Journal of Personality and Social Psychology
2008, Vol. 94, No. 6, 1078–1093

0022-3514/08/$12.00 DOI: 10.1037/0022-3514.94.6.1078

The Social Endocrinology of Dominance: Basal Testosterone Predicts Cortisol Changes and Behavior Following Victory and Defeat

Pranjal H. Mehta, Amanda C. Jones, and Robert A. Josephs
University of Texas at Austin

Past research suggests that individuals high in basal testosterone are motivated to gain high status. The present research extends previous work by examining endocrinological and behavioral consequences of high and low status as a function of basal testosterone. The outcome of a competition—victory versus defeat–was used as a marker of status. In Study 1, high testosterone men who lost in a dog agility competition rose in cortisol, whereas high testosterone men who won dropped in cortisol. Low testosterone men's cortisol changes did not depend on whether they had won or lost. Study 2 replicated this pattern of cortisol changes in women who participated in an experimental laboratory competition, and Study 2 extended the cortisol findings to behavior. Specifically, high testosterone winners chose to repeat the competitive task, whereas high testosterone losers chose to avoid it. In contrast, low testosterone winners and losers did not differ in their task preferences. These results provide novel evidence in humans that basal testosterone predicts cortisol reactivity and behavior following changes in social status. Implications for the social endocrinology of dominance are discussed.

Keywords: testosterone, cortisol, dominance, status, competition

Social groups are often organized into status hierarchies, with some individuals earning higher status over others. Competitions are an important means for determining status within a hierarchy. In contemporary human societies, for example, individuals compete for status through physical fights, verbal arguments, contests, and sports competitions. The benefits of winning in competition are clear—an individual will rise in social status and gain access to limited resources (Barton & Whiten, 1993; Buss, 2003; De Waal, 1998; Furuichi, 1983; Marmot, Shipley, & Rose, 1984; Sapolsky, 1983; van Noordwijk & van Schaik, 1999). This rise in status, however, might also come with costs. For instance, individuals in high status positions often experience more social conflicts (Goyman & Wingfield, 2004) and negative health consequences (Muller & Wrangham, 2004; Noser, Gygax, & Tobler, 2003; Schieman, Whitestone, & Van Gundy, 2006). Thus, high status may not appeal to everyone because the benefits may be outweighed by the physical and psychological costs. So is there an individual difference variable that determines who is motivated to gain high status and who is not? And might this individual difference variable predict how individuals react to gaining or losing status? In the present research, we tested whether individual differences in basal testosterone (T) would predict endocrinological and behavioral consequences of gaining or losing status in competition.

T and Dominance

The large literature on hormones and social behavior indicates that T levels are associated with dominance—behaviors intended to gain or maintain high status (Mazur & Booth, 1998). Both naturally occurring and experimentally elevated levels of T are positively associated with social rank and dominant behaviors in a variety of species, including primates (chimpanzees, Anestis, 2006; baboons, Beehner, Bergman, Cheney, Seyfarth, & Whitten, 2006, and Sapolsky, 1991; lemurs, Cavigelli & Pereira, 2000; squirrel monkeys, Coe, Mendoza, & Levine, 1979; sifakas, Kraus, Heistermann, & Keppeler, 1999; Muller & Wrangham, 2004), as well as many other animals (e.g., birds, Collias, Barfield, & Tarvyd, 2002; fish, Oliveira, Almada, & Canario, 1996; lambs, Ruiz-de-la-Torre & Manteca, 1999). This relationship between T and dominance tends to emerge most strongly during periods of social instability. In his research in wild baboons, for example, Sapolsky (1991) demonstrated that T predicted status-related behaviors when the status hierarchy was unstable (after the alpha male was crippled in fighting and social competition broke out). When the hierarchy was stable, however, T and behavior were unrelated. This basic pattern of results has been found in a number of other species (fish, Oliveira, Almada, & Canario, 1996; lambs, Ruiz-de-la-Torre & Manteca, 1999; birds, Wingfield, Hegner, Dufty, & Ball, 1990). In Ruiz-de-la-Torre and Manteca's (1991) study of lambs, for instance, males injected with T increased in dominant behaviors only after they were placed in a group of

Pranjal H. Mehta, Amanda C. Jones, and Robert A. Josephs, Department of Psychology, University of Texas at Austin.

Preparation of this article was supported by National Science Foundation Grant BCS0423405 awarded to Robert A. Josephs, a National Science Foundation Graduate Fellowship awarded to Amanda C. Jones, and a David C. McClelland Fellowship awarded to Pranjal H. Mehta.

We thank Kerri Sharp (Study 1), Dante Garcia (Study 2), Kimberly Huang (Study 2), and Manish Punjabi (Study 2) for their help with data collection. We are grateful to Yvon Delville and his graduate students for their assistance in conducting hormone assays. Finally, we thank Richard Slatcher and Matthew Newman for their helpful comments on previous versions of this article.

Correspondence concerning this article should be addressed to Pranjal H. Mehta, Department of Psychology, University of Texas at Austin, 1 University Station A8000, Austin, TX 78712-0187. E-mail: pmehta@mail.utexas.edu

unfamiliar lambs and not when they were placed back in their original social group. Taken together, the animal literature suggests that when social status is uncertain, high T levels motivate individuals to seek out higher status.

The association between higher T and dominance has also been extended to humans. For instance, people high in basal T tend to be more aggressive and more socially dominant than individuals low in basal T (Archer, 2006; Archer, Birring, & Wu, 1998; Cashdan, 1995; Grant & France, 2001; Jones & Josephs, 2006; Josephs, Newman, Brown, & Beer, 2003; Josephs, Sellers, Newman, & Mehta, 2006; Mazur & Booth, 1998; Newman, Sellers, & Josephs, 2005; Sellers, Mehl, & Josephs, 2007; Tremblay et al., 1998). T also increases vigilance toward dominance cues, such as angry, threatening faces (van Honk et al., 1999; Wirth & Schultheiss, 2007), and decreases vigilance toward submissive cues, such as fearful faces (van Honk, Peper, & Schutter, 2005). These effects of T on attention seem to be strongest when dominance–submission cues are presented outside conscious awareness (e.g., van Honk et al., 2005; Wirth & Schultheiss, 2007), suggesting that the relationship between T and dominant behaviors may be mediated, at least in part, by subconscious motivational and attentional processes.

T levels, when measured around the same time of day, are temporally stable across 5 days (Sellers et al., 2007), 8 weeks (Dabbs, 1990), or even 1 year (Granger, Shirtcliff, Booth, Kivlighan, & Schwartz, 2004). T levels also have a substantial genetic component. Twin studies suggest that genes explain approximately 66% of the variance in men's T concentrations and approximately 41% of the variance in women's T concentrations (Harris, Vernon, & Boomsma, 1998). Other studies have identified specific genetic polymorphisms that are related to T levels (CAG repeat polymorphism in the androgen receptor gene, Crabbe et al., 2007; *CYP19* aromatase gene, Schilling et al., 2007).

Environmental factors also influence basal T. For example, previous experiences with victory and defeat can affect T concentrations prior to a subsequent competition (Booth, Shelley, Mazur, Tharp, & Kittok., 1989; Mazur, Booth, & Dabbs, 1992). T also fluctuates before, during, and after competition (Booth et al., 1989; Elias, 1981; Gladue, Boechler, & McCaul, 1989; Mazur et al., 1992; Mazur & Lamb, 1980; McCaul, Gladue, & Joppa, 1992; Suay et al., 1999; van Anders & Watson, 2007a). These competition-induced changes in T last several hours (Booth et al., 1989; Elias, 1981; Gladue et al., 1989; Mazur & Lamb, 1980) but may persist for multiple days or weeks during a series of competitive events (Booth et al., 1989; Mazur et al., 1992). Other environmental factors, including chronic stress (Sapolsky, 1985) and relationship status (McIntyre et al., 2006; van Anders & Watson, 2007b), also affect T levels. Overall, the evidence suggests that both genetic and environment factors influence basal T.

The relationship between basal T and dominance has been further demonstrated through experimental studies in which social status is manipulated (Josephs et al., 2003; 2006; Newman et al., 2005). One widely employed method for manipulating status is to assign individuals to victory and defeat in competitive social interactions (Gladue et al., 1989; Keeney et al., 2006; Kramer, Hiemke, & Fuchs, 1999; Mehta & Josephs, 2006; Overli, Harris, & Winberg, 1999; Schultheiss et al., 2005). Consistent with this research, Josephs et al. (2006) randomly assigned humans to high and low status by rigging the outcome of a cognitive-based laboratory competition. The findings indicate that high T individuals function better in high status positions than in low status ones. Specifically, high T individuals paid more attention to status cues, became dysphoric, and performed poorly on complex cognitive tasks after defeat but paid less attention to status cues, showed no evidence of dysphoria, and performed well on complex cognitive tasks after victory. This pattern of findings has been replicated with different status manipulations (Josephs et al., 2003; Study 2, Josephs et al., 2006; Newman et al., 2005). Taken together, this literature suggests that high T individuals are driven to rise in status; when they achieve high status, high T individuals experience pleasure and adaptive functioning (e.g., good cognitive performance), but when they fail to achieve high status, high T individuals experience dysphoria and maladaptive functioning (e.g., poor cognitive performance).

Across these same studies, low T individuals reacted very differently to changes in status. In some of the studies, low T individuals' reactions to high and low status were similar to control conditions (Josephs et al., 2003; Newman et al., 2005), suggesting that they do not have the same strong drive for status that high T individuals have. But in other studies, low T individuals reacted more negatively to high status than to low status. Specifically, low T participants were hypervigilant to status cues, showed elevated cardiovascular arousal, and performed poorly on complex cognitive tasks in a high status position but not in a low status position (Josephs et al., 2006). These latter findings suggest that low T individuals might actually prefer low status and actively avoid high status. As Josephs and colleagues (2006) argued, low T individuals "might shun high status positions . . . because they lack a strong power motive . . . they lack a dominating, aggressive personality . . . and they may not believe they have what it takes physically to maintain such positions" (p. 1001). Thus, when low T individuals are thrust into a high status position, they may experience arousal and maladaptive functioning out of a desire to return to a more comfortable and safer position of low status.

The bulk of the research on T and dominance has been conducted in men, but a small, growing literature suggests that T may also tap into dominance in women. For example, women's basal T predicts aggressive and dominant behaviors (Dabbs & Hargrove, 1997; Dabbs, Ruback, Frady, & Hopper, 1988), social status (Edwards, Wetzel, & Wyner, 2006), and cognitive impairment after status threats (Josephs et al., 2003; Newman et al., 2005). In the few studies that examined the interaction between basal T and status with mixed-sex samples, no evidence for sex differences were found (Josephs et al., 2006), indicating that similar to high T men, high T women react negatively to low status but not to high status. Other research, however, shows sex differences in the association between T and dominance, with many effects established in men failing to replicate in women (Bateup, Booth, Shirtcliff, & Granger, 2002; Edwards et al., 2006; Kivlighan, Granger, & Booth, 2005; Mazur, Susman, & Edelbrock, 1997). These sex differences may be due to basic physiological differences in T production. Whereas T in men is produced primarily by the gonads and to a lesser extent by the adrenal glands, T in women is produced by the adrenal glands and the ovaries. Furthermore, some evidence suggests that T may be less temporally stable in women than in men (Granger et al., 2004; Sellers et al., 2007).

