

Testosterone, cognition, and social status

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Abstract

What leads some people to perform better than others on certain cognitive tasks? One explanation involves individual differences in testosterone. Testosterone is associated with higher performance on spatial tests, and lower performance on verbal tests. However, a large literature suggests that testosterone only predicts behavior when status is in jeopardy. In the present study, we manipulated status before administering a spatial and verbal test. In a high-status position, high-testosterone individuals performed well on both tests, and blood pressure dropped. In a low-status position, high-testosterone individuals performed relatively poorly on both tests, and blood pressure did not change. These data suggest that differences in cognitive performance stem from an interaction between testosterone and the social situation. © 2004 Elsevier Inc. All rights reserved.

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Introduction

Why do some individuals perform better than others on cognitive tests? Do these performance differences reflect biological influence, environmental influence, or a combination of the two? One popular explanation has focused on the role played by individual differences in testosterone (T) levels. T has been associated with higher performance on spatial tests, and lower performance on verbal tests (e.g., Christiansen and Knussman, 1987; Gouchie and Kimura, 1991; Hampson, 1990; for reviews, see Christiansen, 1998; Kimura, 2000). The predominant assumption has been that T influences cognition neuroanatomically, by shaping developing brain structures and/or by activating these structures after puberty (e.g., Aleman et al., 2004; Gouchie and Kimura, 1991; Postma et al., 2000; Resnick et al., 1986). However, according to Wingfield's *challenge hypothesis*, T should only influence social behavior when status is threatened or challenged (Wingfield et al., 1987). The substantial body of research supporting this hypothesis suggests that the link between T and cognitive performance

might be moderated by an individual's status in a particular situation.

Research with humans and a wide variety of animal species suggests that individuals higher in baseline T are (1) more driven to gain and maintain status; and (2) more responsive to information about their status in a situation. Behaviors intended to achieve, maintain, and enhance status are observed primarily among high-T animals (e.g., Ruiz-de-la-Torre and Manteca, 1999; for reviews, see Christiansen, 1998; Mazur and Booth, 1998). Indeed, a single measurement of T in men and women predicts occupational status (Dabbs et al., 1990; Purifoy and Koopmans, 1979) and status-related behaviors across a variety of situations (Jeffcoate et al., 1986; Scaramella and Brown, 1978).

Single salivary measurements of T appear to be reliable from 2 days ($r = 0.64$; or $r = 0.71$ if outliers are removed from the analysis) to 8 weeks ($r = 0.59$; Dabbs, 2000). In addition, in our laboratory, we reanalyzed some of our previously published data and found correlations of $r = 0.88$ over 5 days (Josephs et al., 2001). T levels also show a temporary change in response to winning and losing a competition. After a match, the winner's T level is higher than the loser's for about 2 h, before returning to baseline (for a review, see Mazur and Booth, 1998). Thus, individuals' T levels seem to fluctuate around a characteristic baseline.

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An important qualification to these behavioral findings (many of which are predicted by single measurements of T) is that T predicts behavior *only* in situations in which one's status is threatened (Josephs et al., 2003; Morgan et al., 2000; Ostner et al., 2002; Ruiz-de-la-Torre and Manteca, 1999; Wingfield et al., 1987). According to a review by Sapolsky (1991), there is almost never a relationship between T and rank during times of stability among the male olive baboon. Rather, it is only when status is in flux or undetermined that we find a strong relationship between T and rank. This research suggests a person–situation interaction: High T individuals are more aware of their status, but T should only predict behavior when status is up for grabs.

Not all researchers agree that basal T is solely indicative of a need for status. Derived from the biosocial theory of status (Mazur, 1985), researchers such as Mazur and Booth (1998) are proponents of a reciprocal model of T and status. According to this model, experiences of winning and losing status battles can alter T levels, which then predict subsequent status seeking behavior. For example, in a study of male tennis players (Booth et al., 1989), participants' T levels rose after winning a tennis match whereas losers experienced a drop in T. This change in T carried over to subsequent matches, such that winners who showed an increase in T after winning began their subsequent matches with higher T. Similar findings have been seen in non-physical domains such as chess, albeit with mixed results (Mazur et al., 1992).

