (height, weight, and body mass index). Additionally, we tested
4 the relationship between the psychological characteristics associated with status motivation
5 (discussed above) and performance after controlling for height, weight, and body mass index
6 (BMI). Overall and separately in men and women, physical qualities associated with strength
7 were not related to performance in the competitive will task and, did not explain the positive
8 associations between performance and the psychological factors previously discussed (results
9 shown in supplemental data).

10 **Procedure**

11 Men and women were randomly assigned to either be the only participant in the room or
12 one of two tested at the same time, thereby competing against each other. Dyads were randomly
13 assigned so that there was a combination of same- and mixed-sex pairs². Upon arrival,
14 participants read and signed a consent form and received a brief introduction to the study (i.e.,
15 that the study was about the relationships among hormones, competition, and social context).
16 The same female experimenter walked each participant through the study. After consent, they
17 completed questionnaires for approximately 15 minutes, then provided their first (baseline)
18 saliva sample. Next, the experimenter gave specific instructions about the competitive will task
19 and potential for prize money (see description above). Participants then competed in the task.
20 After the competition, participants provided their immediate post-competition saliva sample (the

² Although samples sizes of experimental groups were not large enough for adequately powered analyses based on sex of one's competitor for dyads (Men who competed against a woman $N = 26$; Men who competed against a man $N = 16$; Women who competed against a man $N = 26$; Women who competed against a woman $N = 58$), exploratory analyses revealed no significant differences in testosterone reactivity, task performance, or their relationship based on whether one's opponent was of the same or opposite sex (supplemental data).

1 time elapsed from the baseline sample to the immediate post-competition sample was different
2 for each participant, depending on their performance time in the task). They then completed an
3 unrelated questionnaire designed to serve as filler task (selecting behaviors that the participant
4 has ever and typically expresses themselves with in interactions with others) for 15 minutes
5 between the end of competition and the final saliva sample (delayed post-competition sample).

6 **Saliva Samples and Hormone Assay**

7 Participants were instructed not to eat, exercise, smoke, or consume caffeinated
8 beverages or food within the hour prior to arriving at the laboratory for the study. Saliva samples
9 were obtained prior to, immediately after, and 15 minutes after competing in the competitive will
10 task. Immediately before providing a saliva sample, each participant rinsed his/her mouth with
11 water. Approximately 1.5-1.8 ml of saliva was collected for each sample via passive drool into 2
12 ml plastic vials using plastic saliva collect aids (Salimetrics). Collection time varied according to
13 the individual, but typically took between 3-5 minutes. Samples were stored at -20°C initially
14 and then transferred to a -80°C freezer within several hours. Samples were assayed in duplicate
15 for testosterone³ on a single thaw by the Emory Clinical Translational Research Laboratory
16 (Atlanta, Georgia) using competitive enzyme immunoassay kits from Salimetrics (State College,
17 PA). Inter-assay coefficients of variation for low and high controls were 18.0 and 6.2%. All
18 participants were tested in the afternoon between 2-4 PM to standardize collection time with
19 reference to normal diurnal fluctuation in testosterone levels.

20 **Testosterone Reactivity**

³ This research was a part of a larger study that also included measurement of cortisol levels. Only testosterone levels are included for analysis in the present study.

1 Testosterone concentrations for two women participants were not obtained due to
2 insufficient saliva provided during the collection periods leaving a total sample size for analyses
3 involving testosterone reactivity of 188 (men N=59; women N=129). In men, testosterone levels
4 were normally distributed. In women, testosterone levels at all three collection points were
5 positively skewed. Outlier participants, i.e., individuals whose testosterone levels were more than
6 three standard deviations higher or lower than the mean for their sex, were identified (a common
7 SD benchmark for identifying outliers in hormone analyses, Pollet & van der Meij, 2017).
8 Testosterone levels for these individuals (three women and one man) were replaced with the
9 mean plus or minus three standard deviations, effectively replacing outlier values with high and
10 low values that maintain relative position among other data points while reducing skewness
11 (Erceg-Hurn, & Mirosevich, 2008).

12 Competition-related testosterone reactivity was calculated as the percent change in
13 hormone level from pre-competition baseline ($\Delta T\%$). Values for this variable are represented in
14 both magnitude, absolute percent change, and direction of change resulting in both negative and
15 positive values. Because hormones were sampled three times (immediately before competition,
16 immediately after, and 15 minutes after competition), there are two time references for
17 expressing change associated with the competition – from before to immediately after and from
18 before to 15 minutes after. Laboratory studies of hormones and competition typically derive
19 hormone-behavior relationships from saliva samples obtained 10-15 minutes following
20 competition (e.g., Mehta and Josephs, 2006; Schultheiss et al., 2005) on the assumption that a
21 hormone value for a saliva sample obtained 15-minutes after the end of competition reflects the
22 blood level of hormone during competition. Consonant with this precedent, all results presented
23 in this study regarding testosterone change refer to the relative change from baseline to 15

1 minutes after competition. However, there is some evidence for more rapid steroid hormone
2 diffusion from blood into saliva (for review, Casto & Edwards, 2016a). Change values for saliva
3 samples obtained immediately after the end of competition are presented in the supplemental
4 results. For $\Delta T\%$ used in subsequent analyses (calculated from before competition to 15 minutes
5 after), two additional outlier participants (both women) whose testosterone *change* score was
6 more than three standard deviations higher or lower than the mean were identified. Testosterone
7 levels for these individuals were replaced with the mean plus or minus three standard deviations
8 depending on the direction of change for the original value. As a robustness check, hypotheses
9 were also tested in relation to two other common ways of expressing testosterone change in the
10 literature: the unstandardized residual change in testosterone from pre-to-post competition (Tres)
11 and area under the curve with respect to increase (AUC_i, an indicator of the intensity of hormone
12 change over time, Pruessner et al., 2003). For both of these additional metrics of change, values
13 are represented in terms of magnitude and direction of change meaning there will be a range of
14 negative to positive values. For AUC_i, when a participant's testosterone levels decrease over
15 time, the resulting value "must be regarded as an 'index of decrease' rather than an area
16 (Pruessner et al., 2003, p.921)".

17 **Hormonal Contraceptive Use**

18 Following consent, each female participant provided information regarding contraceptive
19 use. Specifically, women were asked to circle "yes" or "no" to four questions: "Are you
20 currently using an oral contraceptive?"; "Are you currently using an injected or patch-delivered
21 hormone-based contraceptive?"; "Are you currently using an intrauterine device (IUD)?"; and
22 "Are you currently using a Nuvaring?" Of the 131 women participating in this study, 66
23 reported that they were not using any form of contraception, 55 reported using an oral

1 contraceptive, three a hormone-based injection or patch, six an IUD, and one reported using a
2 Nuvaring.

3 Women using oral contraceptives typically have lower basal levels of testosterone than
4 non-users (e.g. Edwards & O'Neal, 2009; Wiegratz et al., 2003; Zimmerman et al., 2014), but do
5 not appear different from non-users in competition-related testosterone responsivity (Casto &
6 Edwards, 2016a; Edwards & O'Neal, 2009). Although not the main purpose of the study, among
7 women participants, hormonal contraceptive use (HC use; yes/no) was tested as an additional
8 moderator of the relationship between testosterone reactivity and performance. For the purposes
9 of analysis, oral contraceptive and hormone patch users were combined into a single category of
10 hormonal contraception users ($N = 58$) for comparison to women not using any form of hormone
11 contraception ($N = 66$). IUD ($N = 6$) and Nuvaring ($N = 1$) users were excluded from analyses by
12 HC use due to an incomplete understanding of the peripheral hormone exposure from these
13 contraception methods and the small sample size of these groups⁴. These seven participants were
14 not excluded from main analyses.

15 Study 1 Results

16 Descriptive statistics and correlations for the principal variables of the study are shown
17 separately for men and women in Table 1 as are between-sex statistical comparisons and
18 comparisons between women hormonal contraceptive users and non-users. As expected, men
19 had significantly higher testosterone levels than women. Men and women did not significantly
20 differ in testosterone reactivity to competition whether measured as $\Delta T\%$, unstandardized
21 residual, or AUCi. Women using hormonal contraceptives had significantly lower salivary

⁴ Because testosterone levels for two women participants are missing, the final sample size for analyses involving HC use and testosterone reactivity is 122.

1 testosterone levels relative to women not using any form of hormonal contraception, but users
2 and non-users did not significantly differ in testosterone reactivity to competition ($\Delta T\%$,
3 unstandardized residual, or AUCi). $\Delta T\%$, T_{res} , and AUCi are highly positively correlated.

4 There were no significant differences in task performance between those who competed
5 individually ($M= 242.5$, $SD= 79.2$) and those who competed in the presence of an opponent ($M=$
6 241.1 , $SD= 73.5$), $t(188) = .12$, $p = .905$. Among women, hormonal contraceptive users showed
7 significantly lower performance on average (see magnitude of difference and Cohen's d in Table
8 1). For those who competed in dyads, performance was significantly and positively correlated
9 with the performance of the other member of the dyad, $r = .42$, $p < .001$). When separating men
10 and women, this relationship was weaker and non-significant among men, while remaining quite
11 strong among women (men: $r = .27$, $p = .083$; women: $r = .46$, $p < .001$), although the difference
12 between the correlation coefficients was not significant ($z = -1.15$, $p = .25$). As shown in Table 1,
13 testosterone levels and metrics of reactivity were positively correlated with performance among
14 men and women, but only the relationship between absolute testosterone levels and performance
15 in women was significant, whether at baseline or after competition.

16 **Testosterone reactivity and task performance**

17 On average, across conditions (i.e., competing individually or with an opponent)
18 testosterone levels decreased slightly in men and women from before to after competition,
19 although there were large individual differences in both the magnitude and direction of
20 testosterone change (Table 1). There were no significant differences in testosterone reactivity by
21 condition (overall or by sex). Further, for dyads (i.e., participants competing with an opponent
22 present), there was no significant difference in testosterone reactivity for those who won
23 compared to those who lost (overall or by sex). For more detail, see the supplemental results.