To date, studies testing the predictive validity of basal T on reactions to high and low status have examined only a few out-

come measures, namely, affectivity, cardiovascular arousal, and cognition. But clearly, if basal T taps into the motivation to gain status then basal T should predict a variety of important outcomes. The goal in the present research was to expand on these initial studies with the aim of testing the relationship between basal T and status preference in important and previously untested domains. In particular, we examined whether basal T would predict individuals' cortisol changes and approach–avoidance behaviors following social victory and defeat.

Basal T, Social Status, and Cortisol Changes

The steroid hormone cortisol is released by the hypothalamic–pituitary–adrenal (HPA) axis in response to physical exertion (Mastorakos, Pavlatou, Diamanti-Kandarakis, & Chrousos, 2005) and psychological stress (Dickerson & Kemeny, 2004). States such as hypoglycemia (Davis, Shavers, Costa, & Mosqueda-Garcia, 1996) and psychological engagement (Mason et al., 2001; Nes, Segerstrom, & Sephton, 2005; Tops, Boksem, Wester, Loris, & Meijman, 2006) increase cortisol as well, whereas psychological relaxation (Teixeira, Martin, Prendiville, & Glover, 2005) and disengagement (Mason et al., 2001; Tops et al., 2006) decrease cortisol. The primary physiological function of cortisol is to mobilize energy (glucose) and down-regulate other physiological systems, such as immune and digestive systems (Sapolsky, 1998). Prolonged cortisol activation has been linked to a variety of negative health consequences, including hypertension, impaired immune functioning, and memory loss (Sapolsky, 1998; Segerstrom & Miller, 2004). Therefore, an understanding of the types of events that lead to cortisol fluctuations may help shed light on the development and progression of important physical and mental health outcomes.

One social stressor in particular that can activate the HPA axis in a variety of species is low social status. Indeed, social defeat after competitive encounters raises cortisol in fish (Overli, Harris, & Winberg, 1999), mice (Keeney et al., 2006), and tree shrews (Kramer, Hiemke, & Fuchs, 1999). Naturalistic studies of baboons also reveal that low-ranking males have higher basal cortisol levels than do high-ranking males (Virgin & Sapolsky, 1997). But the evidence in humans that low status elevates cortisol is more mixed. Although some studies found that defeat increases cortisol relative to victory (e.g., Bateup et al., 2002), other studies failed to find such differences (McCaul, et al., 1992; Mehta & Josephs, 2006; Salvador et al., 2003; Suay et al., 1999; Wirth, Welsh, & Schultheiss, 2006). These null findings suggest that there may be variation across individuals in who rises and who falls in cortisol following dominance contests (cf. Wirth et al., 2006). Given its empirical links to dominance and motivation to gain status, basal T levels might be an important predictor of cortisol reactivity to social victory and defeat.

A large literature has already examined T-cortisol relationships in social settings, but most of these studies have focused on the effects of cortisol on T. Across both naturalistic and experimental animal studies, it has been well-established that chronic stress can cause drops in T levels, which is at least partially driven by increases in glucocorticoids—including cortisol— following the stressor (Orr & Mann, 1992; Sapolsky, 1985). Very few studies, however, have explored the reciprocal relationship: whether basal T influences cortisol responses to stressors. The few animal studies on this topic suggest that basal T does affect HPA responses to certain stressors, such as restraint stress in rats (e.g., Viau & Meany, 1996; Viau, 2002). But no research to date, in animals or in humans, has tested whether basal T levels might predict HPA axis activation following victory or defeat in dominance encounters.

Although basal T has not been tested as a moderator of cortisol changes in competition, an individual difference variable closely linked to basal T has been examined. In a recent series of studies, Wirth and colleagues (2006) found that individual differences in the implicit power motive—defined as the unconscious need to have impact on others (McClelland, 1975)—moderated the effects of victory and defeat on postcompetition cortisol changes in humans. Specifically, high power individuals rose in cortisol after defeat and dropped in cortisol after victory. Conversely, low power individuals rose in cortisol after victory and dropped in cortisol after defeat. On the basis of these findings, Wirth and colleagues concluded that individuals with the motivation to dominate others find social defeat more stressful than victory, but individuals who lack this motivation might find victory more stressful than defeat.

Past research has documented a small positive correlation between implicit power motive and basal T (Schultheiss et al., 2005), suggesting that both constructs tap into motivation to gain or maintain high status. This overlap between T and implicit power motive, along with the large literature linking T to dominance, suggests that basal T might also predict cortisol responses to victory and defeat. That is, if high T individuals are indeed motivated to gain status then they might rise in cortisol after defeat because their goal of attaining high status has been thwarted. Conversely, these same individuals might drop in cortisol after victory because their goal of attaining high status has been achieved.

Low T individuals might exhibit a different pattern of postcompetition cortisol changes than do high T individuals. As indicated earlier, some previous studies found that low T individuals showed similar reactions to high status, low status, and no change in status (Josephs et al., 2003; Newman et al., 2005), suggesting that low T individuals might show little to no change in cortisol after victory and defeat. But in other studies, it was found that low T individuals react more negatively to high status than to low status (Josephs et al., 2006), suggesting that low T individuals might actually rise in cortisol after victory and drop in cortisol after defeat.

Basal T, Social Status, and Approach–Avoidance Behavior

Besides predicting cortisol changes, the interaction between basal T and status might also be associated with subsequent behavior. In particular, it seems possible that basal T might moderate the effects of victory and defeat on an individual's decision to reapproach or avoid the same competitive task against the same opponent following a competition. Although the interactive effect of status and basal T on approach–avoidance behavior has not been tested, other human studies have tested the interactive effect of status and the implicit power motive—a construct related to basal T—on learning. Schultheiss and colleagues (2005) found that high power losers exhibited learning deficits on a task that was instrumental in leading to defeat, whereas high power winners exhibited enhanced learning on a task that was instrumental in leading to

victory. The authors argued that high power individuals were rewarded by victory and punished by defeat, but low power individuals were not. On the basis of these findings linking implicit power motive to learning and the initial evidence linking high basal T to drive for high status, it seems plausible that high T individuals who win in competition might choose to repeat the competitive task because it was instrumental in leading to high status. Conversely, high T individuals who lose in competition might choose to avoid the competitive task because it was instrumental in leading to low status.

The Current Studies

In the present research, we sought to test whether the interaction between basal T and status would predict cortisol changes and behavior. The outcome of competition—victory versus defeat—was used as a marker of status. Two studies tested whether basal T moderates the effects of victory and defeat on cortisol changes. In Study 1, we examined this question in a mixed-sex sample of individuals who participated in a real-world dog agility competition, and in Study 2, we examined this question in a sample of women who participated in an experimentally manipulated laboratory competition. In both studies, we hypothesized that high T individuals would increase in cortisol after defeat but would decrease in cortisol after victory. The design of Study 1 also allowed us to test for sex differences in the interactive effect of basal T and status on cortisol changes.

In Study 2, we further examined whether basal T moderates the effects of victory and defeat on decisions to reapproach or avoid the same competitive task against the same opponent. We hypothesized that high T individuals would choose to repeat the competitive task after victory but would choose to avoid the competitive task after defeat.

We expected that low T individuals would show a different pattern of cortisol changes and behaviors after victory and defeat than would high T individuals. However, because the literature on low T individuals has yielded inconsistent findings, we did not make any specific predictions for them.

Study 1: Dog Agility Competition

The data for Study 1 were collected from individuals who participated in a dog agility competition. In dog agility competitions, each person (handler) guides his or her dog through an obstacle course without leash or physical contact. This naturalistic social setting provides several methodological benefits for research on the neuroendocrinology of social status.

First, there are clear status consequences associated with winning and losing because of the real-world nature of the competition. Handlers are likely highly invested in their team's performance. In fact, many handler–dog teams train for weeks, if not month, prior to the competition. In addition, handlers compete in front of a large audience of judges, spectators, and other competitors. The public nature of the competition makes the status consequences of winning and losing even more salient, in large part because status is often defined by how individuals are perceived by others in their peer group (Anderson, John, Keltner, & Kring, 2001). All in all, a dog agility competition represents an ideal social setting for conducting research on social status.

Second, unlike several other competitive domains in which either men or women participate, both sexes participate side by side in dog agility competitions, allowing researchers to collect high-powered mixed-sex samples quickly and efficiently. For the purposes of the present research, the large sample of men and women allowed us to test for sex differences in the interaction between basal T and status on changes in cortisol.

In the dog agility competition that we examined, teams earned points by completing the course quickly and with minimal faults (e.g., deviations or improper maneuvers). Teams that earned a minimum of 85 out of 100 points earned qualifying scores. In the present research, teams that earned qualifying scores were considered to have won the competition, and teams that failed to earn qualifying scores were considered to have lost the competition. We collected saliva samples before and after the competition to test the interactive effect of basal T and status on cortisol changes.

Method

Participants

Participants were 184 handlers (93 men, 91 women) who registered for a dog agility competition sponsored by the North American Dog Agility Council. All but 10 women reported having regular menstrual cycles; the 10 exceptions were menopausal. We removed the 10 menopausal women from our data set because endocrine functioning in menopausal women tends to differ from endocrine functioning in premenopausal women (e.g., Alevizaki, Saltiki, Mantzou, Anastasiou, & Huhtaniemi, 2006; Kajantie & Phillips, 2006). Thirty-six handler–dog teams were disqualified from the competition because they did not complete the course or because they exhibited aberrant behaviors; these teams did not receive a score at all. We removed these teams from our data set because we could not consider them to have won or lost in the competition. Our final data set included 140 participants: 83 men (ages 20–65 years; $M = 44.54$ years, $SD = 9.99$ years; 43 winners, 40 losers) and 57 women (ages 32–57 years; $M = 45.00$ years, $SD = 7.86$ years; 16 winners, 41 losers). Eight of these 57 women were on birth control pills. None of the 140 participants reported being on any other medications.

Procedure

Each participant provided a 2.5 mL saliva sample 90 min ($M = 93.89$; $SD = 3.95$) prior to the competition. The time of the first sample for all participants was between 12:00 p.m. and 1:00 p.m., to control for circadian changes in T and cortisol levels (Touitou & Haus, 2000). Participants then competed, leading their dogs through the agility course as quickly as possible with as few mistakes as possible. Judges, spectators, and other competitors watched. The average time teams took to complete the course was 215 s ($SD = 79$ s). After all teams at a given level of competition had finished, results of the competition were publicly posted. Approximately 20 min ($M = 20.39$, $SD = 3.05$) after each team had received these results, participants provided a second saliva sample. This second saliva sample was provided approximately 2.5 hr ($M = 147$ min, $SD = 6$ min) after the first one. In order to control for the effects of food intake on endocrine functioning,

participants were asked not to eat or drink anything besides water between the two saliva samples.

For both pre- and postcompetition saliva samples, participants chewed sugar-free gum in order to stimulate salivation. Then they passively drooled 2.5 mL of saliva into a sterile polypropylene microtubule. Saliva samples were immediately frozen to avoid hormone degradation and to precipitate mucins. For details about the full procedure, see Jones and Josephs (2006).