These reciprocal studies differ significantly from most basal studies primarily because participants are aware that they will be competing in a dominance battle right before their T is assessed. Because the initial measurements of T are taken in anticipation of a competition, they are not indicative of basal T. Furthermore, the participants in many of these studies presumably have knowledge of their relative ability prior to these competitions, making pre-match rises and declines in T difficult to interpret. Thus, although this research answers important questions about how changes in the social situation influence changes in T, it does not speak to the influence of basal T on performance.

T levels have also been linked to implicit motivation and attention. Schultheiss et al. (1999, 2003) have found that individuals with higher T levels have a higher implicit need for power (i.e., they use more “power” imagery to describe ambiguous pictures). van Honk et al. (1999) found that baseline T was highly correlated with selective attention to an angry face (a threatening stimulus), but not with attention to neutral faces. This study suggests that high-T individuals might be highly attuned to, and therefore easily distracted by anything they perceive as threatening to their status. This distraction may underlie many of the behavioral responses to status, such that high-T individuals are more likely to respond to status threats because they are more likely to notice status threats.

What about the outcomes of dominance battles? Are high-T individuals any more successful at regaining status? The

prototypical dominance contest involves a physical challenge, and dominance must be regained through physical means (e.g., winning a fight, intimidation). In these cases, testosterone, which enhances muscle mass and metabolism, should provide an advantage to those who wish to regain lost status. Not surprisingly, higher-T animals are more likely to be the winners of these types of encounters (e.g., Morgan et al., 2000; Ostner et al., 2002).

However, things may be rather different if status must be regained through cognitive performance. Performance on most cognitive tasks requires concentration. We theorize that high-T individuals have a higher “need” for status than low-T individuals, and this need should be activated when status is threatened (i.e., in a low-status position). The desire to regain status may consume valuable cognitive resources, and, ironically, hamper their efforts to regain status.

Thus, we predict that the performance of high-T individuals on a cognitive task will depend upon their status in the situation. In a high-status position, high-T individuals should experience a match between their status needs and the current situation. Because their status needs are being met, high-T individuals should be able to avoid negative arousal and focus attention on the cognitive task. Therefore, high-T individuals should perform well in a high-status position. In a low-status position, however, status is threatened, and high-T individuals should experience a mismatch between their needs (high status) and the current situation (low status). When this mismatch occurs, high-T individuals should experience arousal and be driven to regain status. Ironically, however, this drive to regain status may serve as a distraction from the cognitive task. Therefore, high-T individuals should perform poorly in a low-status position.

Conceptually, this prediction of arousal is related to work by Blascovich and Tomaka (1996) on the physiological differences associated with challenges versus threats. According to these researchers, a “threat” response occurs when one perceives a lack of ability or resources to achieve a goal. The resulting physiological response, including increased heart rate, but also an increase in blood pressure, is thought to represent an inefficient mobilization of resources (e.g., Tomaka et al., 1993). High-T people in a low-status position, preoccupied by thoughts of their low status, would indeed be consuming resources needed to perform on a subsequent task, and could be said to be functioning under a condition of threat. A “challenge” response, in contrast, occurs when one perceives having the ability or resources to achieve a goal. The resulting physiological response, including increased heart rate but a decrease in blood pressure, represents a more effective mobilization of resources. High-T individuals in high-status positions would not be distracted by thoughts of their status, and would therefore have ample resources needed to perform on a subsequent task.

A series of recent experiments have tested these predictions about T, status, and cognitive performance (Josephs et al., 2003; Guinn Sellers et al., 2002). On a math test and on

an analytical test, high-T individuals perform better in a high-status position than in a low-status position. Also consistent with predictions, these changes in cognitive ability are accompanied by changes in physiological *arousal*, such that high-T individuals are less aroused in a high-status position, and changes in *attention*, such that high-T individuals focus more on their status in a low-status position.

What is missing, however, is the application of this model to the cognitive challenges typical of the T and cognition literature. Typically, researchers have focused on the correlations between T and cognition. Few, if any studies have used an experimental design to test their findings on humans (but see Aleman et al., 2004; Postma et al., 2000 for T-level manipulations). The present study was designed to examine the effects of a systematic manipulation of status on spatial and verbal performance.

We had two hypotheses. First, if spatial and verbal performance depends on the interaction between T levels and status, then high-T individuals should perform well on a spatial test and a verbal test in a high-status position, but poorly on these tests in a low-status position. Second, if these performance differences are related to “comfort” with one’s current level of status, the blood pressure of high-T participants should be lower in a high-status position than in a low-status position.