1 A hierarchical regression analysis was conducted to test the relationship between
2 testosterone reactivity and performance. Step 1 included condition, sex, and $\Delta T\%$, step 2
3 included the interaction of condition by $\Delta T\%$ and sex by $\Delta T\%$, and step 3 included the three-way
4 interaction between condition, sex, and $\Delta T\%$. Results revealed a significant main effect (in Step
5 1) for $\Delta T\%$ in predicting performance ($N=188$, $b=.46$, $SE=.22$, $t=2.12$, $p=.035$, $95\%CI=.03-.88$,
6 $R^2_{\text{partial}}=.02$), but no other significant main effects or interactions. This main finding was in the
7 same direction when using the unstandardized residual for testosterone and when testosterone
8 change was represented as AUCi, although the magnitude of the relationship was reduced
9 (supplemental results).

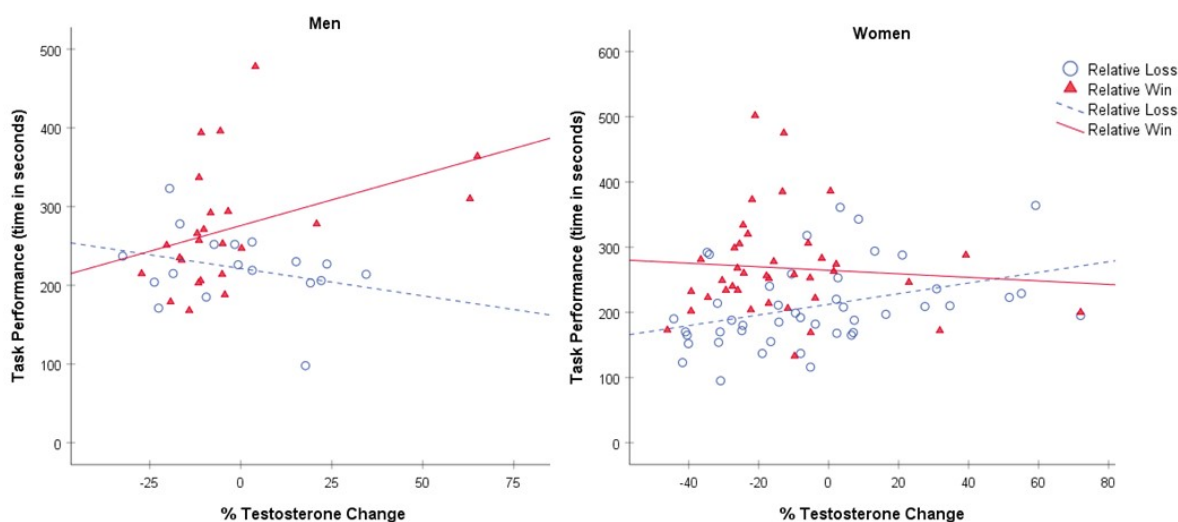
10 In women participants, a follow-up hierarchical regression analysis was conducted in
11 which step 1 included condition, HC use, and $\Delta T\%$, step 2 included the interaction of condition
12 by $\Delta T\%$ and HC use by $\Delta T\%$, and step 3 included the three-way interaction between condition,
13 HC use, and $\Delta T\%$. Results showed that the relationship between $\Delta T\%$ and performance
14 previously demonstrated among the combined sample of women and men was supported among
15 this sample of just women ($N=122$, $b=.47$, $SE=.26$, $t=1.78$, $p=.075$, $95\%CI=-.05-.99$,
16 $R^2_{\text{partial}}=.03$), although no longer statistically significant. Results also revealed a significant main
17 effect (in step 1) for contraceptive use on performance ($N=122$, $b=-34.61$, $SE=14.61$, $t=-2.37$,
18 $p=.019$, $95\%CI=-63.54-5.68$, $r^2_{\text{partial}}=.05$), such that HC users had lower performance times than
19 non-users, but no other significant main effects or interactions. Despite the absence of an
20 interaction between $\Delta T\%$ and HC use, the simple correlation between $\Delta T\%$ and performance
21 was stronger in users compared to non-users ($R^2=.07$ vs. $R^2<.01$). These results were supported
22 when using the unstandardized residual for testosterone and when testosterone change was
23 represented as AUCi (supplemental results).

1 **Testing relative Win/Loss as a moderator.** Winning and losing in the task was
2 determined by the total amount of time spent competing— winners endured longer than their
3 losing counterpart. However, because winning and losing was only in reference to the other
4 person’s performance who was present at the time of testing, winning was not always associated
5 with better absolute performance overall and losing was not always associated with a worse
6 absolute performance overall. As a result, winning/losing was significantly, but not strongly
7 correlated with absolute performance ($r=.39, p<.001$). Thus, although win/loss and performance
8 are overlapping variables, the relative status shift during competition is a property of the
9 competitive environment that is functionally different than absolute performance. Among the
10 men and women participants who competed in the presence of an opponent (N=126), a
11 hierarchical regression analysis was conducted with step 1 including relative win/loss, sex, and
12 $\Delta T\%$, step 2 included the interaction of win/loss by $\Delta T\%$ and sex by $\Delta T\%$, and step 3 included
13 the three-way interaction between win/loss, sex, and $\Delta T\%$. Results revealed a significant 3-way
14 interaction (in step 3) between win/loss, sex, and $\Delta T\%$ ($F_{change}(1,119)=6.80, p=.010, R^2_{change}=.04$;
15 $b=-2.99, SE=1.15, t=-2.61, p=.010, 95\%CI=-5.25--.72$). As shown in Figure 1, $\Delta T\%$ was
16 positively correlated with performance only for men who won ($b=1.31, SE=.61, t=2.13, p=.035$,
17 $95\%CI=.09-2.52$) and women who lost ($b=.82, SE=.35, t=2.34, p=.021, 95\%CI=.13-1.51$). This
18 three-way interaction was supported when using the unstandardized residual for testosterone and
19 when testosterone change was represented as AUCi (supplemental data). Additionally, although
20 samples sizes were uneven across groups and too small for adequately powered tests by the sex
21 of the competitor (see Footnote 2 for further information), exploratory analysis of this interaction
22 revealed that the fairly strong positive association between testosterone reactivity and
23 performance among women who lost was apparent regardless of whether she lost to a man or

1 woman (competed against a woman, $N = 29$: $R^2 = .14$; competed against a man: $N = 16$: $R^2 = .13$).
 2 Likewise, the fairly strong positive association between testosterone reactivity and performance
 3 among men who won was apparent regardless of whether he defeated a man or woman
 4 (competed against a woman, $N = 16$: $R^2 = .34$; competed against a man: $N = 8$: $R^2 = .49$).

5 Due to the previously discussed positive correlation between an individual's performance
 6 and the performance of the opponent who was present during competition, the above analysis
 7 was repeated with the opponent's performance time included as a covariate. The same three-way
 8 interaction between win/loss, sex, and $\Delta T\%$ was found after controlling for the opponent's
 9 performance (supplemental results).

10



11 Figure 1. Correlation between testosterone reactivity and performance. Separate graphs
 12 for men (Win: $R^2 = .15$, Loss: $R^2 = .08$) and women (Win: $R^2 < .01$, Loss: $R^2 = .14$).
 13

14
 15 **Testing “time over opponent” as a special case dependent variable.** For winners in the
 16 dyad condition, the shift in relative social status occurred while they were still competing (i.e.,
 17 they were aware of when the loser dropped his or her arm and could continue on as long after as

1 possible). Thus, for these individuals, testosterone change during the competition could have,
2 over the absolute performance time, uniquely predicted the amount of time they endured after
3 knowing that they were a relative winner. There were individual differences in how long a
4 winner continued to compete after relative status was determined ($N = 63$, in seconds: $M=60$;
5 $SD= 62$; $\min=2$, $\max=320$). As an exploratory analysis, testosterone reactivity for winners was
6 regressed on “time over opponent” (performance time minus their opponent’s performance time).
7 No significant effects emerged using any of the measures of testosterone reactivity ($N=63$, $b=-$
8 $.31$, $SE=.34$, $t=-.92$, $p=.361$, $95\%CI=-.99-.37$, $r^2_{\text{partial}}=.01$).

9 **Study 1 Discussion**

10 Overall, results of Study 1 demonstrate a positive but weak relationship between
11 testosterone reactivity and task performance in men and women, independent of whether one was
12 competing alone or in the physical presence of an opponent. Specifically, because testosterone
13 reactivity essentially centered around zero, those who increased in testosterone endured longer
14 relative to those whose testosterone decreased. For those who competed in the physical presence
15 of an opponent, and thus, were exposed to shifts in relative social status, this positive association
16 emerged only among men who won and women who lost relative to their opponent.

17 The presence or absence of an opponent had no clear effect on testosterone reactivity,
18 performance, or the relationship between testosterone reactivity and performance. Although the
19 presence of an opponent did afford the opportunity for shifts in relative status outcomes that
20 produced differences in the direction and strength of the relationship between testosterone
21 reactivity and performance (as discussed above), physical presence of a competitor alone does
22 not appear to be an essential environmental condition for stimulating greater competitive effort,
23 testosterone reactivity, or their coupling. Indeed, men and women who competed individually, in

1 the absence of an opponent, also showed a positive testosterone reactivity-performance
2 relationship.

3 Real-world competitions for status, resources, and mates occur within the context of
4 relevant social groups. Although the presence of a single opponent was not sufficient to alter
5 testosterone reactivity, performance, or the relationship between these two variables, the
6 presence of a group and relevant competitor group may be a more ecologically valid test of
7 social presence effects (Wagner et al., 2002, Oxford et al., 2010, Flinn et al., 2012; Mehta et al.,
8 2009). Competition among groups provides an opportunity for individuals to gain status both
9 within and across groups and reflects a more realistic coalitional nature of competition. Thus, in
10 a follow-up study, we test the relationship between testosterone reactivity and performance
11 among men and women participants competing in teams, with and without the presence of a
12 competitor team, a context in which status *rank* is established among those present based on
13 relative performance in the competitive will task.