Hormone Assays

Saliva was first thawed and separated from residuals (e.g., mucins) by thorough mixing by vortex followed by centrifugation at 3,000 rpms for 15 min. Then the saliva samples were analyzed for T and cortisol concentrations with enzyme immunoassay kits purchased from Salimetrics (State College, Pennsylvania). The T plates were coated with antibodies to T, and the cortisol plates were coated with antibodies to cortisol. Samples were assayed at least twice. We ran two in-house control samples in every assay. Interassay coefficient of variation (CV) was 3.7% for T and 2.5% for cortisol. If the intra-assay CV for a given sample was greater than 7.5%, the sample was assayed again. This occurred for only seven of the samples. The lower limit of detection ($B_0 + 3SD$) for cortisol kits was .002 μg/dL. The lower limit of detection ($B_0 + 3SD$) for T kits was 4 pg/mL. Although T concentrations were measured in both the first and the second saliva samples, only T concentrations from the first saliva sample (basal T) are relevant to the research questions addressed in the current article. Analyses for change in T are not reported in this article, but interested readers may refer to a previous publication for some selective analyses concerning changes in T in men from this sample (Jones & Josephs, 2006).

Results

Preliminary Analyses

Basal levels of T and basal levels of cortisol were measured from the precompetition saliva sample (men's basal T: $M = 119.4$ pg/mL, $SD = 79.9$ pg/mL; women's basal T: $M = 38.9$ pg/mL, $SD = 35.1$ pg/mL; men's basal cortisol: $M = .28$ μg/dL, $SD = .15$ μg/dL; women's basal cortisol: $M = .27$ μg/dL, $SD = .13$ μg/dL). In previous research, it has been found that basal T is moderately positively correlated with basal cortisol in both sexes (e.g., Gray, Jackson, McKinlay, 1991; Popma et al., 2007; Vicennati et al., 2006), perhaps reflecting overlap in adrenal release of both hormones, especially in women. Consistent with this research, there was a positive relationship between basal T and basal cortisol in men, $r(83) = .47$, $p < .01$, and in women $r(57) = .43$, $p < .01$. Across the entire sample, basal cortisol was correlated with postcompetition cortisol, $r(140) = .45$, $p < .01$, indicating that there was moderate stability in cortisol levels. To control for sex differences in basal T, we standardized basal T scores separately for men and women by converting the raw basal T scores for every participant to z scores. High scores on this distribution indicated high T levels relative to other individuals of the same sex.

Cortisol Change

To examine predictors of cortisol change, we employed regression analyses in which basal cortisol was entered as a covariate and postcompetition cortisol was entered as the dependent variable. Initial analyses with this analytical strategy found that variation in the elapsed time between the two saliva samples did not predict cortisol change and did not interact with basal T, gender, or win/lose to predict cortisol changes ($ps > .15$). Hence, it was excluded from subsequent statistical analyses.

We next tested the hypothesis that basal T would moderate the effects of victory and defeat on postcompetition changes in cortisol. Specifically, we predicted that high T losers would rise in cortisol but that high T winners would drop in cortisol. We did not expect low T individuals to show this same pattern of cortisol changes. To test these hypotheses and to test for sex differences, we ran a hierarchical regression analysis with postcompetition cortisol as the dependent variable and the following variables as predictors: basal cortisol in Step 1; gender (dummy-coded as 0 for men and 1 for women), the win/lose result (dummy-coded as 0 for lose and 1 for win), and basal T in Step 2; the three two-way interactions (Gender × Win/Lose, Gender × Basal T, Win/Lose × Basal T) in Step 3; and the Gender × Win/Lose × Basal T three-way interaction in Step 4. This analysis revealed a statistically significant three-way interaction ($\Delta R^2 = 3.8\%$), $F(1, 131) = 8.22$, $p < .01$, indicating that there were sex differences.

To interpret this three-way interaction, we ran separate multiple regression models in men and women. In both of these models, we entered postcompetition cortisol as the dependent variable and the following variables as predictors in a hierarchical regression: basal cortisol in Step 1, the win/lose result (dummy-coded as 0 for lose and 1 for win) in Step 2, basal T in Step 3, and the Win/Lose × Basal T interaction in Step 4. In men, the results of this model revealed that win/lose predicted cortisol changes ($\Delta R^2 = 16\%$), $F(1, 80) = 20.35$, $p < .001$, such that men who lost increased in cortisol relative to men who won ($M_{\text{Winners}} = -.11$, $SE_{\text{Winners}} = .02$; $M_{\text{Losers}} = .03$. $SE_{\text{Losers}} = .02$, based on postcompetition cortisol minus basal cortisol scores). This main effect, however, was qualified by a statistically significant Win/Lose × Basal T interaction ($\Delta R^2 = 9.3\%$), $F(1, 78) = 13.76$, $p < .001$.

To interpret this two-way interaction found in men, we computed change in cortisol scores by saving the unstandardized residuals of a regression analysis with basal cortisol as the predictor and postcompetition cortisol as the dependent variable. Then we ran simple regressions in winners and losers separately. See Figure 1. In support of the idea that high T individuals are motivated to gain status, there was a positive relationship between basal T and cortisol change in male losers ($\beta = .43$), in contrast with a negative relationship between basal T and cortisol change in male winners ($\beta = -.27$). In addition to the statistically significant difference in these slopes as indicated by the interaction term, the positive slope in male losers was also statistically different from zero, $t(38) = 2.95$, $p < .01$. As shown in Figure 1, these results indicate that high T men rose in cortisol after defeat, but high T men dropped in cortisol after victory. Low T men who won and low T men who lost, however, did not differ in their cortisol changes; both of these groups showed very slight drops in cortisol.

The results in women revealed no main effect for basal T but did reveal a main effect for win/lose ($\Delta R^2 = 10.2\%$), $F(1, 54) = 7.78$, $p < .01$, indicating that women who won in the competition dropped in cortisol relative to women who lost ($M_{\text{Winners}} = -.09$, $SE_{\text{Winners}} = .03$; $M_{\text{Losers}} = .00$, $SE_{\text{Losers}} = .02$, based on postcompetition cortisol minus basal cortisol scores). Inconsistent with

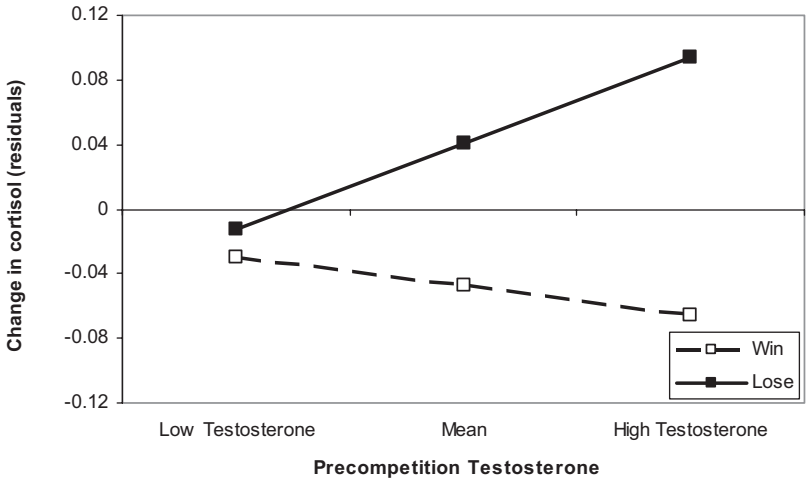

Figure 1. Study 1 regression slopes of precompetition testosterone predicting change in cortisol (μg/dL; unstandardized residuals of postcompetition cortisol controlling for basal cortisol) in men. Low testosterone = 1 *SD* below the mean; high testosterone = 1 *SD* above the mean. Standardized beta for winners: $\beta = -.27$, $p < .10$; standardized beta for losers: $\beta = .43$, $p < .01$.

our expectations, however, the Win/Lose × Basal T interaction failed to reach statistical significance in women, $F(1, 52) = 0.73$, $p > .30$. Excluding women on birth control still yielded a nonsignificant interaction ($p > .90$). Overall, our analyses showed that basal T moderated the effects of victory and defeat on cortisol changes in men but not in women.

Cortisol change in handlers may have reflected physical exertion during the competition. These differences in physical exertion could potentially account for the effects of competition outcome and basal T on cortisol changes. To test this alternative interpretation, we examined one measure we thought should tap into physical exertion: the time participants took to run the course. We reasoned that running the course more quickly would be a marker of greater physical exertion.

The time to complete the course was an important factor that judges used to determine winners and losers, with faster times leading to wins and slower times leading to losses, $t(138) = 17.9$, $p < .001$ ($M_{\text{Winners}} = 138$ s, $SD_{\text{Winners}} = 49$ s; $M_{\text{Losers}} = 272$ s, $SD_{\text{Losers}} = 39$ s). The faster times in winners suggest that these individuals showed greater physical exertion than did losers. Therefore, if physical exertion was responsible for cortisol changes in the present study, we would expect winners to have shown greater increases in cortisol compared with losers. However, as demonstrated by the analyses reported above, the exact opposite effect emerged; winners dropped in cortisol, on average, relative to losers. We next conducted a multiple regression in men with postcompetition cortisol as the dependent variable and the following variables as predictors: basal cortisol, win/lose, time to complete the course, basal T, and the Win/Lose × Basal T interaction. A statistically significant Win/Lose × Basal T interaction still emerged ($\Delta R^2 = 9\%$), $F(1, 77) = 13.23$, $p < .001$. We then ran the same multiple regression analysis in women. The Win/Lose × Basal T interaction still failed to reach statistical significance, $F(1, 51) = 0.82$, $p > .30$. These additional analyses demonstrate that even when controlling for a measure of physical activity, the findings in men and women stayed the same; basal T moderated the effects of victory and defeat on cortisol changes in men but not in women.

Discussion

Study 1 provides the first empirical evidence that men's T levels prior to competing predict cortisol changes following victory and defeat. High T men who lost in the dog agility competition increased in cortisol, but high T men who won decreased in cortisol. In contrast, low T men who won and low T men who lost did not differ in cortisol changes; both of these low T groups showed very slight drops in cortisol. These findings extend previous research on T and status, which shows that low and high T individuals differ in their affective, cognitive, and cardiovascular responses to low and high status (Josephs et al., 2003; 2006; Newman et al., 2005). Our results also provide greater support for the hypothesis that basal T serves as a biological marker for status-seeking motivation (Josephs et al., 2003, 2006; Mazur & Booth, 1998; Newman et al., 2005; Sellers et al., 2007). Presumably, high T men in the present study rose in cortisol after defeat because they failed to gain the high status they desired, but high T men dropped in cortisol after victory because their goal of attaining high status had been achieved. And, presumably, low T men did not have a strong preference for high status, and thus their cortisol changes did not depend on whether they won or lost.

There are a number of underlying states that could account for this pattern of cortisol changes. One possibility is that a cortisol rise after defeat reflects psychological distress and anxiety (Dickerson & Kemeny, 2004) and a cortisol drop after victory reflects relaxation (Teixeira et al., 2005). This explanation is consistent with Josephs et al.'s (2006) findings that high T individuals had higher negative affect after defeat than after victory. It is also consistent with the large set of literature on cortisol activity and dominance, which by and large interprets a cortisol rise after social defeat as an indicator of psychological stress (e.g., Keeney et al., 2006; Wirth et al., 2006).

An alternative interpretation is that cortisol rises after defeat may reflect a person's mobilization to change his state of affairs. After all, the primary physiological function of cortisol is to mobilize glucose (Sapolsky, 1998). This interpretation is consistent with Josephs et al. (2006)'s arguments that high T individuals show strong negative reactions to a status loss because they are motivated to regain high status; a rise in cortisol after defeat may be a marker of this motivational state. Other psychological states associated with HPA activity may have also led to the pattern of postcompetition cortisol changes we found (e.g., engagement–disengagement, effort, Mason et al., 2001; Nes, Segerstrom, & Sephton, 2005; Tops et al., 2006). Follow-up studies that measure psychological variables in addition to endocrinological ones can determine which states are most likely to underlie cortisol responses in competitive social settings.

