Available online at www.sciencedirect.com
ScienceDirect
Hormones and Behavior 50 (2006) 684–692
Hormones and Behavior
www.elsevier.com/locate/yhbeh

Testosterone change after losing predicts the decision to compete again

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Received 14 March 2006; revised 30 June 2006; accepted 7 July 2006
Available online 22 August 2006

Abstract

Testosterone (T) levels can fluctuate after wins and losses, but surprisingly, there are no empirical studies in humans that have tested whether these post-competition T changes predict the social behaviors that follow. The present study examined whether changes in T after losing in a competition predicted who wanted to compete again in a second competition. Sixty-four males provided saliva samples immediately before and 15 min after a rigged one-on-one competition. After the second saliva sample, participants chose whether or not to compete again against the same competitor. Winners did not increase in T relative to losers, but pre-competition cortisol, change in cortisol, and pre-competition T were associated with T changes, especially in losers. Importantly, changes in T predicted decisions to compete again in losers. Losers who increased in T were more likely to choose to compete again than losers who decreased in T. T changes were unrelated to decisions to compete again in winners. These findings provide novel data in humans that T changes after a status loss predict subsequent social behavior. Our discussion focuses on the theoretical implications of these findings for the link between short-term T changes and status-related behaviors.

Keywords: Testosterone; Cortisol; Status; Competition; Humans; Decisions; Affect; Social behavior

A large body of literature indicates that higher levels of testosterone (T) are associated with higher status. Across a number of animal species, T is positively related to social rank and dominant behaviors, especially when the status hierarchy is unstable (Beaver and Amoss, 1982; Cavigelli and Pereira, 2000; Coe et al., 1979; Collias et al., 2002; Elofsson et al., 2000; Kraus et al., 1999; Oliveira et al., 1996; Wingfield et al., 1990). And in humans, T is associated with constructs closely linked to status, such as aggression, social dominance, implicit power motive, and attention to status threats (Archer, 2006; Archer et al., 1998; Cashdan, 1995; Grant and France, 2001; Josephs et al., 2006; Mazur and Booth, 1998; Sellers et al., in press; Schultheiss et al., 2005; Van Honk et al., 1999).

Because the literature linking T to social behaviors is largely correlational, investigators have been skeptical of a causal effect of T on status-related behaviors. Instead, some researchers have proposed a reciprocal relationship between T and status (Mazur, 1985; Mazur and Booth, 1998; see research on the *challenge hypothesis* for a similar theory, Wingfield et al., 1990). According to this reciprocal model, T levels should rise after wins and fall after losses in status battles, and these changes in T levels should, in turn, produce a reciprocal effect by influencing subsequent status-seeking behaviors. Specifically, there has been speculation that T increases may encourage further attempts at gaining status, while T decreases may lead individuals to flee the situation in order to avoid any further loss of status.

Empirical support for this reciprocal model comes from research in real-world sports competitions and rigged laboratory competitions. Several studies have shown that winners increase in T relative to losers for a few hours following a competition (Elias, 1981; Gladue et al., 1989; Mazur et al., 1992; Mazur and Lamb, 1980; McCaul et al., 1992). However, other studies have *not* found this overall win–lose effect (Gonzalez-Bono et al., 1999; Mazur et al., 1997; Schultheiss et al., 2005) but instead have shown that T changes after competing depend on a number of psychological factors. Overall, the evidence suggests that winners may rise in T relative to losers on average, but some winners actually decrease and some losers actually increase in T after competing (Archer, 2006).

Although this literature has uncovered several important variables that predict T changes after wins and losses, to date researchers have simply assumed that these competition-

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doi:10.1016/j.yhbeh.2006.07.001

induced fluctuations in T produce meaningful changes in social behaviors after the competition. Surprisingly, there are *no* empirical studies in humans that have tested reciprocity, that is, whether T changes after wins and losses influence the social behaviors that follow. As such, it remains to be seen whether the predictions of the reciprocal model linking T changes to subsequent social behaviors bear out. The present study was designed to fill this large gap in the literature by examining the relationship between post-competition T changes and subsequent decisions to compete again.