14 **Study 2 Method**

15 **Participants**

16 A sample of 208 undergraduates (with a mean age of 20 years, $SD = 3.0$, range = 18-42)
17 from the University of Oregon participated in the study. Seventy-nine participants identified
18 themselves as assigned male at birth. Three of the 129 participants identifying themselves as
19 assigned female at birth reported their current gender identity as transgender and reported using
20 hormonal therapy. These three individuals were excluded from all analyses. Two individuals
21 assigned female at birth reported their current gender identity as genderqueer, but had
22 testosterone levels typical of females and were not taking hormonal therapy – these participants
23 were combined with the women for analyses by “sex”. This gives a sample size of 205

1 participants (79 men and 126 women). Ethnicity was predominantly European/European-
2 American (58%) with relatively large subsets of Hispanic/Latino (17%) and Asian/Asian-
3 American (14%). Participants were recruited from the psychology department subject pool
4 composed of undergraduates enrolled in introductory psychology and linguistics courses, each of
5 which has a research participation option as a condition for the satisfactory completion of the
6 course. The study was approved by the university's Research Compliances Services.

7 **Competitive Will Task**

8 The same competitive task from Study 1 was employed in Study 2; participants held a
9 weight (a common dumbbell used for resistance training, 1lb. for women, 2 lbs. for men) at
10 arm's length and shoulder height for as long as they felt they could in competition against other
11 participants. The incentive scheme was altered for the group setting to promote task investment
12 at both the individual and group level. The top five individuals of all participants from each
13 academic semester would receive a cash prize based on place: 1st = \$50, 2nd = \$40, 3rd=\$30,
14 4th=\$20, 5th=\$10. Additionally, individuals were assigned to teams (details below) to facilitate
15 our operationalization of competing in the presence or absence of others. Each team was in
16 competition against all other teams for an overall grand prize, 1st = \$200, 2nd=\$150, 3rd=\$100,
17 given to the top three teams whose average score of all its members was the longest of all other
18 teams competing in the same academic semester (and split evenly among team members).
19 Importantly, regardless of the number of competitors and teams present at any one testing
20 session, all participants were competing against each other for the same prize (to the five
21 individuals and three teams who performed the best) and respective winners were not contacted
22 until the end of the academic term to collect their prize. Data collection took place over the
23 course of two semesters, so there were two batches of prize money winners. This incentive
24 scheme was necessary to standardize the competition across conditions. That is, even if a

1 participant held their arm up longer than others within their testing session, they continued to
2 compete against the unknown others for the best possible performance to count towards the
3 rankings.

4 As in Study 1, relative status rank among participants during each testing session as a
5 result of performance in the competitive will task was an available social context factor. “Group
6 rank” was determined for all groups of participants who shared the same testing session by
7 categorical separation into subgroups for individuals who finished in the top 25% of the
8 participants who were present, middle 25-75% of the participants who were present, and the
9 bottom 25% of the participants who were present.

10 **Additional construct validation.** To provide additional evidence of validity for the
11 competitive will task, participants completed a series of questionnaires designed to determine
12 individual differences in constructs related to status motivation – competitiveness
13 (Competitiveness Orientation Measure – COM, Newby & Klein, 2014), social power (Power and
14 Dominance System Scales – PDSS, Murphy, 2016), dominance and prestige (Cheng et al.,
15 2010), grit (Duckworth & Quinn, 2009), and academic achievement motivation (Academic
16 Motivation Scale – AMS, Vallerand et al., 1992). Task performance was significantly and
17 positively related to all subscales for competitiveness orientation (general: $r = .31, p < .001$;
18 dominant: $r = .22, p = .002$; competitive affectivity: $r = .24, p = .002$; personal enhancement: $r =$
19 $.32, p < .001$), prestige ($r = .16, p = .024$), grit ($r = .20, p = .005$), PDSS dominance motivation (r
20 $= .25, p < .001$), and AMS intrinsic motivation ($r = .17, p = .015$) demonstrating good
21 convergent validity (full correlation matrix shown in supplementary data). Performance was not
22 significantly correlated to dominance (as measured by Cheng et al., 2010), PDSS felt power,
23 PDSS attention to power cues, AMS extrinsic motivation, or AMS amotivation. Additionally,

1 participants completed task-specific items related to motivation following competition (“I tried
2 really hard to win the competition,” and “I really wanted to win the competition”). Task
3 performance was significantly and positively correlated with responses to both items ($r = .52, p <$
4 $.001$ and $r = .51, p < .001$, respectively). Correlations were generally the same among both men
5 and women. All p-values for each correlation were considered significant after adjusting the
6 “statistical significance” set point for alpha based on false detection rate from conducting
7 multiple tests (Benjamini & Hochberg, 1995). Consonant with analyses from Study 1, physical
8 qualities associated with strength (i.e., height, weight, BMI) were not related to performance in
9 the competitive will task and, did not explain the positive associations between performance and
10 the psychological factors previously discussed (results shown in supplemental data).

11 **Procedure**

12 Participants arrived to the laboratory in mixed-sex groups of three to eight people. Two
13 experimenters, one male and one female, were present for all testing sessions. Upon arrival,
14 participants read and signed a consent form and received a brief explanation of the study (i.e.,
15 that the study was about the relationships among personality, social context, competition, and
16 hormones). After consent, participants completed questionnaires in private testing rooms for
17 approximately 25 minutes and then, afterward, provided their first saliva sample. For groups of
18 three to five individuals, the experimenter told them they would be competing as a team in
19 subsequent tasks (specific instructions to follow) and then asked them to come up with a team
20 name for recording purposes. If more than six participants were present, the groups were
21 randomly split into two teams and asked to stand on opposite sides of the room. The
22 experimenter then told each group that they would be competing as a team in the following tasks
23 and asked them to come up with a team name for recording purposes. There were no testing
24 sessions held with fewer than three participants. Next, the experimenter gave specific

1 instructions about the competition and the prize money structure (discussed above). Participants
2 were reminded that they were competing for an overall individual and team prize and told that
3 they were free to talk and interact during the competition. On the “Begin” command each
4 participant raised their arm to initiate the competitive will task. Once participants dropped their
5 arms to signal end to their competition, their individual timer was stopped and they were
6 instructed to return to their individual testing rooms to complete a post-competition survey.
7 Participants were retrieved from their private room 10 minutes later to give the second saliva
8 sample. Because participants finished the task at different times, beginning the second saliva
9 sample was tapered based on finish place to ensure that each participant had approximately 10
10 minutes between the end of their competition and the start of the saliva sample (i.e., the time
11 elapsed from the baseline sample to the post-competition sample was different for each
12 participant, depending on their performance time in the task). For purposes beyond the scope of
13 the present study, participants next completed a team-based cooperative task, followed by a third
14 saliva sample, and a set of questionnaires regarding group identification.

15 The participants did not know each other. They were requested not to sign up to
16 participate with anyone they knew and this was confirmed upon arrival to the laboratory. The
17 ecological validity of status among groups of people who do not interact outside of the
18 laboratory is a concern for this kind of research. However, this paradigm is consistent with
19 psychological research that employs a “minimal groups design” (Tajfel et al., 1971; Otten, 2016)
20 which is effective for altering perceptions of in-group identity and belonging.

21 **Saliva Samples and Hormone Assay**

22 Saliva samples were collected using the same procedure as Study 1 at two time points,
23 immediately before and 10 minutes after competition. Samples were stored at -20°C initially and

1 then transferred to a -80°C freezer. Samples were assayed for testosterone⁵ by Dresden Lab
2 Service using IBL chemiluminescence immunoassay kits with 20% of samples tested in
3 duplicate. CV% for low and high controls were 4.86% and 4.29%, respectively and intraassay
4 CV% was 4.5%.

5 **Testosterone Reactivity**

6 Testosterone concentrations for five women participants and two men participants were
7 not obtained due to insufficient or contaminated saliva provided during the collection periods
8 leaving a total sample size for analyses involving testosterone of 198 (men N=77; women
9 N=121). In men and women, testosterone levels at both points were positively skewed.
10 Following the same procedure for correcting outliers discussed in Study 1, five individuals (three
11 women and two men) were identified as outliers and testosterone levels for these individuals
12 were replaced with the mean plus or minus three standard deviations, effectively reducing
13 skewness. As in Study 1, testosterone reactivity was calculated as the percent change from before
14 to 10 minutes after. Four additional outlier participants' (2 women, 2 men) testosterone levels
15 were replaced with the mean plus or minus three standard deviations depending on the direction
16 of change for the original value. As in Study 1, hypotheses were also tested as a robustness check
17 using two additional metrics of testosterone reactivity, Tres and AUCi.

18 **Hormonal Contraceptive Use**

19 Following consent, each participant provided information regarding contraceptive use.
20 Specifically, participants were asked to respond “yes” or “no” to the question “Are you taking
21 any form of hormonal contraceptive/birth control (e.g., pill, patch, injection)?” No men
22 answered yes to this question. Among women, 54% of participants said “Yes” and were then

⁵ This research was a part of a larger study that also included measurement of cortisol and DHEA-S levels. Only testosterone levels are included for analysis in the present study.

1 asked to indicate “What kind of hormonal contraception are you taking?” with options for oral
2 contraceptive pill, hormonal patch, hormonal injection, IUD, and hormonal implant. Of the 126
3 females participating in this study, 58 reported that they were not using any form of
4 contraception, 44 reported using pill, 12 an IUD, 8 a hormonal-based implant, and 4 a hormone-
5 based injection or patch.