Although it is possible that physical exertion caused the pattern of cortisol changes in the present study, our analyses suggest that this is unlikely. According to our measure of physical exertion, the time to complete the course, winners showed greater physical exertion than losers. Therefore, winners should have increased in cortisol over losers if physical exertion was the primary cause of cortisol changes. But the exact opposite effect emerged; winners dropped in cortisol relative to losers. Further analyses showed that even when controlling for physical exertion, men's T levels prior to competing still predicted their cortisol responses to victory and defeat. Even if physical exertion influenced a portion of the variance in cortisol changes, previous research suggested that the physical and psychological effects of competition on hormone changes are additive and nonredundant (Passelergue & Lac, 1999; Suay et al., 1999). Overall then, it seems that cortisol changes in the present study were driven, at least in part, by psychological responses to changes in status. Nevertheless, our measure of physical exertion was not ideal, and an important effect of physical exertion on cortisol responses cannot be ruled out completely. Future studies should use more accurate measures (e.g., accelerometers) to control for physical activity's influence on endocrinological changes in competition.

Given the empirical evidence demonstrating the temporal stability of T (Sellers et al., 2007), precompetition T levels are likely a marker of basal T. However, it is likely that a portion of the variance in precompetition T is the result of anticipatory T changes. Several studies have shown that T prior to competition can rise over baseline in some individuals (Suay et al., 1999). If such anticipatory T changes also occurred in the present study, then perhaps the findings in men can be explained by a combined effect of basal T and anticipatory changes in T. A future study would ideally measure T at a true resting baseline, such as on the day before or after competition, in order to distinguish basal from anticipatory changes in T as predictors of postcompetition fluctuations in cortisol.

Consistent with the results in men, women also dropped in cortisol after victory, as compared with defeat. But inconsistent with the results in men, women's T levels prior to competing did not moderate this effect of competition outcome on cortisol changes. That is, low and high T women did not differ in their cortisol responses to victory and defeat. One possible explanation for the null results in women is that precompetition T may not be a strong predictor of women's cortisol responses to victory and defeat. This interpretation is consistent with some previous research on women's T and competition, which failed to replicate effects observed in men (Bateup et al., 2002; Edwards et al., 2006; Kivlighan et al., 2005; Mazur et al., 1997). At the same time, this interpretation is inconsistent with other research demonstrating that basal T interacts with status to predict emotional, cognitive, and physiological outcomes in women as well as men (Josephs et al., 2003, 2006; Mehta et al.; Newman et al., 2005). So what else might explain the failure of T to predict cortisol changes among women in the present study?

Another possibility is that due to the social nature of the dog agility competition, women's social interactions after the competition may have had a more potent effect on cortisol changes than T did. According to the tend-and-befriend theory (Taylor et al., 2000), women are more likely than men to affiliate with others following a stressor, and this affiliation is thought to affect women's physiological recovery. If this is the case, perhaps the quality of women's social interactions after the competition was a stronger predictor of cortisol changes than precompetition T was, such that high quality social interactions may have buffered against the physiological stress response, whereas low quality social interactions or a complete absence of such interaction may have exacerbated it. The effects of social interactions on cortisol changes may have superseded any association between precompetition T and cortisol changes. Unfortunately, we were unable to measure the frequency and quality of participants' social interactions with other handlers and friends, and therefore, we could not empirically test this possibility.

A third possibility is that factors specific to the sample may have contributed to the failure of T to predict cortisol changes in women. Specifically, the number of female winners was much lower than the number of male winners, female losers, or male losers. The substantially smaller group of female winners may have impacted the probability of obtaining a statistically significant T $\times$ Status interaction in women.

A fourth possibility is that measurement error in assessing basal T may have led to the null results in women. As indicated above, our measure of precompetition T may have reflected a combined effect of basal T and anticipatory T changes. Although researchers have generally assumed that both basal T and short-term fluctuations in T are associated with the motivation to gain status, it is possible that anticipatory T rises in women may not reflect this motivation. In fact, in one study, it was found that that a greater anticipatory T rise prior to competition was associated with worse competitive performance (Kivlighan et al., 2005), which led the authors of that study to conclude that "little evidence emerged to support linkages between anticipatory T levels and individual differences in competitiveness and dominance" (p. 66). If it is true that anticipatory T changes in women do not reflect dominance motivation but basal T does, the error introduced by anticipatory T changes may have led to the lack of relationship between precompetition T and cortisol change for women.

Although T failed to interact with status among women in the dog agility competition, some previous studies demonstrated that women's basal T predicts reactions to victory and defeat in certain competitive domains (Josephs et al., 2003, 2006; Newman et al., 2005). Thus, we thought it important to place women in a different, more controlled competitive setting and further investigate whether basal T moderates the effects of victory and defeat on cortisol changes in women.

Study 2: "Intelligence" Test Competition

The goal of this second study was to examine the interactive effect of basal T and status on cortisol changes in women, in order to explore whether the findings for men in Study 1 could extend to women. The design of this study differed from Study 1 in four important ways. First, we used a different competitive domain: a series of puzzles presented to participants as a test of intelligence. We chose this particular domain because previous work has found that college-aged women seem to perceive these types of cognitive competitions as having important consequences for status. That is, women seem to care about their performance during the competition, and personality variables related to power and status have been found to predict women's reactions to victory and defeat after the competition (Josephs et al., 2006; Schultheiss et al., 2005; Wirth et al., 2006). Second, instead of competing in a large group as was the case in Study 1, the participants in the current study competed against each other head-to-head and were unable to interact with others following the competition. We chose this strategy because we wanted to remove any of the variance in women's cortisol changes that could be explained by their social interactions. Third, we experimentally manipulated the outcome of the competition, as opposed to allowing victory and defeat to emerge naturally. And fourth, to remove any potential confounding effect of anticipatory T changes on basal T levels, participants in this second study were not informed prior to arriving at the lab that they would be competing.

In addition to examining cortisol changes, in Study 2, we also investigated participants' approach–avoidance behaviors after victory and defeat. Specifically, we asked participants after they won or lost whether they wanted to repeat the same competitive task a second time against the same opponent. We included this behavioral measure because we thought that status preferences would have important implications for participants' decisions to approach or avoid the competitive task. That is, we expected that if high T individuals were motivated to gain high status then high T winners would choose to repeat the competitive task because it led to high status. Conversely, we expected that high T losers would choose to avoid the competitive task because it led to low status. We did not make any specific predictions for the behaviors of low T individuals.

In this second study, women reported to the lab, 2 at a time, and competed against each other on an ostensible test of intelligence. Unbeknownst to the participants, the competition was rigged. Participants were brought to a private lab room immediately after the competition in order to minimize the opportunity for social interactions. Saliva samples were collected before and after the competition to measure basal T and cortisol changes. After the second saliva sample, participants were asked whether they wanted to repeat the same competitive task against the same opponent. This paradigm allowed us to test whether the interaction between basal T and status predicts cortisol changes and behavior in women.

Method

Participants

Seventy women enrolled in an introductory psychology course at the University of Texas at Austin participated in the study in exchange for credit toward a research requirement. Four of the participants provided inadequate saliva samples that could not be assayed for hormone concentrations. Another 4 participants' saliva samples were assayed, but at least one of the samples provided by these participants had mucous content that was too high to get an accurate measure of hormone concentrations (CV greater than 15%). One participant had a basal T score well out of the expected range (390.35 pg/mL), most likely due to blood contamination. We removed these 9 participants from our data set, leaving 61 participants with complete data. Unfortunately, participants' medication use was not recorded.

Procedure

Participants reported to the lab in pairs between 12:00 p.m. and 3:30 p.m., to minimize the effects of circadian fluctuations in T and cortisol levels (Touitou & Haus, 2000). Participants were first asked to leave all of their belongings in a storage room and were asked to turn off their cell phones. The experimenter then led each participant to a separate lab room, obtained informed consent, and collected the first saliva sample. For this first saliva sample, participants first rinsed out their mouths to remove any food particles. After that, participants chewed on a piece of Trident sugar-free gum for 3 min in order to stimulate salivation. Then participants drooled 2.5 mL of saliva into a sterile polypropylene microtubule, and spit out their gum. Saliva samples were immediately brought to a freezer in an adjacent lab room in order to avoid hormone degradation and to precipitate mucins.

Competition. After saliva collection, both participants were escorted into the same room and seated at two desks facing opposite walls. Participants sat facing away from each other in order to minimize participants' suspicion with the win/loss manipulation. The experimenter announced to the participants that they would be competing against each other on a test of an important type of intelligence called "spatial processing speed." The task used for the competition was the Number Tracking Task (Schultheiss, Campbell, & McClelland, 1999). This task has been used successfully in past studies on T and competition; participants seem to care about their performance on this task, and personality variables such as implicit power motive and basal T have been found to predict cognitive, hormonal, and affective reactions to winning and losing in a Number Tracking Task competition (Josephs et al., 2006; Schultheiss et al., 1999). Further, the task is powerful because it allows researchers to experimentally manipulate the winner and loser of the competition.

The Number Tracking Task consists of a several puzzles. Each puzzle contains a grid of numbers, and participants must trace through the numbers in sequential order until a highlighted number is reached. Participants thought they were competing on the same puzzles, but the competition was rigged. The participant randomly assigned to win was given easier puzzles than the participant assigned to lose. Participants completed six puzzles, saying "done" after completing each one. The experimenter recorded the time it took each participant to complete all six puzzles. The average duration of the competition was 8 min, 41 s.

Postcompetition saliva. Immediately after the competition, participants were escorted to separate rooms where they worked on a filler task (a word search). Fifteen minutes after the competition had ended ($M = 34$ min, $SD = 3$ min after the first saliva sample),

the experimenter collected the word search, and participants provided a second saliva sample. The second saliva sample was taken to measure cortisol changes from before to after the competition. For this second saliva sample, participants were given a second piece of sugar-free gum to chew on for 3 min, and then participants drooled 2.5 mL of saliva into a second plastic vial. Participants spit out their gum after they finished. Saliva samples were immediately transported to a nearby freezer. We waited 15 min after the end of the competition to collect the second saliva sample because it takes several minutes for hormone levels in blood to reach saliva (cf. Riad-Fahmy, Read, Walker, Walker, & Griffiths, 1987). Although previous research suggests that salivary cortisol peaks 30 min after a public speaking stressor (Kirschbaum, Pirke, & Hellhammer, 1993), recent evidence suggests that cortisol levels 15 min and 30 min after a laboratory-based competition did not differ from each other (Wirth et al., 2006). Therefore, it seems that a 15-min delay is sufficient to measure salivary cortisol responses to competition. Participants were not explicitly asked to refrain from eating or drinking in between saliva samples, but it is highly unlikely that they ate or drank during the study because all of their belongings were being stored in a separate room. Furthermore, none of the saliva samples showed any obvious signs of food particles or change in color that would indicate food or beverage consumption had occurred.

Task preference. Following the second saliva sample, participants filled out the choice questionnaire, which asked them to choose the next experimental task. They were asked to choose one of two options: (a) compete again on six new puzzles of the Number Tracking Task against the same participant or (b) complete a questionnaire on food, music, and entertainment preferences. The choice questionnaire indicated that option (b) would take about as long to complete as the Number Tracking Task. Participants made their choice by circling (a) or (b), and handed the questionnaire to the experimenter.