Materials and methods

To test our hypotheses, a group of male and female college students completed two cognitive measures (mental rotation and verbal fluency), in a 2 (T Level: High or Low) by 3 (Status: high, low, or control) between-subjects, quasi-experimental design. Status was manipulated by giving people the impression they would take part in a group task, as either the “leader” (high status), the “follower” (low status), or neither (control). T levels were collected at the beginning, and blood pressure was measured throughout.

Participants and design

Participants were 88 individuals (52 F, 36 M) recruited from two sources. Thirty-one of these (16 F, 15 M) were psychology students at the University of Texas at Austin, who participated in partial fulfillment of the course research requirement ($M_{\text{age}} = 18.7$; $SD = 1.8$). The remaining 57 participants (36 F, 21 M) responded to fliers placed around the University of Texas campus, and were paid \$15 for their participation. No differences emerged between the two samples on any of our dependent measures, and all results are collapsed across recruitment method.

Experimental procedure

Participants completed all tasks individually, but under the impression that a second participant was in another

room. Experimental sessions were conducted between 12 and 4 pm to control for a diurnal decline in T (e.g., Granger et al., 1999).

Baseline measures

After participants gave their informed consent, we collected baseline measures of blood pressure and T. To minimize measurement error, baseline blood pressure was taken three times, 1 min apart, by trained experimenters. The first measurement was dropped, and the two remaining measures were averaged to create the baseline. At each measurement, the experimenter recorded systolic and diastolic blood pressure.

Baseline T was obtained from salivary samples. Upon arrival, participants were asked to take a drink of water and rinse out their mouths. Following blood pressure measurement, the experimenter gave participants a piece of Trident original flavor sugarless gum to facilitate salivary secretion. Participants spit out their gum and drooled into a 1.8-ml vial. The saliva samples were then placed into a -20°C freezer until later T analysis (see below). Salivary collection was consistent with the procedure described by Granger et al. (1999).

Cover story

The procedure was modified from Brown et al. (2000). All participants were told that the purpose of the experiment was to investigate “the effects of individual variables on group functioning.” Towards this end, they were told that they would complete a number of individual tasks, followed by a group task with another person. In reality, all participants were alone. They were told that each “group” would receive a total score, which would be a combination of their individual tasks, their partner’s individual tasks, and their group performance on the final task. As an incentive, participants were also told that the highest-scoring group each week would be entered into a drawing for a pair of \$50 gift certificates to a local record store. All participants were actually entered into this drawing.

Status manipulation

Following this cover story, participants were randomly assigned to the *high status*, *low status*, or *control* condition. Participants in the two status conditions were told that based on a pretest measure, we had identified them as someone who would be a good leader (*high status*) or follower (*low status*) for the upcoming group task. However, they were also told that we would be looking at their scores on the cognitive tests to verify their assignment to leader or follower. This was done to ensure that their performance would have implications for their status in the group.

Participants in the *control group* were not given any information about their status in the upcoming group task. This group was informed of the group scoring procedure, and completed the cognitive measures described below. The leader/follower information was omitted to ensure that their

performance would not have implications for their status within the group.

Testing session

Following the status manipulation, all participants completed two tests of cognitive ability, a mental rotation test, and a verbal fluency test (in that order). Blood pressure was taken after each test. To minimize measurement error, two measurements of blood pressure were taken at each time point, and these were later averaged together for analysis. At each measurement, the experimenter recorded systolic and diastolic blood pressure.

Our mental rotation test was an adaptation of Shepard and Metzler's (1971) original test. Participants were asked to compare a target object composed of cubes to four comparison figures, and determine which two of the four were the same objects as the target. All objects were two-dimensional representations of three-dimensional objects, rotated at different angles. Participants were given 10 min to complete 20 of these items. The test was scored to correct for random guessing. Participants received two points if they identified two correct figures out of two answers; one point if they identified one correctly out of one answer; and zero correct if they identified one correctly out of two answers.

The Controlled Associations Test (Ekstrom et al., 1976) was used as our verbal fluency measure. This test presents participants with a target word (e.g., "short"), and asks them to list as many synonyms as possible (e.g., "brief," "little"). Participants were given 12 min to list synonyms for eight words. The target words were *clear*, *dark*, *strong*, *wild*, *company*, *sharp*, *tell*, and *turn*. The test was scored by averaging the number of synonyms listed across all eight words.