6 As in Study 1, among women, hormonal contraceptive use (HC use; yes/no) was tested as
7 a moderator of the relationship between testosterone reactivity and performance. For the
8 purposes of analysis, oral contraceptive pill and hormonal patch, injection, and implant users
9 were combined into a single category of hormonal contraception users ($N = 56$) for comparison
10 to women not using any form of hormone contraception ($N = 58$). The twelve IUD users were
11 excluded from analyses involving HC use as an experimental variable due to incomplete
12 understanding of the peripheral hormone exposure from these contraception methods and the
13 small sample size of this group⁶. These participants were not excluded from main analyses.

14 **Study 2 Results**

15 Descriptive statistics and correlations for the main study variables for men and women
16 are shown in Table 2. As with Study 1, salivary testosterone levels before and after competition
17 were significantly higher for men compared to women. Men and women did not significantly
18 differ in testosterone reactivity to competition ($\Delta T\%$, unstandardized residual, or AUCi). Women
19 using hormonal contraceptives had significantly lower testosterone levels relative to women not
20 using any form of hormonal contraception, although effects were small (Table 2). Users and non-

⁶ Because testosterone levels for five women participants are missing, the final sample size for analyses involving HC use and testosterone reactivity is 109.

1 users did not significantly differ in testosterone reactivity to competition ($\Delta T\%$, unstandardized
2 residual, or AUCi). $\Delta T\%$, Tres, and AUCi were highly positively correlated.

3 Individuals who competed in the condition where another competitor team was present
4 had significantly higher performance than those who competed without a competitor team
5 present ($Mean_{diff} = 57.67$, $t(203) = -3.59$, $p < .001$, $d = .50$). As shown in Table 2, men had
6 significantly higher performance on average than women (even with a 1 lb. higher weight
7 differential). Among women, hormonal contraceptive users showed lower performance on
8 average, but this effect was not significant. Task performance was significantly and positively
9 correlated with the mean performance of the other competitors present for each testing session (r
10 $= .210$, $p = .002$). When separating men and women, the relationship was weaker and not
11 significant among men ($r = .11$, $p = .331$), but remained strong among women ($r = .32$, $p < .001$),
12 although the difference between the correlation coefficients was not significant ($z = -1.48$, $p =$
13 $.14$). As shown in Table 2, post-competition testosterone levels and metrics of reactivity were
14 generally positively correlated with performance among men, but not women.

15 **Testosterone reactivity and task performance**

16 As in Study 1, in both men and women and across experimental condition, testosterone
17 levels decreased on average from before to after competition, although the magnitude of this
18 decrease was small and there were large individual differences in both the magnitude and
19 direction of testosterone reactivity (Table 2). There were no significant differences in mean
20 testosterone reactivity between experimental groups (whether analyzed overall or separately by
21 sex) or across group rank (overall or by sex). For more detail, see the supplemental results.

22 A hierarchical regression analysis was conducted to test the relationship between
23 testosterone reactivity and performance. Step 1 included condition (presence or absence of a
24 competitor team), sex, and $\Delta T\%$, step 2 included the interaction of condition by $\Delta T\%$ and sex by

1 $\Delta T\%$, and step 3 included the three-way interaction between condition, sex, and $\Delta T\%$. Results
2 revealed a significant interaction (in step 2) for sex by $\Delta T\%$ in predicting performance above and
3 beyond sex, condition, and $\Delta T\%$ alone ($N=198$, $F_{change}(2,192)=9.93$, $p<.001$, $R^2_{change}=.09$; $b=-$
4 2.94 , $SE=.66$, $t=-4.45$, $p<.001$, $CI=-4.24--1.63$). Simple slopes analysis revealed a significant
5 positive relationship between testosterone reactivity and performance in men ($N=77$, $b=2.84$,
6 $SE=.68$, $t=4.21$, $p<.001$, $CI=1.50-4.18$, $r^2_{partial}=.19$), while there is no direct relationship in women
7 ($N=121$, $b=.19$, $SE=.23$, $t=.82$, $p=.417$, $CI=-.27-.65$, $r^2_{partial}<.01$). This main finding was supported
8 when using the unstandardized residual for testosterone, however, the interaction was weaker
9 and the main effect for testosterone reactivity independent of sex explained the most variance in
10 performance. Similarly, when testosterone change was represented as AUCi, the main effect for
11 AUCi significantly predicted performance independent of participant sex (supplemental results).
12 In summary, both men and women showed a positive linear relationship between testosterone
13 reactivity and performance, but the effect was stronger in men across all three metrics of
14 testosterone reactivity. Specifically, because testosterone change ranged from negative to
15 positive, larger testosterone increase was related to relatively better performance in the
16 competitive will task, while larger testosterone decrease was related to relatively worse
17 performance.

18 In women participants, a follow-up hierarchical regression analysis was conducted in
19 which step 1 included condition, HC use, and $\Delta T\%$, step 2 included the interaction of condition
20 by $\Delta T\%$ and HC use by $\Delta T\%$, and step 3 included the three-way interaction between condition,
21 HC use, and $\Delta T\%$. Results revealed a significant main effect (in step 1) for HC use ($N=109$, $b=-$
22 37.07 , $SE=17.05$, $t=-2.17$, $p=.032$, $CI=-70.87--3.26$, $r^2_{partial}=.21$), such that HC users had lower
23 performance than non-users. Additionally, there was also a significant main effect for group

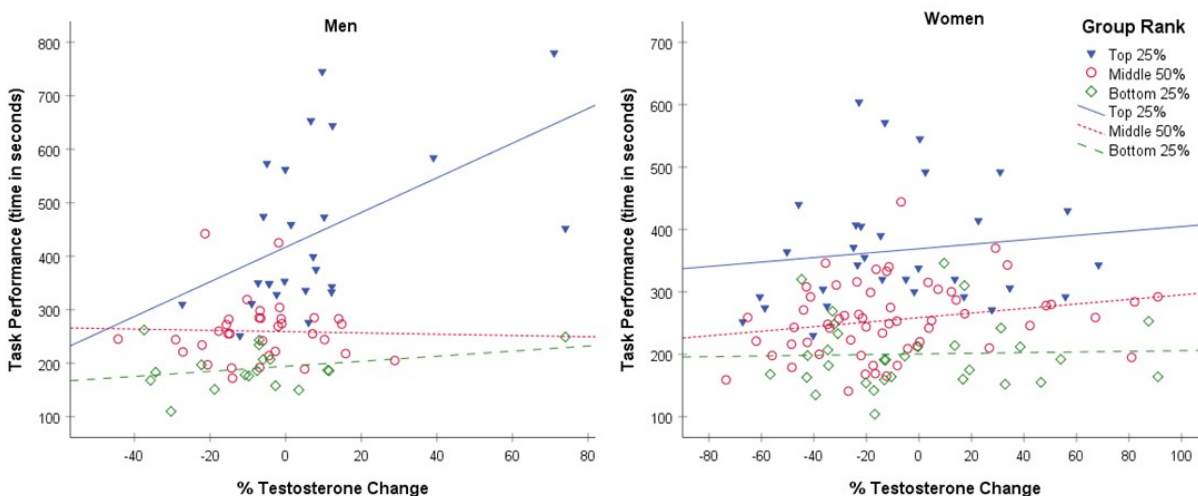
1 condition ($N=109$, $b=52.38$, $SE=17.46$, $t=3.00$, $p=.003$, $CI= 17.76-87.00$, $r^2_{\text{partial}}=.28$), such that
2 women competing in the presence of a competitor group had higher performance than in the
3 absence of a competitor group. There were no other statistically significant main effects or
4 interactions. Robustness analysis using the unstandardized residual for testosterone and AUCi
5 produced the same overall results in terms of the direction and magnitude of effects
6 (supplemental results).

7 **Testing Group Rank as a moderator.** As in Study 1, relative status was determined
8 among participants competing at the same time. Group rank is a categorical variable that relates
9 to ($r=.67$, $p<.001$), but is also conceptually independent from absolute performance. To test the
10 moderating effect of relative status outcome (group rank), a hierarchical regression analysis was
11 conducted with step 1 including group rank, sex, and $\Delta T\%$, step 2 included the interaction of
12 group rank by $\Delta T\%$ and sex by $\Delta T\%$, and step 3 included the three-way interaction between
13 group rank, sex, and $\Delta T\%$. Results revealed a significant 3-way interaction (in step 3) between
14 group, sex, and $\Delta T\%$ ($N = 198$, $F_{\text{change}}(1,191)=6.37$, $p=.012$, $R^2_{\text{change}}=.016$; $b=1.45$, $SE=.57$,
15 $t=2.52$, $p=.012$, $CI= .32-2.59$). As shown in Figure 2, only men who ranked within the top 25% of
16 their group showed a significant positive relationship between $\Delta T\%$ and performance ($N=25$,
17 $b=3.24$, $SE=1.18$, $t=2.75$, $p=.011$, $CI=.80-5.68$, $r^2_{\text{partial}}=.25$). Although simple slopes were in the
18 positive direction for men ranking in the bottom 25% and women above the bottom 25%, these
19 trends were non-significant (supplemental results). In summary, men who increased in
20 testosterone during competition endured relatively longer in the task (performed better overall),
21 but only if they also placed relatively high among the other participants who competed at the
22 same time. Likewise, only among high-ranking men were decreasing or relatively unchanged

1 testosterone levels associated with reduced competitive endurance relative to other participants'
 2 performances.

3 Due to the previously discussed positive correlation between an individual's performance
 4 and the performance of all others present during testing, the above analysis was repeated with the
 5 mean performance time of others present included as a covariate. This analysis produced the
 6 same results as above, a three-way interaction between group rank, sex, and $\Delta T\%$, after
 7 controlling for the mean performance of the others present (supplemental results). Additionally,
 8 although robustness analysis using the unstandardized residual for testosterone and AUCi
 9 produced slightly larger effect sizes for the relationship between testosterone reactivity and
 10 performance among women participants, the same overall results were observed in terms of the
 11 direction and magnitude of the positive relationship between testosterone reactivity and
 12 performance among top-ranking individuals, particularly among men (supplemental results).