Immediately afterward, participants were given a second questionnaire, which asked them to indicate the strength of their task preference on a 6-point scale (1 = *I strongly prefer to complete the entertainment questionnaire,* 2 = *I moderately prefer to complete the entertainment questionnaire,* 3 = *I slightly prefer to complete the entertainment questionnaire,* 4 = *I slightly prefer to compete again on the Number Tracking Task,* 5 = *I moderately prefer to compete again on the Number Tracking Task,* 6 = *I strongly prefer to compete again on the Number Tracking Task*). Participants indicated the strength of their preference by circling the corresponding number. We included this question because we thought it would be a more sensitive measure of participants' task preferences than the forced choice measure that preceded it.

Suspicion check. Participants then filled out another short questionnaire, which included three questions to check for suspicion. These questions were "What did you think this study was about?" "Was there anything about the study that you thought was odd? If yes, what?" and "During the study, did you at any point feel that you were being misled? If yes, when and how?" Participants' open-ended responses to these questions were later coded for suspicion associated with the win/loss manipulation. Immediately after filling out this questionnaire, participants were debriefed as to the true nature of the study and were dismissed. The entire experiment took approximately 1 hr and 15 min to complete.

Hormone Assays

The saliva samples were analyzed for T and cortisol concentrations with enzyme immunoassay kits purchased from Salimetrics (State College, Pennsylvania). Samples were assayed in duplicate. The T plates were coated with antibodies to T, and the cortisol plates were coated with antibodies to cortisol. Interassay CVs for Salimetrics assays conducted in our lab average 8.7% for T and 2.8% for cortisol. Intra-assay CV averaged across all 61 participants was 4.2% for T and 3.7% for cortisol. The lower limit of detection (B_0 + 3*SD*) for cortisol kits was .01 μg/dL. The lower limit of detection (B_0 + 3*SD*) for T kits was 1.6 pg/mL. Although T concentrations were measured in both the first and second saliva samples, only T concentrations from the first saliva sample (basal T) are relevant to the research questions addressed in the current article. Therefore, analyses for change in T are not reported in this article.

Results

Suspicion Check

All participants correctly indicated whether they had won or lost in the competition, but one participant indicated some degree of suspicion with the win/loss manipulation. Thus, we decided to remove this participant from our analyses. All analyses below were conducted on the remaining 60 participants (29 winners, 31 losers).

Preliminary Analyses

Basal T and basal cortisol were calculated from the precompetition saliva sample (Basal T: $M = 61.5$ pg/mL, $SD = 38.2$ pg/mL; Basal cortisol: $M = .22$ μg/dL, $SD = .19$ μg/dL).[1] There was a trend for individuals in experiments later in the afternoon to have higher basal T, $r(60) = .22$, $p = .09$. There was no relationship between time of experiment and basal cortisol, $r(60) = .13$, $p > .30$. Consistent with the results of Study 1 and with some previous research (e.g., Vicennati et al., 2006), there was a positive relationship between basal T and basal cortisol, $r(60) = .39$, $p < .01$.

[1] The mean for basal T in Study 2 was consistent with the means reported in previous research with Salimetrics kits (Josephs et al., 2006; Kivlighan et al., 2005; Newman et al, 2005; Sellers et al., 2007; Shirtcliff et al., 2002) but was higher than the means reported in research with other assay kits (e.g., radioimmunoassay, DPC, Schultheiss et al., 2005; radioimmunoassay, Diagnostic Statistical Laboratory (DSL), Shirtcliff et al., 2002). Therefore, we decided to verify whether the T scores measured from Salimetrics kits would correlate with T scores measured with another type of kit. We sent a subset of the saliva samples for which there was sufficient volume of saliva left ($n = 20$) to an external lab (Yerkes Endocrine Core Laboratory, Atlanta, GA) for reanalysis with Diagnostic Statistical Laboratory (DSL) radioimmunoassay kits. The basal T mean from the DSL kits was significantly lower ($M = 20.04$, $SD = 10.26$) than the basal T mean for the same 20 samples measured with Salimetrics kits ($M = 72.52$, $SD = 36.82$), $t(38) = 6.14$, $p < .01$. This difference in means was consistent with previous research that compared results from these two assay kits (Shirtcliff et al., 2002). And as expected, there was a strong correlation between the T levels as measured independently from the two assay kits, $r(20) = .65$, $p < .01$, suggesting that the Salimetrics assays were indeed capturing T levels similar to DSL kits.

There was also evidence for temporal stability in cortisol levels across the two time points, $r(60) = .79$, $p < .001$.

Cortisol Change

To examine predictors of cortisol change, we employed regression analyses in which basal cortisol was entered as a covariate and postcompetition cortisol was entered as the dependent variable. With this technique, it was found that the elapsed time between the two saliva samples did not predict cortisol change, $F(1, 57) = 0.03$, $p > .80$, nor did it interact with the outcome of the competition to predict cortisol change, $F(1, 55) = 0.24$, $p > .60$. Similarly, the time of the experiment did not predict cortisol change, $F(1, 57) = 0.07$, $p > .70$, nor did it interact with the outcome of the competition to predict cortisol change, $F(1, 55) = 0.03$, $p > .80$. Therefore, we excluded the time between samples and the time of the experiment from subsequent analyses.

Did basal T moderate the effects of victory and defeat on changes in cortisol? To examine this question, we first centered basal T scores prior to regression analysis. Then we used a hierarchal regression model in which postcompetition cortisol was entered as the dependent variable and the following variables were entered as predictors: basal cortisol in Step 1, win/lose (dummy-coded as 0 for lose and 1 for win) in Step 2, basal T in Step 3, and the Win/Lose × Basal T interaction term in Step 4. Inconsistent with the results of Study 1 but consistent with other research on laboratory-based competitions (e.g., Wirth et al., 2006), there was no main effect of win/lose on cortisol changes, $F(1, 57) = 1.86$, $p > .10$. However, a statistically significant Win/Lose × Basal T interaction emerged ($\Delta R^2 = 2.5\%$), $F(1, 55) = 3.97$, $p = .05$.

To interpret this interaction, we computed change in cortisol scores by saving the unstandardized residuals of a regression analysis with basal cortisol as the predictor and postcompetition cortisol as the dependent variable. Then we ran simple regressions in winners and losers separately. See Figure 2. Consistent with the idea that high T individuals are motivated to gain status, there was a positive relationship between basal T and cortisol change in losers ($\beta = .20$), in contrast with a negative relationship between basal T and cortisol change in winners ($\beta = -.35$). The statistically significant interaction term indicates that these slopes statistically differed from each other. As Figure 2 shows, high T losers rose in cortisol, but high T winners dropped in cortisol. Low T winners and low T losers did not seem to differ from one another in their cortisol changes.

We also investigated whether the Win/Lose × Basal T interaction depended on the time of the experiment or on the elapsed time between the two saliva samples. Multiple regression models did not show a significant effect for the Win/Lose × Basal T × Time of Experiment interaction, $F(1, 52) = 0.42$, $p > .50$ or for the Win/Lose × Basal T × Elapsed Time Between Saliva Samples interaction, $F(1, 52) = 0.16$, $p > .60$.

Task Preferences

We next tested whether basal T moderated the effects of victory and defeat on participants' preferences to reapproach or avoid the competitive task. Recall that we had two measures of task preference: a forced choice measure and a strength of task preference measure. We decided to examine the interactive effect of basal T and status on both of these measures separately because we believed each measure had its distinct merits. That is, the forced choice measure seemed to be a more ecologically valid measure of a participant's decision to approach or avoid the competitive task; but the strength of task preference question, we reasoned, might be more sensitive because it assessed preferences on a more finely graded 6-point scale. We report analyses for the forced choice measure first, followed by analyses for the strength of preference measure. Because the time of the experiment did not have a statistically significant effect on task preference and did not interact with basal T or win/lose to predict task preference ($ps > .20$), it was not included in any of the analyses for task preference.

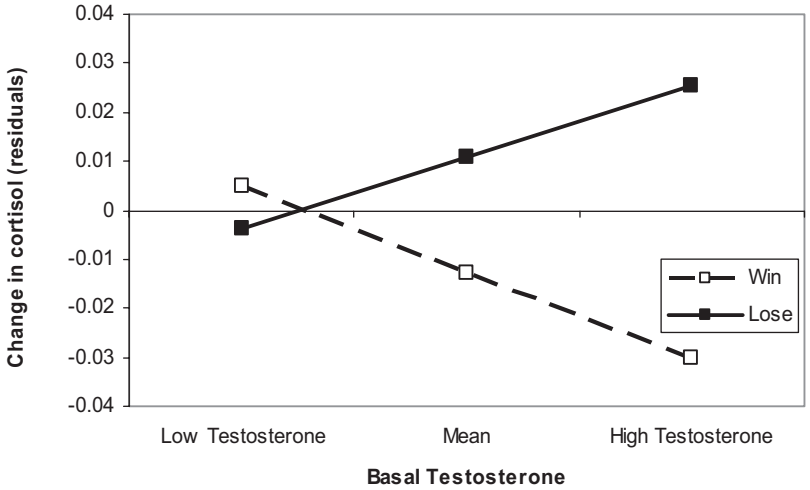

Figure 2. Study 2 regression slopes of basal testosterone predicting change in cortisol (μg/dL; unstandardized residuals of postcompetition cortisol controlling for basal cortisol) in women. Low testosterone = 1 *SD* below the mean; high testosterone = 1 *SD* above the mean. Standardized beta for winners, $\beta = -.35$, $p < .10$; standardized beta for losers, $\beta = .20$.

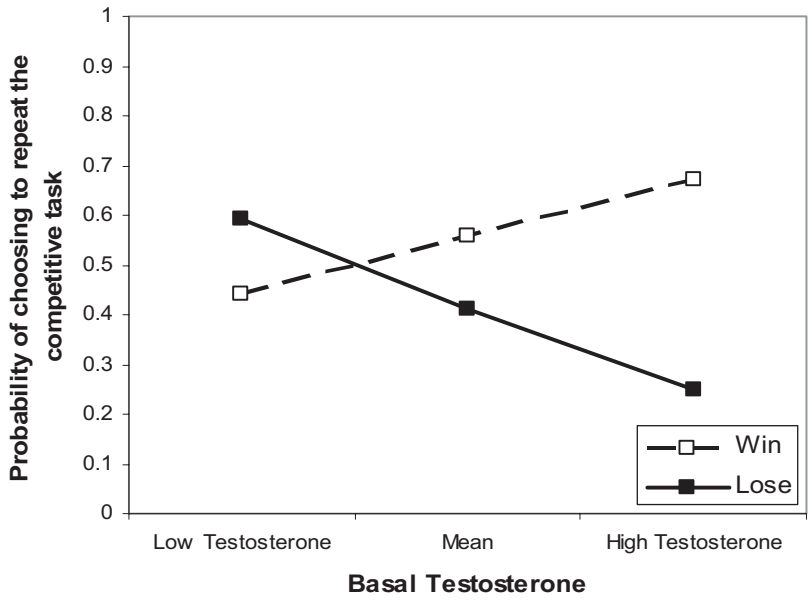

Figure 3. Study 2 probability of choosing to repeat the competitive task (instead of choosing the alternative questionnaire task) as a function of basal testosterone and win/lose. Low testosterone = 1 *SD* below the mean; high testosterone = 1 *SD* above the mean.