A second goal of our study was to extend previous research on the factors that influence post-competition T changes. We examined two factors in particular: the stress hormone cortisol and affect. Cortisol has been shown to suppress the secretion of T in animal studies (Sapolsky, 1985), and thus, we tested whether high cortisol levels would be associated with post-competition T drops. And because studies of affect and post-competition T changes have yielded inconsistent results (e.g., Booth et al., 1989; Schultheiss et al., 2005), we further examined whether affect predicted post-competition changes in T.

In addition to influencing post-competition T changes, cortisol and affect may influence decisions to compete again. Cortisol is associated with behavioral inhibition tendencies (Kagan et al., 1988; Kalin et al., 1998), and affect is associated with approach-avoidance motivation (Carver et al., 2000). So it is possible that high cortisol levels or high negative affect might predict avoiding a second competition, and low cortisol levels or high positive affect might predict choosing to compete again. The present study tested these possibilities as well.

Our study design was simple. We first measured initial T and cortisol levels, and then we rigged a dyadic competition to randomly assign individuals to win or lose. After the competition ended, we measured T, cortisol, and affect. Finally, we asked participants whether or not they wanted to compete again against the same competitor. Our primary goal was to test whether changes in T after losing in the competition would predict one's decision to compete again or avoid a second competition. Based on the literature linking T to status-seeking behaviors and based on the predictions of the reciprocal model, we hypothesized that losers who increased in T would be driven to gain social status and as a result, would choose to compete again against the first-time winner as an attempt to reclaim their lost status. Conversely, we hypothesized that losers who decreased in T would flee from a second competition in order to avoid any further loss of status.

We also measured T changes and decisions to compete again in winners, but it was unclear what our predictions for winners should be. On the one hand, theorists have hypothesized that increases in T should increase one's confidence and drive to challenge others (Archer, 2006; Mazur and Booth, 1998; Wingfield et al., 1990), suggesting that individuals who increase in T after a win should choose to compete again. On the other hand, some investigators have suggested that T predicts behaviors intended to gain or *maintain* high status (Mazur and Booth, 1998). If this is the case, then winners who increase in T may not want to compete again against someone they just beat because doing so exposes these winners to the possibility of losing status were they to lose the second competition. Thus, it is possible that winners who increase in T may choose to avoid a second competition as a strategy to *maintain* their higher social status. Because of these competing hypotheses, we made no specific predictions about the relationship between T changes and decisions to compete again in winners.

Our study also explored whether cortisol and affect predicted post-competition T changes and decisions to compete again. Because previous research on the relationships among these variables is either lacking or has yielded inconsistent findings, we made no specific predictions regarding these relationships.

Methods

Participants

Sixty-four males (61% Caucasian; 18% Asian; 18% Hispanic/Latino) 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. Five of the participants provided inadequate saliva samples that could not be assayed for hormone concentrations. Another two 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 (coefficient of variation greater than 15%). Data for these seven participants were removed from the data set, leaving 57 participants with complete data.

Procedure

Participants reported to the lab in pairs between 12:00 P.M. and 5:00 P.M. to minimize the effects of circadian fluctuations in T and cortisol levels (Touitou and Haus, 2000). The experiment consisted of a pre-competition, competition, and post-competition phase.

Pre-competition phase

The experimenter led each participant to a separate room, obtained informed consent, and collected the first saliva sample. The samples were immediately brought to a nearby freezer for storage and were later analyzed for T and cortisol concentrations using enzyme immunoassay. For details of the saliva collection procedure, see Granger et al. (1999).

Competition

Following the saliva collection, both participants were brought 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 et al., 1999). We chose this task because it has been used successfully in past studies on T and competition. That is, past research suggests that participants care about their performance on this task and that personality constructs such as implicit power motive and need for status influence cognitive, hormonal, and affective responses to winning and losing in a Number Tracking Task competition (Josephs et al., 2006; Schultheiss et al., 1999). In addition, the task is powerful because it allows researchers to experimentally manipulate the outcome of the competition.

The Number Tracking Task consists of a series of 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 seven and a half minutes.