13
 14



15
 16 *Figure 2.* Correlation between testosterone reactivity and task performance by group rank.
 17 Separate graphs for men (top 25%: $R^2=.25$, middle 50%: $R^2<.01$, bottom 25%: $R^2=.09$) and
 18 women (top 25%: $R^2=.02$, middle 50%: $R^2=.05$, bottom 25%: $R^2<.01$).

19

1 **Testing “time over the group mean” as a special case dependent variable.** For those
 2 who outperformed the majority of the group (top 25%), the shift in relative social status occurred
 3 while they were still competing (i.e., they were aware of when the others dropped their arm and
 4 could continue on as long after as possible). That is, for these individuals, testosterone change
 5 during the competition could have, over the absolute performance time, uniquely predicted the
 6 amount of time they endured after knowing that they were relatively high-ranking within their
 7 group. On average, these participants ($N = 58$) continued to compete for 133 seconds over the
 8 group mean of others present during testing ($SD = 104$; $\min = 1$, $\max = 526$). As an exploratory
 9 analysis, testosterone reactivity for individuals in the top 25% of their group was regressed on
 10 “time over group mean” (absolute performance time minus the mean performance time of all
 11 others in the group). Sex and the interaction of sex and testosterone reactivity were included in
 12 the analysis. Results revealed an interaction for testosterone reactivity and sex ($N = 56$,
 13 $F_{change}(1,52) = 11.49$, $p = .001$, $R^2_{change} = .143$; $b = -3.05$, $SE = .90$, $t = -3.39$, $p = .001$, $CI = -4.86$ – -1.25).
 14 For men, but not women who ranked fairly high and thus, received feedback about their high
 15 status while competing, testosterone reactivity significantly positively predicted the amount of
 16 time they endured past the group mean performance time (men: $N = 25$, $R^2 = .33$, $b = 3.16$, $SE = .95$,
 17 $t = 3.33$, $p = .003$, $CI = 1.20$ – 5.12 ; women: $N = 31$, $R^2 < .01$, $b = .11$, $SE = .36$, $t = .30$, $p = .765$, $CI = -.62$ –
 18 $.83$). However, after controlling for the absolute performance (which is highly correlated, $r = .90$,
 19 with “time over group mean”), this effect was the same direction, but no longer significant and
 20 substantially reduced in magnitude (men: $b = .78$, $SE = .45$, $t = 1.72$, $p = .100$, $CI = -.16$ – 1.71 ; women:
 21 $b = -.09$, $SE = .22$, $t = -.42$, $p = .675$, $CI = -.55$ – $.36$). Testosterone reactivity among the top-ranked
 22 individuals measured as the unstandardized residual ($b = 3.57$, $SE = .94$, $t = 3.80$, $p < .001$, $CI = 1.69$ –
 23 5.46 , $r^2_{partial} = .21$) and AUCi ($b = 3.71$, $SE = 1.31$, $t = 2.84$, $p = .006$, $CI = 1.09$ – 6.34 , $r^2_{partial} = .13$)

1 significantly predicted endurance time over the group mean. Although the interaction of sex was
2 not significant in these robustness analyses, the effects of both unstandardized residual change in
3 testosterone and AUC_i were substantially larger in men (Men: $R^2=.32$ and $.18$, respectively;
4 Women: $R^2=.01$ and $.01$). As with percent change in testosterone, the effect was the same
5 direction, but no longer significant and substantially reduced in magnitude after controlling for
6 absolute performance (supplemental results).

7 **Exploratory analysis of the role of trait dominance**

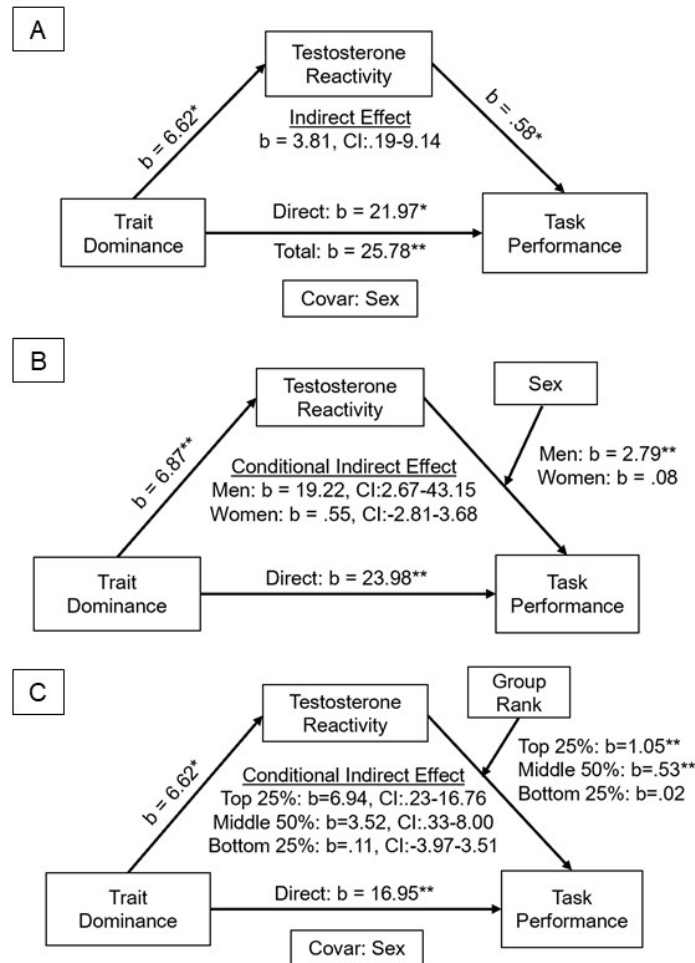
8 When conducting construct validation for the competitive will task, two self-report
9 personality traits representing dominance motivation were positively related to both performance
10 *and* testosterone reactivity: *dominant competitiveness* from the competitiveness orientation
11 measure (Newby & Klein, 2014, this subscale contains 13 items rated on a 5-point Likert scale,
12 e.g., “I like to be better than others at almost everything.”) and social power-based *dominance*
13 *motivation* from the power and dominance systems measure (Murphy, 2016, this subscale
14 contains 6 items rated on a 7-point Likert scale, e.g., “I like to have power over other people.”).
15 Thus, the three-way positive relationship between trait dominance, testosterone reactivity, and
16 performance raises the possibility of mediation. Using PROCESS version 3.0 software (Hayes,
17 2018), a simple mediation analysis (model 4, shown in Fig 3A) was tested first with X=Trait
18 Dominance, M=Testosterone reactivity, Y=Performance and, with Sex as a covariate. Next,
19 given the interaction of sex and testosterone reactivity in predicting performance in the main
20 analyses, a moderated mediation (model 14, shown in Fig3B) with Sex moderating the path
21 between M and Y (path b) was conducted. Lastly, given the role of relevant social status in
22 moderating the testosterone reactivity-performance relationship in men and women, a second

1 moderated mediation analysis (model 14, shown in Fig3C) was conducted with Group Rank
2 moderating the path between M and Y and Sex included as a covariate.

3 Path analyses and results for all models are shown in Figure 3 (all output for both
4 measures of trait dominance is provided in the supplemental results). Effects were the essentially
5 identical whether using trait competitive or social-power based dominance motivation (results in
6 Fig3 are for *dominant competitiveness*). Generally, results supported the main analyses in all
7 respects: 1) testosterone reactivity positively predicts task performance (total model: $R^2=.08$), but
8 this effect is moderated by sex ($R^2_{\text{change}}=.08$, significant in men but not women) and 2) regardless
9 of participant sex, group rank also moderated this relationship ($R^2_{\text{change}}=.01$, the positive
10 relationship is strongest for men and women who ranked in the top 25% of their group). As
11 expected, trait dominance was a significant predictor of performance. All paths were significant
12 and the bootstrapped confidence intervals for the indirect effects did not cross zero (Figure 3).
13 While all three variables are inter-related, testosterone reactivity to competition only minimally
14 (statistically) *explains* the relationship between trait dominance and subsequent dominance-
15 related behavior. This suggests that testosterone reactivity is likely one of several possible
16 mechanisms for translating competitive motivation into competitive behavior.

17 Due to precedent for the role of trait dominance in *moderating* testosterone's effect on
18 competitive behavior, we also tested "dominant competitiveness" and "dominance motivation"
19 as a moderator of the effect of testosterone reactivity on performance. Although the independent
20 effects of both testosterone reactivity and trait dominance on performance remained, the
21 interaction was not significant in either case ($R^2_{\text{change}}=.002$ and $.004$, respectively; full analysis in
22 supplemental results).

23



1

2 *Figure 3.* Exploratory mediation analysis of the relationships between trait dominance,
 3 testosterone reactivity, and task performance (N=197). A) Simple Mediation B) Moderated-
 4 Mediation with sex C) Moderated-Mediation with group rank. * $p < .05$, ** $p < .01$. Indirect effects
 5 are bootstrapped.

6

Study 2 Discussion

7

8 Study 2 was designed to extend evidence on the relationship between testosterone
 9 reactivity and task performance within the group context. With groups of 3-8 participants
 10 assigned to teams, the social presence of a competitor team was manipulated and the incentive
 11 structure of the competitive will task was altered to motivate both individual and team-based
 12 competitive effort. In addition to physical presence of a competitor team, the moderating effects
 of participant sex and social status in the form of relative rank among the competitors present in

1 each testing session were tested. Generally, testosterone reactivity positively predicted
2 performance, the amount of endurance expressed in competition, but this effect was significant
3 only among men. Specifically, because testosterone reactivity centered around zero, greater
4 increases related to better performance and greater decreases related to worse performance. In
5 both men and women, those who attained higher status relative to the others present (performed
6 relatively better) showed the strongest positive relationship between testosterone reactivity and
7 performance, but again, effects were most pronounced among men. Although participants
8 performed better on average with increasing number of people present, the presence or absence
9 of a competitor team did not affect testosterone reactivity or its relationship with performance.