Forced choice. Across the entire sample, 29 participants chose to repeat the competitive task, and 31 participants chose to complete the alternative task (the entertainment questionnaire). In addition, winners did not differ from losers in their task preferences, $\chi^2(1, N = 60) = 1.05, p > .30$.

We next tested whether basal T moderated the effects of victory and defeat on participants' decisions to reapproach or avoid the competitive task. To do so, we ran a binary logistic regression analysis with the win/lose result (dummy-coded as 0 for lose and 1 for win) and basal T as predictors in Step 1, the Win/Lose × Basal T interaction as a predictor in Step 2, and task preference (1 = repeat the competition, 0 = complete the alternative task) as the dependent variable. There was a statistically significant Win/Lose × Basal T interaction, $\chi^2(1, N = 60) = 4.32, p < .04$.

To interpret this interaction, we computed the predicted probability of choosing to repeat the competitive task, based on the binary logistic regression model, at the basal T mean, one standard deviation below the basal T mean and one standard deviation above the basal T mean, for winners and losers. As shown in Figure 3, the pattern of results indicates that high T winners were more likely to choose to repeat the competitive task than were high T losers. In contrast, low T winners and low T losers did tend to differ in their task preferences; if anything, low T individuals showed the opposite pattern of task preferences from high T individuals.

Strength of task preference. We next tested whether basal T moderated the effects of victory and defeat on the strength of participants' task preferences. We entered the win/lose result (dummy-coded as 0 for lose and 1 for win), basal T, and the Win/Lose × Basal T interaction as predictors of the strength of task preference in a multiple regression model. This model revealed a statistically significant Win/Lose × Basal T interaction ($\Delta R^2 = 13.1\%$), $F(1, 56) = 3.97, p < .01$.

To interpret this interaction, we ran simple regressions in winners and losers for the relationship between basal T and strength of task preference. As shown in Figure 4, basal T showed a positive relationship with the strength of task preference measure in winners ($\beta = .32$), but basal T showed a negative relationship with the strength of task preference measure in losers ($\beta = -.42$). In addition to the statistically significant difference in these slopes as indicated by the interaction term, the negative slope in losers was also statistically different from zero, $t(29) = -2.49, p < .02$. Mimicking the results of the forced choice data, the pattern of results indicates that high T winners preferred to repeat the competitive task, whereas high T losers preferred to avoid it. In contrast, low T winners and low T losers did not differ from each other in the strength of their task preferences. Both low T groups' mean strength of task preference scores were close to the midpoint on the 6-point scale. Overall, high T individuals' task preferences depended on whether they had won or lost the competition, but low T individuals' preferences did not depend on the competition outcome. The findings were similar for the forced choice and the strength of task preference measures.[2]

[2] To determine whether the same pattern of findings would emerge with the DSL kits, we computed separate correlations in winners and losers for the relationship between DSL basal T scores and cortisol change as well as DSL basal T scores and strength of task preference. Because of the low sample size ($n = 20$), we did not expect statistically significant differences; instead, we looked to see whether the pattern that emerged in the original analyses would still emerge. Consistent with the original analyses, there was a positive relationship between DSL basal T scores and cortisol change in losers ($\beta = .44$), but there was a negative relationship between DSL basal T scores and cortisol changes in winners ($\beta = -.53$). In addition, there was a negative relationship between DSL basal T scores and strength of task preference in losers ($\beta = -.05$), but there was a positive relationship between DSL basal T scores and strength of task preference in winners ($\beta = .12$). These analyses suggest that our findings in Study 2 generalize across assay technique.

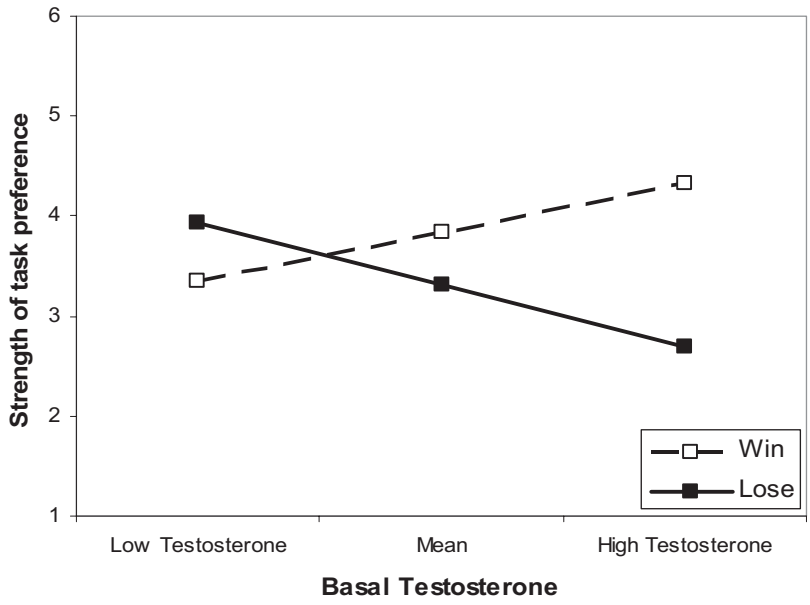

Figure 4. Study 2 regressions slopes for basal testosterone predicting strength of task preference measured on a 6-point scale (1 = *strong preference to complete the alternative task*: an entertainment questionnaire, 6 = *strong preference to repeat the competitive task*). Low testosterone = 1 *SD* below the mean; high testosterone = 1 *SD* above the mean. Standardized beta for winners: $\beta = .32$, $p < .10$; standardized beta for losers: $\beta = -.42$, $p < .05$.

Cortisol change and task preference. We also tested whether the interaction between basal T and status as a predictor of task preference was mediated by cortisol changes. But this was not the case; a binary logistic regression showed that change in cortisol did not predict our binary choice measure, $\chi^2(1, N = 60) = 0.68$, $p > .40$. The correlation between cortisol change and strength of task preference also failed to reach statistical significance ($r = -.11$), $p > .40$.

Discussion

Study 2 provides evidence that basal T moderates the effects of victory and defeat on cortisol changes and behavior in women. After competing in a one-on-one cognitive competition, high T women rose in cortisol following defeat, but high T women dropped in cortisol following victory. Low T women's cortisol changes did not depend on victory or defeat; that is, low T winners and low T losers showed minimal changes in cortisol. The pattern of findings was remarkably similar to the pattern for men in Study 1; high T men in Study 1 also rose in cortisol after defeat and dropped in cortisol after victory. And low T men in Study 1, regardless of whether they had won or lost, also exhibited only slight changes in cortisol. As was the case in Study 1, cortisol changes in the present study may reflect a number of underlying psychological states, such as distress and relaxation, an individual's mobilization to change her state of affairs, or engagement–disengagement.

This study also extended the interactive effect of basal T and status to behavior. High T winners chose to repeat the competitive task a second time against the same opponent, whereas high T losers chose to avoid it. These effects were observed on both the forced choice measure and on the strength of task preference measure. Presumably, high T women who won in the competition chose to repeat the competitive task because it led to high status, whereas high T women who lost in the competition chose to avoid the competitive task because it led to low status. Low T winners and low T losers did not prefer one task over the other; that is, both groups chose to repeat or avoid the competition at about equal rates. Together, the cortisol change and behavioral findings suggest that basal T taps into a woman's status preference; it seems that high T women are motivated to gain high status, whereas low T women are not.

General Discussion

Results from two studies, a naturalistic competition and an experimental laboratory competition, provide converging evidence that basal T moderates the effects of victory and defeat on subsequent cortisol changes and behavior. High T men in Study 1 and high T women in Study 2 rose in cortisol following social defeat and dropped in cortisol following victory. Study 2 further showed that high T women chose to repeat the competitive task following victory, but chose to avoid the competitive task following defeat. Low T women did not differ in their task preferences depending on whether they had won or lost the competition. These results are consistent with past research demonstrating the differential effects of high and low status on high and low T individuals (Josephs et al., 2003, 2006; Newman et al., 2005). It seems that basal T taps into the motivation to gain high status, which in turn, predicts physiological and behavioral responses to social victory and defeat.

Although T failed to predict cortisol changes following competition for women in Study 1, the predictive validity of women's basal T levels on cortisol changes was demonstrated in Study 2. One possible explanation for the discrepant results in women may lie in the different opportunities for socialization across the two studies. Women had the opportunity to engage in social interactions after the dog agility competition (Study 1), and according to the tend-and-befriend theory (Taylor et al., 2000), the quality and frequency of socialization may have had a strong influence on women's cortisol changes in this setting. The potential variability in affiliation after the competition may have had a more potent influence on cortisol changes than did T in this study. In contrast, women were left alone after the one-on-one cognitive competition (Study 2), and thus, social interactions could not have affected women's cortisol changes in this situation. If this explanation is correct, it suggests that women's basal T levels may best predict their cortisol responses to changes in status when there are minimal opportunities for affiliation, as was true in Study 2. Of course, there are other possible explanations that could account for the different results in women across the two studies (e.g., the conflation of basal and anticipatory T in Study 1 but not in Study 2). Clearly, more studies are needed in both sexes to further test the predictive validity of basal T on cortisol changes in a variety of status-relevant situations.

The findings for men in Study 1 and for women in Study 2 provide the first empirical evidence that cortisol changes after victory and defeat depend on basal T levels. This insight may help explain some of the inconsistent findings in the literature on competition and cortisol changes. Although some studies have found that individuals rise in cortisol after defeat (e.g., Bateup et al., 2002), many other studies failed to find such differences (e.g., Booth et al., 1989; Gladue et al., 1989; McCaul et al., 1992; Salvador, 2005). In the future, we suggest strongly that research on hormones and competition take into account the role that basal T and other individual differences variables (e.g., implicit power motive, Wirth et al., 2006) may play in explaining cortisol fluctuations.

Study 2 showed that high T winners chose to reapproach the competitive task after victory, but chose to avoid it after defeat. These findings are consistent with Schultheiss et al.'s (2005) studies in which high power individuals exhibited enhanced learning after victory and impaired learning after defeat. Of course, learning and choice are very different outcomes and are likely to have different motivational and biological correlates. Still, the conceptual overlap of Schultheiss et al.'s (2005) results with ours is interesting and suggests that a learning mechanism may underlie the effects of high and low status on the behaviors of high T individuals. Although speculative, it is possible that high T individuals in Study 2 may have learned to repeat the competitive task because it led to the high status they desired. Conversely, high T individuals may have learned to avoid the competitive task because it led to low status. If this explanation turns out to be correct, it suggests that high T individuals but not low T individuals may self-select into domains in which they can gain high status and actively avoid those domains in which they cannot.

There are some important limitations to our research that should be noted. One limitation is that T levels were not experimentally manipulated, and therefore, we cannot conclude that T was the direct cause of postcompetition cortisol fluctuations and behavior. Instead, we measured naturally occurring T prior to competing—which is thought to reflect an individual's motivation to gain status—and used this variable to predict endocrinological and behavioral reactions to victory and defeat. However, we cannot rule out the possibility that other individual difference variables that are conceptually related to basal T (e.g., implicit power motive, self-reported dominance) might have also predicted the same outcomes we examined. Future research should extend our results and compare these various markers of personality to determine whether they overlap or diverge in their prediction of psychologically meaningful outcomes.