Post-competition phase

Participants were escorted to separate rooms after the competition and completed the Positive and Negative Affectivity Schedule (PANAS) (Watson et al., 1988). The PANAS asks participants to indicate the extent to which they are feeling each of 20 mood descriptors on a scale of one ("very slightly or not at all") to five ("very much"). Two independent dimensions of affect emerge: positive affect and negative affect. The positive affect dimension consists of items such as "alert", "determined", and "inspired", and the negative affect dimension consists of items such as "distressed", "upset", and "irritable". Scores on these two dimensions may range from one to five.

After completing the PANAS, participants were asked to work on a filler task (a word search). Fifteen minutes after the competition had ended (approximately 30 to 35 min after the first saliva sample), the experimenter collected the word search, and participants provided a second saliva sample. We chose to wait 15 min after the end of the competition to collect the second saliva sample because it takes a few minutes for hormone levels in blood to reach saliva (cf. Riad-Fahmy et al., 1987), and because previous research has found that competition outcome influences salivary T changes 15 min after competition, but not immediately after or 30 min after competition (Schultheiss et al., 2005). Following the second saliva sample, participants completed 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). After completing the choice questionnaire, participants 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 h to complete.

Hormone assays

The saliva samples were analyzed for T and cortisol concentrations using enzyme immunoassay kits purchased from Salimetrics (State College, PA, USA). The T plates were coated with antibodies to T, and the cortisol plates were coated with antibodies to cortisol. Samples were assayed in duplicate. For further details of the enzyme immunoassay technique, see Granger et al. (1999). Intra-assay coefficient of variation (CV) averaged across all 57 participants was 4.7% for T and 3.1% for cortisol. Inter-assay CVs for assays conducted in our lab average 8.7% for T and 2.8% for cortisol. Assay performance characteristics for both T and cortisol kits have been previously shown to be very good. For T kits, average recovery across saliva samples spiked with known concentrations of T was 105.0%, inter-assay precision was 5.1% for high T and 9.6% for low T samples, and sensitivity of the T kit was 1.5 pg/mL (Salimetrics, 2005b). For cortisol kits, average recovery across saliva samples with known cortisol concentrations was 100.8%, inter-assay precision was 3.8% for low cortisol and 6.4% for high cortisol samples, and sensitivity of the cortisol kit was 0.003 μg/dL (Salimetrics, 2005a).

Results

Suspicion check

All participants correctly indicated whether they had won or lost in the competition, but seven participants (3 winners, 4 losers) indicated some degree of suspicion with the win/loss manipulation. Thus, we decided to remove these seven suspicious participants from our analyses. All analyses below were conducted on the remaining 50 participants (23 winners, 27 losers). Importantly, retaining suspicious participants does not change the statistical significance in any of the analyses.

Hormone measures and transformations

Descriptive statistics for raw testosterone, cortisol, and affect are reported in Table 1. Consistent with previous research on cortisol (e.g., Wirth et al., 2006), the pre-competition and post-competition cortisol distributions were positively skewed. Therefore, we conducted log transformations on these distributions to make them normal. The change in cortisol distribution (post-competition cortisol minus pre-competition cortisol) was negatively skewed. Therefore, we calculated change in cortisol as log-transformed post-competition cortisol minus log-transformed pre-competition cortisol, which yielded a normal distribution. All statistical analyses with cortisol reported below employ these log-transformed distributions.

The pre- and post-competition T distributions were not skewed and thus did not require transformation. Change in T was calculated as post-competition T minus pre-competition T. All statistical analyses with T reported below employ raw T data.

Initial analyses

We randomly assigned participants to win or lose in the competition, and thus, we did not expect that there would be

Table 1
Descriptive statistics for raw hormone measures and affect

	Winners and Losers (n=50)		Winners (n=23)		Losers (n=27)	
	M	SD	M	SD	M	SD
Pre-competition testosterone (pg/mL)	161.8	72.2	171.0	66.3	154.0	77.3
Post-competition testosterone (pg/mL)	155.1	74.8	163.2	75.9	148.2	74.6
Change in testosterone (pg/mL)[a]	− 6.7	47.4	− 7.8	46.1	− 5.8	51.8
Pre-competition cortisol (μg/dL)[b]	0.32	0.27	0.36	0.30	0.28	0.24
Post-competition cortisol (μg/dL)[c]	0.23	0.14	0.24	0.16	0.22	0.13
Change in cortisol (μg/dL)[d]	− 0.09	0.19	− 0.12	0.20	− 0.06	0.19
Positive affect[e]	2.93	0.80	3.31	0.65	2.60	0.79
Negative affect[f]	1.59	0.54	1.60	0.63	1.58	0.47