10 An exploratory mediation analysis was conducted to test the role of trait dominance as an
11 individual difference factor that drives both testosterone reactivity to competition and the
12 expression of competitive behavior. We provide initial evidence that testosterone reactivity at
13 least partially mediates the strong relationship between trait dominance and task performance.
14 The main effects regarding sex and group rank as moderators of the direct relationship between
15 testosterone reactivity and performance were supported with moderated-mediation. Overall,
16 Study 2 provides novel evidence for a positive association between changing testosterone over
17 the course of competition and performance on an endurance-based task, with greater increases
18 (or less decreases) associated with greater endurance especially among men and those who
19 performed better than their group-mates. This finding was robust across different measures of
20 testosterone reactivity and analytic approach. Additionally, Study 2 provides initial evidence for
21 the potential role of trait dominance in driving both testosterone changes associated with
22 competition and the expression of competitive efforts.

General Discussion

1
2 Performance in the competitive will task is defined as the amount of time a participant
3 endures in a weight-holding contest for time. Endurance requires a combination of physical and
4 mental components that interact to aid in the expression of competitive “effort” in nearly all
5 contests for time. Indeed, holding a weight for time and has been previously and independently
6 validated as a measure of mental toughness, a psychological construct in which competitive
7 persistence is a core feature (Crust and Clough, 2005). Generally, in the absence of obvious
8 differences in skill or knowledge, those who succeed in social contests must display superior
9 energy, effort, mental or physical strength, will-power, and endurance over their opponent.
10 Competitive endurance is just one of the ways in which motivation to dominate or attain social
11 status over others is materialized behaviorally. The weight holding task used in this research is a
12 relatively simple and face valid application for revealing individual differences in the propensity
13 for exerting competitive effort. In support of this notion, we present data from two studies of
14 nearly 400 participants total that demonstrates a significant positive correlation between
15 performance in the competitive will task and individual differences in traits having to do with
16 competitiveness and dominance motivation as well as task-specific desire to win and perceived
17 effort. Furthermore, physical qualities associated with strength – height, weight, and BMI – were
18 unrelated to task performance and did not explain variance in the relationship between
19 performance and psychological traits. Combined, this evidence provides a strong initial case that
20 performance in the competitive will task is a behavioral measure of underlying psychological
21 motives associated with status-seeking.

22 Increasing testosterone during a competitive social encounter is thought to promote
23 psychological states and behaviors that would aid in dominating an opponent (Wingfield et al.,
24 1990; Archer, 2006). However, individuals differ with respect to the direction and magnitude of

1 their hormonal response to competition. The present study is premised on the idea that these
2 individual differences in testosterone reactivity should correlate with individual differences in
3 the degree of competitive behavior expressed during that competition. Across both studies,
4 testosterone reactivity over the course of the competitive will task ranged from around a 60%
5 decrease to a 75% increase with the average response centering just below zero, i.e., no change.
6 Concordant with predictions, increasing testosterone was associated with relatively better
7 performance in the competitive will task and decreasing testosterone was associated with
8 relatively worse performance. Further, in line with previous research and predictions, there were
9 several important moderators of this relationship: participant sex and status outcome relevant to
10 other physically present competitors (Study 1, win/loss; Study 2, group rank). For men in both
11 studies, the correlation between testosterone reactivity and performance was strongest for those
12 who won or ranked highest among their group. For women, the effect was less generalized,
13 appearing only among those who lost to a single competitor (Study 1). In Study 2, among high-
14 ranking men participants, individual differences in testosterone reactivity positively predicted the
15 time one endured over the group mean (time that they continued to compete while knowing they
16 were relatively high in status), but controlling for absolute performance virtually eliminated the
17 effect. Overall, the mere presence or absence of a competitor or competitor group did not affect
18 the relationship between testosterone reactivity and performance.

19 The direction of causality of the hormone-behavior relationship found in the two studies
20 is not known. Although we propose that testosterone reactivity predicts the time-matched
21 expression of competitive behavior, it is also likely that this behavior in the context of
22 competition drives the testosterone response. Indeed, attaining social status through competition
23 is thought to produce elevated testosterone as a means to maintain dominance. Although the

1 design of this research cannot parse direction of causality from the results, trait dominance,
2 which is a stable and pre-existing characteristic of individuals and therefore present before
3 engaging in the competitive task, predicts both performance and testosterone reactivity. Further,
4 initial evidence from the present research shows that testosterone mediates the effect of trait
5 dominance on task performance. This suggests that the testosterone response to competition may
6 act as an underlying mechanism by which individual differences in motivation for dominance are
7 translated into behaviors to achieve this end within particular adaptive contexts. Alternatively,
8 given that performance is confounded with time spent engaging in the task, testosterone change
9 could be a manifestation of time independent of psychological motivation. This limitation could
10 be addressed in future research by including a control group that did not compete while
11 testosterone levels were assessed at different intervals or by using a task in which persistence is
12 not synonymous with time (e.g. number of questions or components of a task completed).
13 Nevertheless, discussions about causality are complicated by the rapid and intertwined nature of
14 hormone-behavior feedback loops, one in which hormones influence behavior and behavior
15 subsequently provides ongoing perceptual information that regulates hormonal responding in
16 real-time to meet the demands of the evolving competitive context.

17 **Moderating role of relative status**

18 Findings from both studies regarding the importance of status-related outcomes in
19 influencing the hormone-behavior relationship of interest is consonant with prior research.
20 According to the biosocial model of status, shifts in status gained or lost through competition
21 should impact the direction of testosterone change during a competitive encounter, increasing for
22 those who experience social victory and decreasing for those who experience social defeat
23 (Mazur, 1985; Mazur & Booth, 1998). Increases and decreases in testosterone levels are thought

1 to respectively promote or discourage future competitive or aggressive behaviors. Meta-analytic
2 evidence (Geniole et al., 2017) generally supports the ‘winner-loser effect’ on testosterone
3 change, but the effects are small overall and significant only for male participants. In the
4 research presented, contrary to the winner-loser effect, there were no significant differences in
5 the testosterone change across competition between winners and losers, in men or women.
6 Rather, relative status moderated the relationship between testosterone reactivity and task
7 performance such that a positive association emerged only among men who experienced relative
8 social victory. This finding is in-line with previous studies showing that, among men,
9 competition outcome moderates the relationship between competition-related changes in
10 testosterone level and psychological variables such as power motivation and competitive
11 decision-making as well as, in the reverse direction, the relationship between competitive effort
12 and post-competition testosterone levels (Carré & McCormick, 2008; Mehta & Josephs, 2006;
13 Mehta et al., 2015b; Oxford et al., 2010; Schultheiss & Rohde, 2002; Schultheiss et al., 2005).

14 The status-relevant outcomes seen in the competitive will task are, by the very nature of
15 the contest rules, highly related to absolute performance time. That is, people who endured
16 longer were more likely to win or finish in the top tier of their group. Still, there were many who
17 would have lost or won and placed lower or higher had they competed against a different
18 opponent (Study 1) or within a different group (Study 2). Importantly, participants were not
19 given any information about average performance times or overall placement; the only
20 information participants had with which to assess their own performance was the performance of
21 others with which they shared that particular space and time. Thus, for participants who
22 competed individually (Study 1), there was no way to assess their relative position. For those
23 who won or finished in the top tier of their group, some portion of their performance continued

1 after they achieved relative victory – participants were all competing for an overall cash prize
2 that would not be determined until a later date based on how their absolute performance
3 compared the much broader body of participants. As a result, status outcome in the present
4 research was absent of a direct monetary outcome and represented a somewhat unique condition
5 of social status achieved based on context-specific criteria – the other participants in the room.

6 The overlapping nature of task performance and relative status outcome (Study 1: $r = .39$,
7 Study 2: $r = .67$) was an intentional component of the present research, one that accurately
8 reflects how status is often determined in real-world contests. While previous studies of the
9 winner-loser effect in the laboratory often “fix” the competition outcome (random assignment to
10 win or loss condition) in an attempt to reduce the influence of competitive effort (e.g., van der
11 Meij et al., 2010; Zilioli & Watson, 2012; for review, Casto & Edwards, 2016), the set of studies
12 presented here provide evidence that testosterone reactivity may actually map onto those efforts
13 in real-time and, as in naturalistic competition, play a major role in determining relative status
14 gained or lost. Alternatively, competitive effort, which still functions to increase the probability
15 of attaining status in the ongoing contest, produces elevated testosterone after the task in order to
16 serve the purpose of future status attainment and maintenance. The implication that testosterone
17 fluctuations coordinate or facilitate real-time competitive effort is corroborated by some prior
18 evidence that testosterone reactivity to competition is linked with time-matched competitiveness
19 and dominance signaling in men (Gonzalez-Bono et al., 1999; Kordsmeyer & Penke, 2019).
20 Furthermore, the present research provides additional evidence that the positive relationship
21 between testosterone reactivity and competitive behavior emerges only among relative winners
22 and high-ranking individuals, a result that demonstrates the compounding nature of effort and
23 status achievement. More so, among the high-ranking participants, the strong positive

1 relationship between testosterone reactivity and individual differences in competitive endurance
2 after achieving relative status (time over group mean) was explained by their absolute
3 performance time across the contest. Thus, an individual's overall effort, perhaps facilitated by
4 rising testosterone, increased the likelihood of achieving status in terms of both high absolute
5 performance and relative social position among others. Future work with the competitive will
6 task should identify a marker for performance time after the onset of discomfort, a variable that
7 could better capture differences in status motivation over absolute performance.