A second limitation is that our control over extraneous variables was imperfect. For example, baseline cortisol samples in both studies were collected around lunchtime and, thus, may have been affected by recent food intake or the cortisol rise that occurs around usual mealtimes even when people are fasting. Further, our measure of physical exertion in Study 1, the time to complete the dog agility course, was also imperfect. More accurate measures of physical exertion (e.g., accelerometers) would have improved our ability to distinguish physical and psychological effects of competition on cortisol changes. Study 1 did not assess social interactions between competitors, a variable that may have influenced cortisol changes. Finally, although our analyses indicated that medication use did not influence the overall results of Study 1, medication use information was not available in Study 2; these data may have impacted the results of this second study.

Our findings demonstrate that T prior to competing predicted cortisol changes and behavior after victory and defeat. But other research suggests that short-term changes in T following a competition are also important predictors of subsequent social behavior (Mehta & Josephs, 2006; Trainor, Bird, & Marler, 2004). There has been much debate in the literature as to whether basal levels of T directly influence social behavior or whether temporary rises or falls in T are the primary influence on social behavior (see commentaries following Mazur & Booth, 1998). Although this debate is far from resolved, we conclude on the basis of the research to date that basal T and transient T changes are both likely to influence behavior, but in different ways. Basal T may tap into a person's stable status preference, analogous to a personality trait (Sellers et al., 2007), whereas short-term fluctuations in T may tap into temporary changes in the motivation to gain high status (e.g., Mehta & Josephs, 2006), analogous to mood. That is, we suspect that basal T and changes in T may be separate constructs altogether. In future research, the efficacy of both basal T and transient fluctuations in T as predictors of social behaviors should continue to be explored.

In recent years, there has been a renewed interest in research on the biological bases of personality and individual differences (Canli, 2006; Mehta & Gosling, 2006), but our approach—using a hormone as a psychologically relevant individual difference variable—is still rare. Instead, the field of personality psychology is dominated by studies of self-reported personality traits. Hormones are certainly more difficult to measure than asking people what they are like. But the findings from an emerging body of literature, the present research included, indicate that hormones can provide valuable insights into personality. The studies reported here along with others suggest that basal T is associated with dominance (Jones & Josephs, 2006; Josephs et al., 2003, 2006; Mazur & Booth, 1998; Mehta & Josephs, 2006; Newman et al., 2005;

Sellers et al., 2007). Additional research suggests that cortisol and progesterone levels may be associated with other aspects of personality (e.g., cortisol and neuroticism, Portella, Harmer, Flint, Cowen, & Goodwin, 2005; progesterone and affiliation, Schultheiss, Wirth, & Stanton, 2004), although the findings from these literatures are somewhat mixed (e.g., Roy, 1996). If future research continues to incorporate hormones and other biological measures (e.g., gene polymorphisms, Serretti, Calati, Ferrari, & De Ronchi, 2007; neural activity, Canli, 2006) in the study of personality, then personality psychology will, one hopes, become a richer science, a science that extends beyond traditional personality measures and that brings a greater understanding of the biological processes that regulate personality and social behavior.

References

Alevizaki, M., Saltiki, K., Mantzou, E., Anastasiou, E., & Huhtaniemi, I. (2006). The adrenal gland may be a target of LH action in postmenopausal women. *European Journal of Endocrinology, 154,* 875–881.

Anderson, C., John, O., Keltner, D., & Kring, A. (2001). Who attains social status? Effects of personality and physical attractiveness in social groups. *Journal of Personality and Social Psychology, 81,* 116–132.

Anestis, S. F. (2006). Testosterone in juvenile and adolescent male chimpanzees (*Pan troglodytes*): Effects of dominance rank, aggression, and behavioral style. *American Journal of Physical Anthropology, 130,* 536–545.

Archer, J. (2006). Testosterone and human aggression: An evaluation of the challenge hypothesis. *Neuroscience and Biobehavioral Reviews, 30,* 319–345.

Archer, J., Birring, S. S., & Wu, F. C. W. (1998). The association between testosterone and aggression in young men: Empirical findings and a meta-analysis. *Aggressive Behavior, 24,* 411–420.

Barton, R. A., & Whiten, A. (1993). Feeding competition among female olive baboons, I. *Papio anubis*. *Animal Behaviour, 46,* 777–789.

Bateup, H. S., Booth, A., Shirtcliff, E. A., & Granger, D. A. (2002). Testosterone, cortisol, and women's competition. *Evolution and Human Behavior, 23,* 181–192.

Beehner, J., Bergman, T., Cheney, D., Seyfarth, R., & Whitten, P. (2006). Testosterone predicts future dominance rank and mating activity among male chacma baboons. *Behavioral Ecology and Sociobiology, 59,* 469–479.

Booth, A., Shelley, G., Mazur, A., Tharp, G., & Kittok, R. (1989). Testosterone and winning and losing in human competition. *Hormones and Behavior, 23,* 556–571.

Buss, D. M. (2003). *Evolutionary psychology: The new science of the mind.* New York: Pearson, Allyn, & Bacon.

Canli, T. (2006). *Biology of personality and individual differences.* New York: Guilford Press.

Cashdan, E. (1995). Hormones, sex, and status in women. *Hormones and Behavior, 29,* 354–366.

Cavigelli, S. A., & Pereira, M. E. (2000). Mating season aggression and fecal testosterone levels in male ring-tailed lemurs (*Lemur catta*). *Hormones and Behavior, 37,* 246–255.

Coe, C. L., Mendoza, S. P., & Levine, S. (1979). Social status constrains the stress response in the squirrel monkey. *Physiology and Behavior, 23,* 633–638.

Collias, N. E., Barfield, R. J., & Tarvyd, E. S. (2002). Testosterone versus psychological castration in the expression of dominance, territoriality, and breeding behavior by male village weavers (*Ploceus cucullatus*). *Behavioural Brain Research, 139,* 801–824.

Crabbe, P., Bogaert, V., De Bacquer, D., Goemaere, S., Zmierczak, H., & Kaufman, J. M. (2007). Part of the interindividual variation in serum testosterone levels in healthy men reflects differences in androgen sensitivity and feedback set point: Contribution of the androgen receptor polyglutamine tract polymorphism. *The Journal of Clinical Endocrinology and Metabolism, 92,* 3604–3610.

Dabbs, Jr., J. M., (1990). Salivary testosterone measurements: Reliability across hours, days, and weeks. *Physiology and Behavior, 48,* 83–86.

Dabbs, J., & Hargrove, M. (1997). Age, testosterone, and behavior among female prison inmates. *Psychosomatic Medicine, 59,* 477–480.

Dabbs, J., Ruback, R., Frady, R., & Hopper, C. (1988). Saliva testosterone and criminal violence among women. *Personality and Individual Differences, 9,* 269–275.

Davis, S. N., Shavers, C., Costa, F., & Mosqueda-Garcia, R. (1996). Role of cortisol in the pathogenesis of deficient counterregulation after antecedent hypoglycemia in normal humans. *Journal of Clinical Investigation, 98,* 680–691.

De Waal, F. B. (1998). *Chimpanzee politics: Power and sex among apes.* Baltimore: Johns Hopkins University Press.

Dickerson, S. S., & Kemeny, M. E. (2004). Acute stressors and cortisol responses: A theoretical integration and synthesis of laboratory research. *Psychological Bulletin, 130,* 355–391.

Edwards, D., Wetzel, K., & Wyner, D. (2006). Intercollegiate soccer: Saliva cortisol and testosterone are elevated during competition, and testosterone is related to status and social connectedness with teammates. *Physiology and Behavior, 87,* 135–143.

Elias, M. (1981). Serum cortisol, testosterone, and testosterone-binding globulin responses to competitive fighting in human males. *Aggressive Behavior, 7,* 215–224.

Furuichi, T. (1983). Interindividual distance and influence of dominance on feeding in a natural Japanese macaque troop. *Primates, 24,* 445–455.

Gladue, B. A., Boechler, M., & McCaul, K. D. (1989). Hormonal response to competition in human males. *Aggressive Behavior, 15,* 409–422.

Goymann, W., & Wingfield, J. C. (2004). Allostatic load, social status, and stress hormones: The costs of social status matter. *Animal Behaviour, 67,* 591–602.

Granger, D. A., Shirtcliff, E. A., Booth, A., Kivlighan, K. T., & Schwartz, E. B. (2004). The "trouble" with salivary testosterone. *Psychoneuroendocrinology, 29,* 1229–1240.

Grant, V. J., & France, J. T. (2001). Dominance and testosterone in women. *Biological Psychology, 58,* 41–47.

Gray, A., Jackson, D., & McKinlay, J. (1991). The relation between dominance, anger, and hormones in normally aging men: Results from the Massachusetts Male Aging Study. *Psychosomatic Medicine, 53,* 375–385.

Harris, J. A., Vernon, P. A., & Boomsma, D. I. (1998). The heritability of testosterone: A study of Dutch adolescent twins and their parents. *Behavior Genetics, 28,* 165–171.

Jones, A. C., & Josephs, R. A. (2006). Interspecies hormonal interactions between man and the domestic dog (*Canis familiaris*). *Hormones and Behavior, 50,* 393–400.

Josephs, R. A., Newman, M. L., Brown, R. P., & Beer, J. M. (2003). Status, testosterone, and human intellectual performance: Stereotype threat as status concern. *Psychological Science, 14,* 158–163.

Josephs, R. A., Sellers, J. G., Newman, M. L., & Mehta, P. H. (2006). The mismatch effect: When testosterone and status are at odds. *Journal of Personality and Social Psychology, 90,* 999–1013.

Kajantie, E., & Phillips, D. I. (2006). The effects of sex and hormonal status on the physiological response to acute psychosocial stress. *Psychoneuroendocrinology, 31,* 151–178.

Keeney, A., Jessop, D. S., Harbuz, M. S., Marsden, C. A., Hogg, S., & Blackburn-Munro, R. E. (2006). Differential effects of acute and chronic social defeat stress on hypothalamic–pituitary–adrenal axis function and hippocampal serotonin release in mice. *Journal of Neuroendocrinology, 18,* 330–338.

Kirschbaum, C., Pirke, K.-M., & Hellhammer, D. H. (1993). The "Trier

Social Stress Test"—A tool for investigating psychobiological stress responses in a laboratory setting. *Neuropsychobiology, 28,* 76–81.

Kivlighan, K. T., Granger, D. A., & Booth, A. (2005). Gender differences in testosterone and cortisol response to competition. *Psychoneuroendocrinology, 30,* 58–71.

Kramer, M., Hiemke, C., & Fuchs, E. (1999). Chronic psychosocial stress and antidepressant treatment in tree shrews: Time-dependent behavioral and endocrine effects. *Neuroscience and Biobehavioral Reviews, 23,* 937–947.

Kraus, C., Heistermann, M., & Kappeler, P. M. (1999). Physiological suppression of sexual function of subordinate males: A subtle form of intrasexual competition among male sifakas (*Propithecus verreauxi*)? *Physiology and Behavior, 66,* 855–861.

Marmot, M. G., Shipley, M. J., & Rose, G. (1984). Inequalities in death–specific explanations of a general pattern? *Lancet, 1,* 1003–1006.

Mason, J., Wang, S., Yehuda, R., Riney, S., Charney, D., & Southwick, S. (2001). Psychogenic lowering of urinary cortisol levels linked to increased emotional numbing and a shame-depressive syndrome in combat-related posttraumatic stress disorder. *Psychosomatic Medicine, 63,* 387–401.

Mastorakos, G., Pavlatou, M., Diamanti-Kandarakis, E., & Chrousos, G. P. (2005). Exercise and the stress system. *Hormones (Athens), 4,* 73–89.

Mazur, A., & Booth, A. (1998). Testosterone and dominance in men. *Behavioral and Brain Sciences, 21,* 353–397.