[a] Post-competition testosterone minus pre-competition testosterone.
[b] Means and standard deviations were calculated from the untransformed pre-competition cortisol distribution.
[c] Means and standard deviations were calculated from the untransformed post-competition cortisol distribution.
[d] Means and standard deviations were calculated from the untransformed change in cortisol distribution (post-competition cortisol minus pre-competition cortisol).
[e] Positive Affect subscale of PANAS (Watson et al., 1988); scores can range from one to five.
[f] Negative Affect subscale of PANAS (Watson et al., 1988); scores can range from one to five.

differences in pre-competition T or pre-competition cortisol between winners and losers. To verify that this was the case, we conducted an independent samples t-test with win/lose as the predictor and pre-competition T as the dependent variable. This analysis revealed that winners and losers did not differ in their pre-competition T levels, $t(48)=0.83$, $p>0.40$ (see Table 1 for means and standard deviations). A second independent samples t-test showed that winners and losers did not differ in their log-transformed pre-competition cortisol levels, $t(48)=1.10$, $p>0.40$.

We next examined whether winners and losers differed in positive affect, negative affect, or change in cortisol. Consistent with previous research (e.g., Schultheiss et al., 2005), winners had higher levels of positive affect than losers, $t(48)=3.42$, $p<0.001$, $d=0.98$ (see Table 1 for means and standard deviations), suggesting that our manipulation was powerful enough to elicit these large differences in positive affect. Also consistent with prior studies, there were no differences in negative affect, $t(48)=0.12$, $p>0.90$ (e.g., Josephs et al., 2006) or in log-transformed change in cortisol, $t(48)=-0.83$, $p>0.40$ (Gladue et al., 1989; Wirth et al., 2006).

Predictors of change in T

According to the reciprocal model, a win in competition should increase T levels relative to a loss. However, this was not the case. An independent samples t-test with win/lose as the predictor and change in T as the dependent variable indicated that winners did not increase in T relative to losers, $t(48)=-0.14$, $p>0.80$ (see Table 1 for means and standard deviations).

We also assessed whether positive affect, negative affect, pre-competition T, log-transformed pre-competition cortisol, or log-transformed cortisol change predicted change in T. Table 2 shows these correlations for the entire sample as well as for winners and losers separately. As shown, log-transformed pre-competition cortisol and pre-competition T were negatively correlated with change in T, especially in losers. In addition, log-transformed change in cortisol was positively correlated with change in T in losers only. In other words, these analyses revealed that individuals with high pre-competition cortisol or high pre-competition T levels who lost in the competition tended to drop in T. And individuals who rose in cortisol after losing tended to rise in T.

Predictors of decisions to compete again

We next examined the decisions that participants as a whole made and whether winning and losing predicted these decisions. Across the entire sample, approximately 48% of all 50 participants chose to compete again. In addition, winners and losers did not significantly differ in their decisions, $\chi^2(1, N=50)=0.30$, $p>0.50$.

Change in T

To examine the relationship between change in T and decisions to compete again, we created two groups based on the top and bottom thirds of the change in T distribution. The bottom third was composed of T-decreasers (M = −55.1, SD = 35.7, $n=16$, 9 losers, 7 winners) and the top third was composed of T-increasers (M = 40.8, SD = 36.2, $n=17$, 11 losers, 6 winners). The middle third of the distribution was composed of participants who experienced little or no changes in T (M = − 8.6, SD = 6.7, $n=17$, 7 losers, 10 winners). Because we were interested in comparing individuals who increased in T to individuals who decreased in T, this middle group was removed from the following analysis.