8 **Sex effects, the inclusion of women, and hormonal contraceptive use**

9 Findings regarding the positive relationship between the testosterone change associated
10 with competition and competitive endurance expressed during that competition, discussed above,
11 were largely specific to men who participated in the present research. Women participants also
12 showed similar directional trends, but the effect sizes were significantly reduced. Results from
13 this research are consonant with prior research that has found smaller effect sizes or no effects
14 for the relationship between testosterone reactivity and competitive choice or implicit power
15 motivation in women compared to men (e.g., Carré et al., 2013; Geniole et al., 2013; Geniole &
16 Carré, 2018). However, studies administering exogenous testosterone have found that, in certain
17 contexts, supplemental treatment with testosterone increased competitive decision-making for
18 trait dominant women (Mehta et al., 2015a). However, given the lower number of men compared
19 to women in this study, interpretations about the replicability of the observed sex difference
20 should be made cautiously.

21 There are several possible explanations for the observed sex difference. First, it is
22 possible that women have a different or interacting hormonal mechanism for regulating
23 competitive behavior that was not accounted for in the present research. For example, some

1 research has shown that fluctuating levels estradiol and progesterone associated with the
2 menstrual cycle influence intra-sexual competition in mating domains (e.g. Cobey et al., 2013;
3 Durante et al., 2008; Puts, 2005, but see Hahn et al., 2016) as well as competitive decision-
4 making in economic tasks (e.g., Buser, 2012; Eisenbruch and Roney, 2016; Pearson and
5 Schipper, 2013). Future research should explore these potential mechanisms among women
6 competing for social status. Second, due to the large differences in how competitive behavior is
7 socialized in western women (punished) compared to men (reinforced) (e.g., Andersen et al.,
8 2013; Carpenter et al., 2018; Williams & Tiedens, 2016), women likely face different social
9 pressures in competitive contexts that are not accounted for in study designs (for review, Casto &
10 Prasad, 2017). In the present research, women who lost when competing against a single
11 opponent showed a fairly strong positive association between testosterone reactivity and
12 performance. Although this effect did not replicate among low-ranking women in the group
13 setting, it suggests a possible avenue for future research that addresses the nuance of social status
14 tradeoffs for women in competitive contexts. This research should consider how society and
15 culture shape and have shaped women's competitive and dominance motivated behavior, having
16 evolved and currently existing within a structure in which these behaviors incur risk (social and
17 physical) and require greater tact, strategy, and concealment (Campbell, 2004; Prentice &
18 Carranza, 2002; Rudman & Phelan, 2008;). A third, and perhaps more parsimonious explanation,
19 could be that there is greater measurement error when determining testosterone concentrations
20 for women (e.g. Welker et al. 2016, Prasad et al. 2019; Schultheiss et al., 2019) making it more
21 difficult to detect what are fairly small to moderate effects. Advancement in techniques for
22 assaying testosterone more precisely even at low concentrations, such as mass spectrometry, will
23 improve understanding of hormonal mechanisms that influence competitive behavior in women.

1 Finally, effects by sex in the present research are limited by the fact that the weight held was
2 twice as much for men as for women. Although this was a deliberate feature of the competitive
3 will task that was designed to reduce sex differences in task difficulty (perhaps owing to
4 differences in body size), it may have inadvertently produced different competitive contexts or
5 experiences between men and women. Future research exploring sex as a moderator of the
6 relationship between testosterone reactivity and competitive effort should consider using a task
7 that is independent of sex when all aspects of the task are held constant.

8 Importantly, the moderating effects of sex in the present research highlights the
9 importance of including women in study designs and testing for the interaction of participant sex;
10 it both provides a relevant reference group for effects observed in men and, adds to larger
11 understanding of the contexts, tasks, and conditions under which women's testosterone reactivity
12 does and does not predict behavior. Importantly, men and women did not differ overall in the
13 direction or magnitude of the testosterone change associated with participating in the competitive
14 will task. The challenge for future research is to uncover what these individual differences mean
15 for women's competitive and status-related behavior.

16 Approximately half of the women who participated in the present research were taking
17 some form of hormonal contraception (pill, patch, or injection-based methods). Although these
18 women had significantly lower testosterone levels, their testosterone reactivity to competition
19 was not significantly different than women not using any form of hormonal contraception, in
20 agreement with what has been reported in other studies (Edwards & O'Neal, 2009; Casto &
21 Edwards, 2016b; Wiegratz et al., 2003; Zimmerman et al., 2014). Further, hormonal
22 contraceptive use did not moderate the relationship between testosterone reactivity and task
23 performance. That said, hormonal contraceptive users across both studies demonstrated, on

1 average, lower performance than women not using hormonal contraception, raising the
2 possibility that the use of hormone contraceptives may negatively affect competitive endurance.
3 This finding is supported by a limited number of previous studies that have found women using
4 hormonal contraception, compared to non-users, make less advantageous competitive bidding
5 decisions (Pearson and Schipper, 2013), self-report lower intrasexual competitiveness (Cobey et
6 al., 2013), and are less likely to self-select into a competitive than non-competitive tournament
7 scheme (Buser, 2012). Further, there is increasing evidence that hormonal contraceptive users
8 display altered social-emotional processing such as reduced fear extinction, dysregulated social
9 reward mechanisms, and increased emotional reactivity to aversive stimuli (Montoya & Bos,
10 2017). Whether or not hormonal contraceptive use influences women's motivation for status,
11 competitiveness, and ability to achieve and maintain high status positions is a critical question
12 for future research.

13 **Individual differences in trait dominance**

14 Although the drive for social status is considered a core psychological motive (Anderson
15 et al., 2015), individuals differ in the intensity with which they desire status and the behavioral
16 effort they are willing to give in attempts to attain and maintain it (Fiske, 2009). In some, this
17 drive is sufficiently strong to prompt efforts to seek out, engage in, and succeed in situations
18 where relative judgments about performance are made (Festinger, 1954; Garcia, Tor, & Schiff,
19 2013). Because comparison to others through competition is how relative social status is
20 determined, individual differences in competitiveness – the “desire to win in interpersonal
21 situations” (Smither & Houston, 1992, p.408) – can be seen as reflecting individual differences
22 in the motivation to acquire social status. As a trait, competitiveness or dominance should be
23 manifest in the level of exertion or persistence expressed towards the goal of winning i.e.,

1 competitive effort. Thus, it is no surprise that trait dominance appears to play an important
2 moderating role in the relationship between testosterone and aggression, dominance, and
3 competitiveness under certain contexts (Carré et al., 2009; Geniole et al. 2013; Carré et al., 2017
4 and Mehta et al., 2015a). In the present research, individual differences in trait competitive-
5 dominance positively predicted both performance and testosterone reactivity to competition, and
6 testosterone reactivity partially explained, statistically, the direct relationship between the
7 competitive trait and behavior. Thus, we propose that individual differences in dominance
8 motivation produce variations in testosterone responses to a competitive social encounter,
9 increasing for those high in dominance and decreasing for those low in dominance. Further,
10 increasing testosterone may function to promote competitive persistence, i.e., the likelihood of
11 success, for those who desire it. As also demonstrated in this exploratory analysis, the path
12 between testosterone reactivity and performance was moderated by sex (apparent in men) and
13 relative status outcome in the form of group rank (apparent among those who ranked highest).
14 The present research provides novel evidence for the importance of accounting for hormonal
15 reactivity and social context in understanding how motives and traits translate into behavior –
16 hormone change perhaps serving as one physiological activator of goal-directed motivation
17 within relevant social contexts.

18 **Social presence**

19 As both the challenge hypothesis and biosocial model of status are founded on the notion
20 that competitive social encounters drive testosterone reactivity, we aimed to test the role of the
21 physical presence of an opponent, an actual social encounter, in affecting the relationship
22 between testosterone change during competition and performance. In Study 1, we manipulated
23 the physical presence of an opponent so that participants competed either individually or in the

1 presence of a singular opponent. In Study 2, we placed participants in teams of 3-5 individuals
2 and then manipulated the physical presence of an opponent team. In both studies, the physical
3 presence or absence of an opponent or opponent team was independent of reward anticipation
4 because the competition rules for determining prize winners were the same in both conditions.
5 However, the two conditions were necessarily confounded by the number of participants present,
6 a fact that is particularly relevant for the group competition where effects could be driven by
7 inter-group vs. intragroup dynamics or simply, the smaller vs. larger number of competitors
8 present.

9 Results from both studies showed that the physical presence of an opponent or opponent
10 team did not significantly affect testosterone reactivity or the relationship between testosterone
11 reactivity and performance. Additionally, in Study 1, the mean performance time for individuals
12 competing individually (in seconds, $M = 243$; $SD = 79$) was scarcely different from the mean for
13 individuals competing in the physical presence of a single opponent (in seconds, $M = 241$; $SD =$
14 73). Although not directly compared, participants who competed as a team, but in the absence of
15 a competitor team in Study 2, showed a similar mean performance time ($M = 244$; $SD = 74$) to
16 individuals and dyads from Study 1. However, Study 2 participants who competed in the
17 presence of a competitor team, and thus competed among at least four other people, had
18 significantly higher mean performance time ($M = 302$; $SD = 123$) than other Study 2 participants
19 who did not compete in the presence of a competitor team. Thus, perhaps larger social groups
20 and/or the element of coalitional competition (between group competitive focus) are necessary
21 conditions for producing social facilitation effects on performance.