Mazur, A., Booth, A., & Dabbs, J. M. (1992). Testosterone and chess competition. *Social Psychology Quarterly, 55,* 70–77.

Mazur, A., & Lamb, T. A. (1980). Testosterone, status, and mood in human males. *Hormones and Behavior, 14,* 236–246.

Mazur, A., Susman, E., & Edelbrock, S. (1997). Sex difference in testosterone response to a video game contest. *Evolution and Human Behavior, 18,* 317–326.

McCaul, K. D., Gladue, B. A., & Joppa, M. (1992). Winning, losing, mood, and testosterone. *Hormones and Behavior, 26,* 486–504.

McClelland, D. C. (1975). *Power: The inner experience.* New York: Irvington Publishers.

McIntyre, M., Gangestad, S., Gray, P., Chapman, J., Burnham, T., O'Rourke, M., et al. (2006). Romantic involvement often reduces men's testosterone levels—but not always: The moderating role of extrapair sexual interest. *Journal of Personality and Social Psychology, 91,* 642–651.

Mehta, P. H., & Gosling, S. D. (2006). How can animal studies contribute to research on the biological bases of personality? In T. Canli (Ed.), *The biological bases of personality and individual differences* (pp. 427–448). New York: Guilford Press.

Mehta, P. H., & Josephs, R. A. (2006). Testosterone change after losing predicts the decision to compete again. *Hormones and Behavior, 50,* 684–692.

Mehta, P. H., Wuehrmann, E., & Josephs, R. A. (2007). *Does competition or cooperation lead to better performance? The moderating role of testosterone.* Manuscript submitted for publication.

Muller, M. N., & Wrangham, R. W. (2004). Dominance, cortisol, and stress in wild chimpanzees (*Pan troglodytes schweinfurthii*). *Behavioral Ecology and Sociobiology, 55,* 332–340.

Nes, L., Segerstrom, S., & Sephton, S. (2005). Engagement and arousal: Optimism's effects during a brief stressor. *Personality and Social Psychology Bulletin, 31,* 111–120.

Newman, M. L., Sellers, J. G., & Josephs, R. A. (2005). Testosterone, cognition, and social status. *Hormones and Behavior, 47,* 205–211.

Noser, R., Gygax, L., & Tobler, I. (2003). Sleep and social status in captive gelada baboons *(Theropithecus gelada*). *Behavioural Brain Research,* 147: 9–15.

Oliveira, R. F., Almada, V. C., & Canario, A. V. (1996). Social modulation of sex steroid concentrations in the urine of male cichlid fish *Oreochromis mossambicus*. *Hormones and Behavior, 30,* 2–12.

Orr, T. E., & Mann, D. R. (1992). Role of glucocorticoids in the stress-induced suppression of testicular steroidogenesis in adult male rats. *Hormones and Behavior, 26,* 350–363.

Overli, O., Harris, C. A., & Winberg, S. (1999). Short-term effects of fights for social dominance and the establishment of dominant–subordinate relationships on brain monoamines and cortisol in rainbow trout. *Brain, Behavior, and Evolution, 54,* 263–275.

Passelergue, P., & Lac, G. (1999). Saliva cortisol, testosterone, and T/C ratio variations during a wrestling competition and during the post-competitive recovery period. *International Journal of Sports Medicine, 20,* 109–113.

Popma, A., Vermeiren, R., Geluk, C. A. M. L., Rinne, T., van den Brink, W., Knol, D. L., et al. (2007). Cortisol moderates the relationship between testosterone and aggression in delinquent male adolescents. *Biological Psychiatry, 61,* 405–411.

Portella, M. J., Harmer, C. J., Flint, J., Cowen, P., & Goodwin, G. M. (2005). Enhanced early morning salivary cortisol in neuroticism, *American Journal of Psychiatry, 162,* 807–809.

Riad-Fahmy, D., Read, G. F., Walker, R. F., Walker, S. M., & Griffiths, K., 1987. Determination of ovarian steroid hormone levels in saliva. An overview. *Journal of Reproductive Medicine, 32,* 254–272.

Roy, A. (1996). HPA axis function and temperament in depression: A negative report. *Biological Psychiatry, 39,* 364–366.

Ruiz-de-la-Torre, J. L., & Manteca, X. (1999). Effects of testosterone on aggressive behaviour after social mixing in male lambs. *Physiology and Behavior, 68,* 109–113.

Salvador, A. (2005). Coping with competitive situations in humans. *Neuroscience and Biobehavioral Reviews, 29,* 195–205.

Salvador, A., Suay, F., González-Bono, E., & Serrano, M. (2003). Anticipatory cortisol, testosterone, and psychological responses to judo competition in young men. *Psychoneuroendocrinology, 28,* 364–375.

Sapolsky, R. M. (1983). Individual differences in cortisol secretory patterns in the wild baboon: Role of negative feedback sensitivity. *Endocrinology, 113,* 2263–2267.

Sapolsky, R. M. (1985). Stress-induced suppression of testicular function in the wild baboon: Role of glucocorticoids. *Endocrinology, 116,* 2273–2278.

Sapolsky, R. M. (1991). Testicular function, social rank, and personality among wild baboons. *Psychoneuroendocrinology, 16,* 281–293.

Sapolsky, R. M. (1998). *Why zebras don't get ulcers.* New York: Freeman.

Schieman, S., Whitestone, Y. K., & Van Gundy, K. (2006). The nature of work and the stress of higher status. *Journal of Health and Social Behavior, 47,* 242–257.

Schilling, C., Gallicchio, L., Miller, S., Langenberg, P., Zacur, H., & Flaws, J. (2007). Genetic polymorphisms, hormone levels, and hot flashes in midlife women. *Maturitas, 57,* 120–131.

Schultheiss, O. C., Campbell, K. L., & McClelland, D. C. (1999). Implicit power motivation moderates men's testosterone responses to imagined and real dominance success. *Hormones and Behavior, 36,* 234–241.

Schultheiss, O., Wirth, M., & Stanton, S. (2004). Effects of affiliation and power motivation arousal on salivary progesterone and testosterone. *Hormones and Behavior, 46,* 592–599.

Schultheiss, O. C., Wirth, M. M., Torges, C. M., Pang, J. S., Villacorta, M. A., & Welsh, K. M. (2005). Effects of implicit power motivation on men's and women's implicit learning and testosterone changes after social victory or defeat. *Journal of Personality and Social Psychology, 88,* 174–188.

Segerstrom, S., & Miller, G. (2004). Psychological stress and the human immune system: A meta-analytic study of 30 years of inquiry. *Psychological Bulletin, 130,* 601–630.

Sellers, J. G., Mehl, M. R., & Josephs, R. A. (2007). Hormones and personality: Testosterone as a marker of individual differences. *Journal of Research in Personality, 41,* 126–138.

Serretti, A., Calati, R., Ferrari, B., & De Ronchi, D. (2007). Personality and genetics. *Current Psychiatry Reviews, 3,* 147–159.

Shirtcliff, E. A., Granger, D. A., & Likos, A. (2002). Gender differences in the validity of testosterone measured in saliva by immunoassay. *Hormones and Behavior, 42,* 62–69.

Suay, F., Salvador, A., González-Bono, E., Sanchís, C., Martínez, M., Martinéz-Sanchis, S., et al. (1999). Effects of competition and its outcome on serum testosterone, cortisol and prolactin. *Psychoneuroendocrinology, 24,* 551–566.

Taylor, S. E., Klein, L. C., Lewis, B. P., Gruenewald, T. L., Gurung, R. A. R., & Updegraff, J. A. A. (2000). Biobehavioral responses to stress in females: Tend-and-befriend, not fight-or-flight. *Psychological Review, 107,* 411–429.

Teixeira, J., Martin, D., Prendiville, O., & Glover, V. (2005). The effects of acute relaxation on indices of anxiety during pregnancy. *Journal of Psychosomatic Obstetrics & Gynecology, 26,* 271–276.

Tops, M., Boksem, M., Wester, A., Lorist, M., & Meijman, T. (2006). Task engagement and the relationships between the error-related negativity, agreeableness, behavioral shame proneness, and cortisol. *Psychoneuroendocrinology, 31,* 847–858.

Touitou, Y., & Haus, E. (2000). Alterations with aging of the endocrine and neuroendocrine circadian system in humans. *Chronobiology International, 17,* 369–390.

Trainor, B. C., Bird, I. M., & Marler, C. A. (2004). Opposing hormonal mechanisms of aggression revealed through short-lived testosterone manipulations and multiple winning experiences. *Hormones and Behavior, 45,* 115–121.

Tremblay, R. E., Schaal, B., Boulerice, B., Arseneault, L., Soussignan, R. G., Paquette, D., et al. (1998). Testosterone, physical aggression, dominance, and physical development in early adolescence. *International Journal of Behavioral Development, 22,* 753–777.

van Anders, S., & Watson, N. (2007a). Effects of ability- and chance-determined competition outcome on testosterone. *Physiology and Behavior, 90,* 634–642.

van Anders, S., & Watson, N. (2007b). Testosterone levels in women and men who are single, in long-distance relationships, or in same-city relationships. *Hormones and Behavior, 51,* 286–291.

van Honk, J., Peper, J., & Schutter, D. (2005). Testosterone reduces unconscious fear but not consciously experienced anxiety: Implications for the disorders of fear and anxiety. *Biological Psychiatry, 58,* 218–225.

van Honk, J., Tuiten, A., Verbaten, R., van den Hout, M., Koppeschaar, H., Thijssen, J., et al. (1999). Correlations among salivary testosterone, mood, and selective attention to threat in humans. *Hormones and Behavior, 36,* 17–24.

van Noordwijk, M. A., & van Schaik, C. P. (1999). The effects of dominance rank and group size on female lifetime reproductive success in wild long-tailed macaques, *Macaca fascicularis*. *Primates, 40,* 105–130.

Viau, V. (2002). Functional cross-talk between the hypothalamic–pituitary–gonadal and –adrenal axes. *Journal of Neuroendocrinology, 14,* 506–513.

Viau, V., & Meaney, M. J. (1996). The inhibitory effect of testosterone on hypothalamic–pituitary–adrenal responses to stress is mediated by the medial preoptic area. *Journal of Neuroscience, 16,* 1866–1876.

Vicennati, V., Ceroni, L., Genghini, S., Patton, L., Pagotto, U., & Pasquali, R. (2006). Sex difference in the relationship between the hypothalamic–pituitary–adrenal axis and sex hormones in obesity. *Obesity, 14,* 235–243.

Virgin, C., & Sapolsky, R. (1997). Styles of male social behavior and their endocrine correlates among low-ranking baboons. *American Journal of Primatology, 42,* 25–39.

Wingfield, J. C., Hegner, R. E., Dufty Jr., A. M., & Ball, G. F. (1990). The "challenge hypothesis": Theoretical implications for patterns of testosterone secretion, mating systems, and breeding strategies. *American Naturalist, 136,* 829–846.

Wirth, M. M., & Schultheiss, O. C. (2007). Basal testosterone moderates responses to anger faces in humans. *Physiology and Behavior, 90,* 496–505.

Wirth, M. M., Welsh, K. M., & Schultheiss, O. C. (2006). Salivary cortisol changes in humans after winning or losing a dominance contest depend on implicit power motivation. *Hormones and Behavior, 49,* 346–352.

Received November 3, 2006
Revision received January 9, 2008
Accepted January 15, 2008 ■