Table 2
Predictors of change in testosterone

Predictors	Winners and Losers ($n=50$)	Winners ($n=23$)	Losers ($n=27$)
	r	r	r
1. Positive affect	− 0.08	0.01	− 0.13
2. Negative affect	0.14	0.29	− 0.23
3. Pre-competition testosterone (pg/mL)	− 0.28 *	− 0.12	− 0.39 *
4. Pre-competition cortisol (μg/dL) [a]	− 0.31 *	− 0.03	− 0.54 *
5. Change in cortisol (μg/dL) [b]	0.17	− 0.13	0.41 *

[a] Log-transformed in order to remove skew in the distribution.
[b] Calculated as log-transformed post-competition cortisol minus log-transformed pre-competition cortisol in order to remove skew in the distribution.
* $p<0.05$.

Based on the literature on T and social behavior and based on the predictions of the reciprocal model, we expected that change in T would predict who wanted to compete again and who did not among losers. Specifically, we expected that individuals who lost in the competition and increased in T would choose to compete again as an attempt to regain their lost social status, but individuals who lost in the competition and decreased in T would choose not to compete again (option b—choosing to complete a questionnaire on food, music, and entertainment preferences) in order to avoid any further status loss. To test this possibility, we conducted a 2 (Change in T: T-increasers/ T-decreasers) × 2 (Choice: compete again/do not compete again) chi-square test in losers. This analysis supported our predictions, $\chi^2(1, N=20)=5.05$, $p<0.05$. As shown in Fig. 1, losers who increased in T were more likely to choose to compete again than losers who decreased in T. Eight out of the 11 losers who increased in T chose to compete again, and the remaining three losers who increased in T chose the alternative task (the questionnaire). Conversely, two out of the nine losers who decreased in T chose to compete again, and the remaining seven losers who decreased in T chose the alternative task (the questionnaire).

We had no specific predictions for winners but were still interested in examining the relationship between changes in T and decisions for this group. To do so, we again ran a two-way chi-square test. This analysis revealed that winners who increased in T did not statistically differ in their choices from winners who decreased in T, $\chi^2(1, N=13)=0.74$, $p>0.30$. Four out of six winners who increased in T chose to compete again, and the remaining two winners who increased in T chose the alternative task (the questionnaire). In addition, three out of

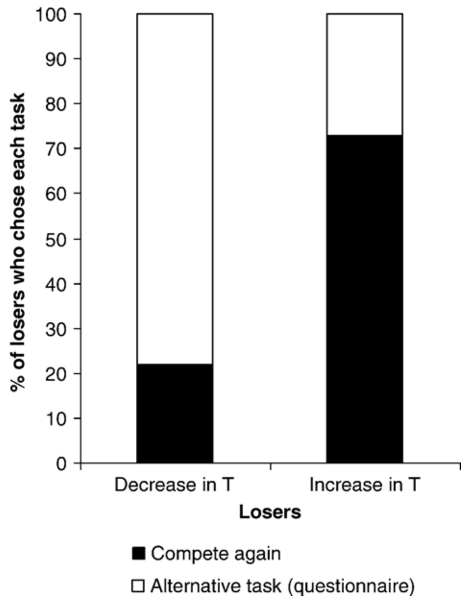

Fig. 1. Percentage of losers who chose to (a) compete again or (b) complete an alternative task (a questionnaire) as a function of change in testosterone. "Decrease in T" = losers in bottom 3rd of change in testosterone distribution, $n=9$. "Increase in T" = losers in top 3rd of change in testosterone distribution, $n=11$.

seven participants who decreased in T chose to compete again, and the remaining four winners who decreased in T chose to complete the alternative task (the questionnaire).

Pre-competition T

The above analysis showed that change in T predicted decisions to compete again in losers, but pre-competition T levels could have also predicted decisions to compete again. To test this possibility, we used the same procedure as above to compare individuals in the top and bottom thirds of the pre-competition T distribution. We first ran a 2 (Pre-competition T: high T/low T) × 2 (Choice: compete again/do not compete again) chi-quare test in losers, and then we ran a similar chi-square test in winners. The results revealed that pre-competition T did not predict decisions to compete again in losers, $\chi^2(1, N=17)=0.49$, $p>0.40$, or in winners, $\chi^2(1, N=16)=0.00$, $p>0.90$.