22 Testing the influence of social presence on competitive behavior and hormonal
23 relationships with competitive behavior is important because it is likely that these behaviors and

1 related mechanisms evolved within the context of complex social groups (Crofoot & Wrangham,
2 2010; Flinn et al., 2012). Further, previous research has found that increased testosterone in
3 response to competition is specific to between-group, but not within-group contests (Wagner et
4 al., 2002, Oxford et al., 2010, Flinn et al., 2012), suggesting that testosterone reactivity to
5 competition is attenuated in contexts in which within-group status dynamics are at play –
6 prosocial and cooperative behavior, in contrast to overt dominance, may also be required to
7 simultaneously maintain within-group status (Diekhof et al., 2014; Reimers and Diekhof, 2015).
8 In the present research, manipulating the physical presence of a competitor group was intended
9 to shift competitive focus toward or away from the out-group by providing a relative reference
10 for out-group when a competitor group was present. When a competitor group was not present,
11 participants' only reference for social comparison would be their own teammates. However, this
12 manipulation did not moderate the relationship between testosterone reactivity and performance.
13 First, it is possible that this manipulation did not effectively alter in-group vs. out-group
14 competitive focus or that the group assignment, via minimal groups design (Tajfel et al., 1971;
15 Otten, 2016), did not substantively alter perceptions of group membership. Second, and perhaps
16 more likely, it is possible that the non-zero-sum competitive scheme was unsuccessful in creating
17 a trade-off between group cooperation and individual competitive motivation. That is, because
18 there were separate individual and team prizes but individual performance also figured into the
19 team mean performance, outperforming one's teammates improved both one's own rank for the
20 individual prize and also raised the group average and thus, rank among other teams.
21 Interestingly, it was not uncommon for participants who dropped their arm earlier to 'cheer on'
22 their persisting teammate(s) as they exited the testing room or for persisting participants to claim
23 that they were 'doing it for the team.' It is perhaps no surprise then that these high-ranking

1 individuals showed the strongest positive correlation between testosterone reactivity and
2 performance – these individuals increased their personal chances of winning money *and* gained
3 prestige among their group. Future research should test the presence or absence of opponent
4 social groups where individual performance comes at a cost to team performance outcomes (e.g.,
5 Cárdenas & Mantilla, 2015; Ronay et al., 2012).

6 One final element of social presence in the context of competition worth discussing is the
7 presence of members of the opposite sex. Recent reviews and meta-analysis of the challenge
8 hypothesis across taxa have found that testosterone does reliably increase during a competitive
9 challenge from another male in fish and insects, but that in other taxa, including mammals, this
10 effect was more variable and perhaps specific to contexts in which there is direct access to a
11 mating opportunity, e.g., male-female interactions (Goymann et al., 2019; Moore et al., 2019;
12 Tibbetts et al., 2019). In the present research, all male participants competed in the presence of a
13 female; many female participants competed in the presence of a male. Although mating
14 opportunities were not part of the formal incentive structure, the degree with which men and
15 women believed their performance influenced their likelihood of garnering sexual interest from
16 others, and differences in this belief, is a potentially interesting and important factor to account
17 for in future research (e.g., Kordsmeyer & Penke, 2019).

18 **Conclusion**

19 In the present research, we introduced a novel competitive task designed to determine
20 individual differences in competitive endurance. Performance in the competitive will task
21 reflects personal characteristics that would be advantageous for success in dominance contests in
22 both early (primitive) and modern human social contexts. Across two studies and a relatively
23 large sample, the present research provides original evidence of a positive relationship, in men,

1 between testosterone reactivity to a competitive social challenge and task performance under
2 conditions of elevated relative social status, particularly among groups of individuals. That is,
3 among men who won against an opponent or performed well relative to a group, increased
4 testosterone over the course of competition predicted relatively better performances. Initial
5 exploratory evidence showed that individuals who reported higher dominance motivation
6 endured longer in the competitive will task, and this relationship is partially mediated by
7 testosterone reactivity. This three-way relationship demonstrates the importance of accounting
8 for hormonal reactivity in understanding how status-seeking motives and traits translate into
9 competitive behavior – perhaps serving as activators of goal-directed activity within relevant
10 social contexts. The notion that “when challenged by another male, testosterone increases to
11 allow the defender to confront the challenge (Oxford et al., 2010, p.202)” is well-espoused and
12 central to the application of the challenge hypothesis to human behavior. Despite this, the
13 relationship between testosterone reactivity to competition and real-time competitive behavior
14 that would aid in success within that competition has heretofore remained relatively unknown.
15 Furthermore, we demonstrate the moderating effects of status shifts on this relationship when
16 status position is not fixed by the experimenters, but rather, is determined by the participant’s
17 own competitive drive relative to others.

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19 **Transparency and Open Science Practices**

20 All supplementary results, analysis code, and data are available on the open science framework
21 (<https://osf.io/6r7da/>).

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Tables

Table 1

Study 1 main variable descriptive statistics, correlations, and mean comparisons

Women (N=129)								
Metrics of T Reactivity								
	M(SD)	CI LB	CI UB	T2	$\Delta T\%$	Tres	AUCi	performance
T1 (pg/ml)	29.82 (15.68)	27.09	32.55	.88**	-.14	-.06	-.30**	.21*
T2 (pg/ml)	26.76 (15.57)	24.06	29.48	--	.30**	.43**	.14	.25**
$\Delta T\%$	-8.62 (26.85)	-13.30	-3.95		--	.88**	.74**	.14
Tres	-1.19 (7.48)	-2.50	.11			--	.85**	.12
AUCi	-58.44 (119.38)	-79.24	-37.64				--	.06
performance	238.0 (80.32)	224.0	252.0					--
Men (N=59)								
T1 (pg/ml)	92.87 (32.84)	84.31	101.4	.83**	-.34**	-.27*	-.40**	.04
T2 (pg/ml)	87.28 (30.06)	79.44	95.11	--	.19	.32*	.09	.16
$\Delta T\%$	-3.41 (22.03)	-9.15	2.33		--	.91**	.77**	.20
Tres	2.61 (17.45)	-1.94	7.15			--	.82**	.20
AUCi	-69.72 (297.6)	-147.3	7.85				--	.16
performance	251.5 (62.08)	235.3	267.7					--
Difference between men and women								
	Mean _{diff}	CI _{diff} LB	CI _{diff} UB	t	df	p	d	
T1 (pg/ml)	63.05	54.09	72.00	14.03	186	<.001	2.06	
T2 (pg/ml)	60.51	52.24	68.78	14.59	186	<.001	2.14	
$\Delta T\%$	5.22	-2.67	13.11	1.30	186	.194	.19	
Tres	3.80	-.921	8.52	1.61	186	.113	.24	
AUCi	-11.28	-91.43	68.86	-2.81	186	.780	.04	
performance	14.35	-6.80	35.51	1.34	188	.182	.20	
Difference between HC users and non-users								
	Mean _{diff}	CI _{diff} LB	CI _{diff} UB	t	df	p	d	
T1 (pg/ml)	16.03	11.21	20.84	6.60	120	<.001	1.20	
T2 (pg/ml)	14.90	10.00	19.03	6.03	120	<.001	1.10	
$\Delta T\%$	-.06	-9.79	9.67	-.012	120	.990	<.00	
Tres	.485	-2.25	3.22	.351	120	.726	.06	
AUCi	-36.74	-79.74	5.49	-1.69	120	.093	.31	
performance	29.09	1.07	57.12	2.06	122	.042	.37	

6 T1 = baseline sample, T2 = 15 min post-competition sample, $\Delta T\%$ = % change in testosterone,
7 Tres = unstandardized residual testosterone change, AUCi = area under the curve increasing, M
8 = mean, SD = standard deviation, CI = confidence interval, LB = lower bound, UB = upper
9 bound. *p <.05, **p<.01

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12 Table 2

13 Study 2 main variable descriptive statistics, correlations, and mean comparisons

Women (N=121)								
Metrics of T Reactivity								
	M(SD)	CI LB	CI UB	T2	$\Delta T\%$	Tres	AUCi	performance
T1 (pg/ml)	19.81 (14.70)	17.16	22.45	.81**	-.23**	-.38**	-.02	-.13
T2 (pg/ml)	17.22 (13.23)	14.84	19.60	--	.23*	.23**	.46**	-.09
$\Delta T\%$	-6.91 (36.29)	-13.44	-.377		--	.75**	.43**	.07
Tres	-1.38 (8.43)	-2.90	.139			--	.76**	.08
AUCi	-.781 (9.89)	-2.56	.999				--	-.01

performance	269.7 (91.95)	253.2	286.3					--
Men (N=77)								
T1 (pg/ml)	90.90 (39.41)	81.95	99.84	.87**	-.19	-.13	-.30**	.04
T2 (pg/ml)	88.13 (40.68)	78.90	97.36	--	.28*	.35**	.19	.28*
$\Delta T\%$	-2.01 (21.20)	-6.92	2.71		--	.93**	.85**	.44**
Tres	1.11 (15.70)	-2.45	4.68			--	.88**	.52**
AUCi	-1.74 (10.98)	-4.23	.749				--	.46**
performance	302.9 (137.7)	271.7	334.2					--
Difference between men and women								
	Mean_{diff}	CI_{diff} LB	CI_{diff} UB	t	df	p	d	
T1 (pg/ml)	71.09	61.78	80.40	15.17	196	<.001	2.17	
T2 (pg/ml)	70.97	61.46	80.49	14.83	198	<.001	2.11	
$\Delta T\%$	4.80	-3.26	12.87	1.18	196	.242	.17	
Tres	2.49	-1.37	6.35	1.28	196	.203	.18	
AUCi	-.961	-4.01	2.08	-.624	196	.534	.09	
performance	30.48	-4.12	65.07	1.75	203	.084	.25	
Difference between HC users and non-users								
	Mean_{diff}	CI_{diff} LB	CI_{diff} UB	t	df	p	d	
T1 (pg/ml)	7.23	1.59	12.87	2.54	107	.012	.49	
T2 (pg/ml)	6.31	1.33	11.29	2.51	109	.013	.48	
$\Delta T\%$	8.54	-5.22	22.29	1.23	107	.221	.24	
Tres	-.514	-3.78	2.75	-.312	107	.756	.06	
AUCi	-2.04	-5.98	1.89	-1.03	107	.305	.20	
performance	29.89	-3.79	63.57	1.76	112	.081	.33	

- 1 T1 = baseline sample, T2 = 15 min post-competition sample, $\Delta T\%$ = % change in testosterone,
2 Tres = unstandardized residual testosterone change, AUCi = area under the curve increasing, M
3 = mean, SD = standard deviation, CI = confidence interval, LB = lower bound, UB = upper
4 bound. *p <.05, **p<.01

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