Manipulation check/debriefing

After the testing session, participants were asked to complete a short questionnaire containing a manipulation check. This single item asked participants to indicate the role they had been assigned in the upcoming group task (control group participants did not complete this item). After a short delay, the experimenter returned and, looking annoyed, told participants that the experiment would have to be ended before the group task due to a scheduling conflict with the room. Participants were thanked for their participation, probed for suspicion, and then debriefed about the true nature of the experiment.

Testosterone assays

At the end of the experiment, T samples were analyzed using enzyme immunoassay kits provided by Salimetrics, LLC. The plates were coated with rabbit antibodies to T, and the enzyme conjugate was tagged with horseradish peroxidase. Sensitivity of the kit is <1.5 pg/ml. The intra-assay CVs averaged 8.8%, and inter-assay CVs averaged 11.2%.

Results

Manipulation check

Attesting to the success of the manipulation, all participants correctly recalled their assigned position for the group task. Anecdotally, only one participant expressed suspicion about the occurrence of the group task. It turned out this individual had managed to participate in the experiment twice, and he was excluded from all analyses.

Hypothesis 1: testosterone, status, and cognitive performance

Males performed significantly better on the mental rotation test across conditions ($P = 0.01$), but there were no sex differences on the verbal test ($P = 0.96$). Sex did not interact with T levels or status condition on either test (P 's between 0.10 and 0.85), so all analyses were performed collapsing across sex.

For all analyses, a median split was performed on T within sex. "High-T" males ($M = 176.16$ pg/ml; $SE = 6.73$) were high relative to "low-T" males ($M = 102.96$ pg/ml; $SE = 6.37$). "High-T" females ($M = 98.08$ pg/ml; $SE = 5.05$) were high relative to "low-T" females ($M = 44.86$ pg/ml; $SE = 5.67$). The females' T levels were atypically high, although similar levels have been reported elsewhere (e.g., Shirtcliff et al., 2002). We return to these levels in our Discussion.

To test our hypotheses regarding cognitive performance, we conducted planned contrasts to compare (1) scores of high-T vs. low-T participants in the low-status condition; and (2) scores of high-T participants in high- vs. low-status conditions.

On the mental rotation test, as hypothesized, high-T participants performed significantly worse than low-T participants in the low-status condition [$t(28) = 2.30$, $P = 0.02$; $d = 0.58$]. Also as predicted, high-T participants performed significantly better in the high-status than the low-status condition [$t(27) = 2.35$, $P = 0.01$; $d = 0.78$]. See the top panel of Fig. 1.

On the verbal fluency test, as hypothesized, high-T participants performed significantly worse than low-T participants in the low-status condition [$t(28) = 2.79$, $P = 0.01$; $d = 0.71$]. Also as predicted, high-T participants performed significantly better in the high-status than the low-status condition [$t(27) = 2.37$, $P = 0.03$; $d = 0.61$]. See the bottom panel of Fig. 1.

Hypothesis 2: testosterone, status, and physiological arousal

To test our hypotheses regarding changes in physiological arousal, we conducted planned contrasts to compare (1) BP change of high-T vs. low-T participants in the low-status condition; and (2) BP change of high-T participants in high- vs. low-status conditions. To compute the BP change