Cortisol and affect

We also tested whether cortisol and affect predicted decisions to compete again. First, we examined whether log-transformed pre-competition cortisol, log-transformed change in cortisol, positive affect, or negative affect predicted decisions to compete again in losers. Then we examined whether any of these variables predicted decisions to compete again in winners. Similar to the analyses reported above, we compared individuals in the top and bottom thirds on each of these variables using chi-square tests. The results revealed that none of these variables predicted decisions to compete again in losers (all p's >0.10). Similarly, log-transformed pre-competition cortisol, log-transformed cortisol change, and positive affect were unrelated to decisions to compete again in winners (p's >0.10). However, negative affect was a marginally significant predictor of choice in winners, $\chi^2(1, N=16)=2.86$, $p=0.09$. Four out of nine winners (56%) with low negative affect chose to compete again, but the remaining five winners with low negative affect chose to complete the questionnaire (56%). Six out of seven winners with high negative affect chose to compete again (86%), and the remaining winner with high negative affect chose to complete the questionnaire (14%). Overall then, change in T was the sole predictor of decisions to compete again in losers, and negative affect was a marginal predictor of decisions to compete again in winners.

Alternative method for calculating change scores

In the above analyses, we used simple change scores (post-competition hormone levels minus pre-competition hormone levels), and we found that T change predicted decisions to compete again in losers. Some statisticians, however, have advocated the use of an alternative method for calculating change scores in which time 1 scores are statistically controlled for in a regression model (Cronbach and Furby, 1970). This method has been referred to as the regressor variable method (Allison, 1990). The debate between the use of simple change scores and the regressor variable method is far from resolved (see Allison, 1990), and thus, we tested whether our results for change in T and change in cortisol predicting decisions to compete again would remain the same when using the regressor variable method. We recalculated changes in T as the unstandardized residuals of a regression analysis with pre-competition T as the predictor and post-competition T as the dependent variable. And we recalculated changes in cortisol as the unstandardized residuals of a regression analysis with log-transformed pre-competition cortisol as the predictor and log-transformed post-competition cortisol as the dependent variable. This method for change score calculation has been used in previous research on hormone changes in competition (Schultheiss et al., 2005; Wirth et al., 2006).

Similar to the analyses reported above, we compared individuals in the top and bottom thirds of these new change in T and change in cortisol distributions using chi-square tests. The results of these chi-square tests matched the chi-square tests reported earlier. Losers who increased in T were more likely to choose to compete again (67%) than losers who decreased in T (11%), $\chi^2(1, N=18)=5.84$, $p<0.05$, change in T did not predict decisions to compete again in winners, $\chi^2(1, N=15)=0.05$, $p>0.80$, and change in cortisol did not predict decisions to compete again in losers $\chi^2(1, N=17)=1.43$, $p>0.20$, or in winners $\chi^2(1, N=16)=0.42$, $p>0.50$. Thus, our findings for change in T and change in cortisol predicting decisions to compete again held up using an alternative method for calculating change scores.

Discussion

The present research offers the first empirical evidence that changes in T after a status loss predict subsequent decisions to compete again. Losers who rose in T were more likely to choose to compete again than losers who dropped in T. These results are consistent with the large literature linking T to status-seeking behaviors as well as with the predictions of the reciprocal model. Until now, no human studies had tested the prediction of several investigators that change in T after a competition should regulate an individual's behaviors towards or away from future attempts at gaining status (Mazur, 1985; Mazur and Booth, 1998). Our findings provide initial evidence in humans suggesting that T changes after a status loss do indeed predict subsequent status-seeking behaviors.

Importantly, the relationship between T changes and choice in losers was driven both by T-increasers and T-decreasers. Presumably, losers who increased in T chose to compete again as an attempt to reclaim their lost status, and losers who decreased in T fled from a second competition in order to avoid any further status loss (Mazur, 1985; Mazur and Booth, 1998). Consistent with the reciprocal model, our results demonstrate that a status loss can be followed by a change in T, which in turn, predicts subsequent status-related behaviors. The large animal literature on T and behavior has by and large focused on the effects of increases in T on social behaviors, but the present findings suggest that in addition to an increase in T, a *decrease* in T after a status loss can also be an especially potent predictor of social behavior.