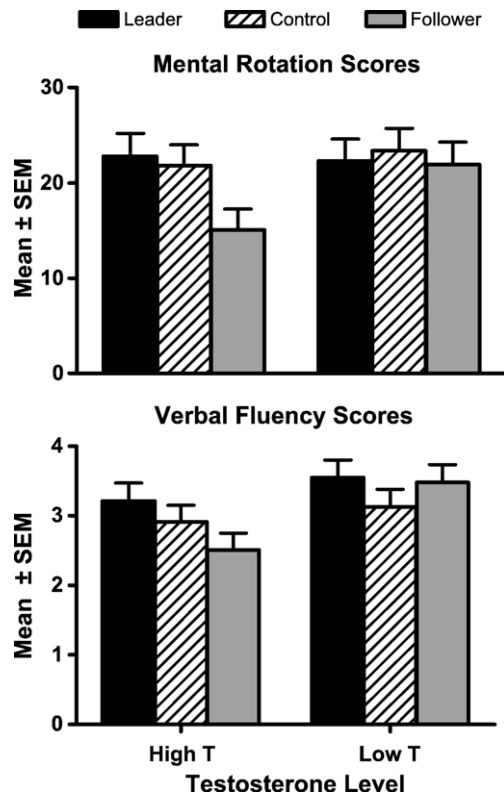


Fig. 1. Mental rotation and verbal fluency performance, by T level and status. Top panel: mental rotation scores. Bars in the top panel represent total score on the mental rotation task. Data are expressed as mean \pm SEM. Bottom panel: verbal fluency scores. Bars in the bottom panel represent average number of synonyms generated across all eight words. Data are expressed as mean \pm SEM. “High T” $N = 45$ (13,16,16). “Low T” $N = 43$ (15,14,14).

scores, we first computed an average “post-manipulation” score by averaging the two measures following each test, and then averaging these numbers together. We then subtracted this post-manipulation score from the “pre-manipulation” (i.e., baseline) measure.

Overall, systolic blood pressure (BP) was lower post-manipulation ($M = 109.42$, $SE = 1.29$) than pre-manipulation [$M = 115.32$, $SE = 1.23$; $t(87) = 5.67$, $P = 0.00$; $d = 1.22$]. Although high-T participants showed a steeper decline in systolic BP (d 's = 1.86 vs. 0.73, P 's < 0.05), contrary to our hypotheses, these changes were not moderated by condition.

Diastolic BP was also lower post-manipulation ($M = 69.85$, $SE = 0.88$) than pre-manipulation [$M = 73.51$, $SE = 1.09$; $t(87) = 3.42$, $P = 0.00$; $d = 0.73$]. Consistent with our hypotheses, high-T participants were less aroused in the high-status condition than in the low-status condition [$t(27) = 2.17$, $P = 0.04$; $d = 0.84$]. The predicted difference between high-T and low-T participants in the low-status condition was not significant ($P = 0.18$). Additionally, in the high-status condition, high-T participants were less aroused than low-T participants [$t(26) = 2.23$, $P = 0.03$; $d = 0.87$]. See Fig. 2 for these means.

Discussion

The results of this experiment offer a new way to conceptualize the T and cognition literature. In the control condition, there were no differences in cognitive performance between high- and low-T participants, for either spatial or verbal ability. Consistent with Wingfield's challenge hypothesis, an effect of T on cognitive performance was observed only when high-T participants were in a high- or low-status position. When high-T participants were in a high-status position, they performed better on tests of spatial ability and verbal fluency than when they were in a low-status position. Interestingly, there is a larger disparity between the low-status position and the control group than between the high-status position and the control group. That is, the performance of high-T individuals seems impaired by low status more than it is enhanced by high status. This possibility should be explored with other manipulations of “status.”

These performance findings were supported by measures of cardiac arousal. High-T individuals demonstrated less cardiac arousal when they were placed in a high-status position, but not when placed in a low-status position. We speculate that high-T individuals are comfortable in a high-status position, and able to concentrate on the task at hand. In a low-status position, however, they appear to be distracted by their low status, and thus presumably less able to concentrate on the task at hand.

Although we did not predict differences in the response of systolic and diastolic blood pressure (BP), only diastolic BP responded to the interaction between T and status. Generally speaking, systolic BP represents the pressure in the arteries as the heart contracts and pumps blood. Diastolic BP represents the pressure in the arteries as the heart relaxes after the contraction. Whereas systolic BP reactivity is stable across laboratory and real-world stressors, the available evidence suggests that diastolic BP may respond to particular types of stressors (e.g., Abel and Larkin, 1991).

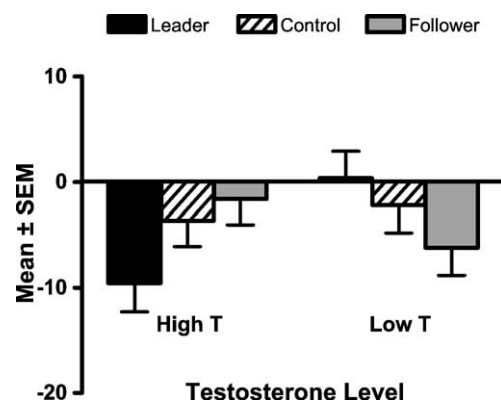


Fig. 2. Drop in diastolic blood pressure, by T level and status. Bars represent drop in diastolic BP (post-pre). Data are expressed as mean \pm SEM. “High T” $N = 45$ (13,16,16). “Low T” $N = 43$ (15,14,14).

Diastolic BP reactivity has been observed when individuals with “dominant” personalities prepare for a debate (Newton et al., 1999), or are placed in a nondominant position (Spicer and Lyons, 1995). Clark (2003) found that individuals who adopted problem-focused coping strategies on a stressful math task showed increased diastolic, but not systolic, BP. Emotion-focused coping did not increase either measure of BP. One interpretation of this pattern of studies is that diastolic BP reacts to challenging situations involving either competition or evaluation. The present results are consistent with this interpretation, but more research is needed on the different antecedents of each component of blood pressure.

We have argued that high-T participants feel threatened by being placed in a low-status position. Conceptually, this feeling of being threatened is similar to Blascovich’s work on the health consequences associated with perceiving events as challenges versus threats (Blascovich and Tomaka, 1996; Tomaka et al., 1993). In Blascovich’s research, participants who perceive an event as threatening experience an increase in blood pressure. In the present study, we suggest high-T individuals perceive being in a follower position as a threat to their status, and consequently show increased blood pressure compared to high-T individuals in a position of leadership. Interestingly, low-T participants did not show this effect, suggesting that they either do not want high status, or do not interpret being in a low-status position as threatening. Future studies should address whether low-T individuals perceive low status as challenging, or perhaps feel more comfortable avoiding high-status positions.

Importantly, although we argue that high- and low-T individuals differ in their appraisals of what is threatening, we do not directly test this assumption. There is a conceptual overlap between the finding that high-T participants in a low-status position experience heightened cardiac arousal and the documented cardiac component of a “threat” appraisal (Blascovich and Tomaka, 1996), but we have not tested this direct link. We are currently studying in our lab whether high T individuals show an implicit attention to status after their status is threatened. Clearly, this is an issue that warrants further investigation.

It is worth noting that the females in our study had higher T levels than are normally observed. One possible reason for this is that the Salimetrics kit used for the assays is particularly sensitive to low concentrations of T. However, these levels are consistent with three other studies from our laboratory (using the same kits), as well as with results observed elsewhere (Shirtcliff et al., 2002). Additionally, several pieces of data suggest that the measured levels are valid, including the low variability in the present study and the high correlation between this kit and other measures (Salimetrics, 2004). Nonetheless, it remains possible that the females in our study somehow had higher T levels than the general population. Future replications with different samples would help to address this possibility.

These results cannot directly address the long-held assumption that T affects cognition by organizing the developing brain. Rather, these results point to an additional, situational, piece of the puzzle, and suggest that cognitive performance is influenced by an interaction between biology (T levels) and environment (social status). The link between T and many social behaviors only exists when status is threatened or challenged (Wingfield et al., 1987). Performance on cognitive tasks—even on those thought to have a direct relationship with T—appears to be no exception.

However, whereas high-T confers an advantage in regaining status through physical means, it appears to hinder attempts to regain status through cognitive performance. We have shown previously that high-T individuals pay more attention to status when it is taken away from them (Guinn Sellers et al., 2002). This attention to status seems to consume cognitive resources that would be more effective if devoted to the cognitive task. Ironically, then, the desire to regain high status may be the biggest obstacle to regaining it—at least on a cognitive task. An important question for future research is whether this is true for human performance on athletic or other physical tasks.

Finally, the paradigm used in this study presents another example of the benefits of adopting an alternative research strategy (for other examples of this approach, see, e.g., Schultheiss et al., 1999, 2003; van Honk et al., 1999, 2001). Although an enormous amount of valuable information has been gained through studying the direct effects of hormones, it is clear that more research should be directed at examining the interactions between hormones and relevant environmental manipulations (see, e.g., Mazur and Booth, 1998; Sapolsky, 1991). It is currently unknown whether, and to what degree, these manipulations moderate other hormone–behavior relationships in humans. Drawing on the vast amount of research conducted on nonhuman animals, empirical tests of the interactions between hormones and social situations would provide valuable insight into the links between hormones and human behavior.

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