Although winners in the present study showed no relationship between T changes and decisions, this result was not particularly surprising. According to several theorists, changes in T after wins should encourage further attempts at gaining status (Mazur and Booth, 1998), but winners in the present study were not offered the opportunity to gain more status. They were asked whether they wanted to compete again against *lower* status individuals (the losers of the first competition). Increases in T may not necessarily predict choosing to compete against individuals of lower status because one has already gained higher status over these individuals, and thus, there is no more status to be gained. Instead, increases in T after wins may predict choosing to compete against *higher* status opponents because doing so offers individuals the opportunity to rise further in status. Future studies in which winners of competitions are offered the chance to compete against a higher status competitor are more likely to uncover a link between T changes and decisions to compete again. Based on this logic, we would hypothesize that winners who increase in T after a competition would choose to compete against a higher status opponent, but not winners who decrease in T.

Our study manipulated the outcome of a competition and examined the relationship between naturally occurring T changes after losing and subsequent social behavior. In addition, we were able to time the sequence of events in our experiment so that participants' T changes were measured *prior* to offering them the choice to compete again, allowing us to make claims that T changes predicted subsequent decisions to compete again. However, we cannot be sure that post-competition T changes *caused* the decisions of our participants. Yet converging evidence from animal studies in which post-competition T levels are experimentally manipulated suggests a causal link between T changes and subsequent social behaviors. For example, one study in California mice found that winners of physical fights who received injections that produced short-term increases in T were more aggressive in a subsequent encounter with a new individual than individuals who won but who did not receive T injections (Trainor et al., 2004). These findings dovetail nicely with our results and support a causal effect of T changes following competitions on subsequent status-seeking behaviors. Most certainly, future experimental research in animals will contribute greatly to our understanding of the effects of short-term T changes in competitive settings on subsequent social behaviors.

The predictions of the reciprocal model along with the literature linking T to status combine to suggest that status-seeking can explain the relationship between T changes and decisions to compete again. But the literature on T and learning suggests that the rewarding properties of T might also explain our results. Previous research has found that rats prefer places that were previously paired with T injections, and follow-up studies indicate that the effect of T on place preference is mediated by T's interactions with dopamine in the nucleus accumbens, a brain area associated with reward (Packard et al., 1997, 1998). Human studies provide further evidence that T increases are associated with reward (Schultheiss et al., 2005; Van Honk et al., 2004; cf. Wood, 2004), and that T decreases are associated with punishment (Schultheiss et al., 2005). Based on these findings, individuals in our study who rose in T after losing the competition may have associated the competition with reward, and in turn, may have learned to subsequently repeat the competition. Conversely, individuals who dropped in T after losing may have associated the competition with punishment, and in turn, may have learned to subsequently avoid a second competition. Future studies should consider testing whether status-seeking, reward/punishment, or a combination of both best explain the link between T changes and decisions to compete again.

Other plausible interpretations for our results include saving face and revenge. That is, losers who rose in T may have chosen to compete again in order to save face or seek revenge against their opponent. Although these explanations seem to differ from a status interpretation, some theorists have suggested that face-saving and revenge actually overlap quite substantially with a concern for status. According to evolutionary theorists (Daly and Wilson, 1988), saving face and seeking revenge may function to protect one's social status by helping to maintain one's reputation as "the sort who [can't] be pushed around" (pg. 128), which may in turn create a credible threat of violence. This credible threat of violence might deter future challenges from other individuals and thus might serve to maintain the individual's high social status. Although future research may be able to consider the subtle differences between revenge, saving face, and seeking status, we conclude based on this argument that these explanations are more similar to one another than distinct.

There are certainly many other alternative explanations (e.g., persistence, Archer, 1977) besides those discussed here that may account for the observed relationship between change in T and decisions to compete again, and it is our hope that future studies examining T and social behavior will consider testing between such explanations. As the field progresses and more data are collected, a clearer picture regarding the psychological mechanisms underlying T change–behavior relationships is likely to emerge.

Our results indicate that T changes after losing predicted subsequent decisions to compete again, but what caused our participants to rise or fall in T in the first place? We found that baseline cortisol, change in cortisol, and baseline T predicted changes in T. Animal research demonstrates that cortisol suppresses T secretion (Sapolsky, 1985), which supports our finding that losers with high baseline cortisol levels dropped in T. The fact that this relationship was statistically significant in losers but not in winners suggests that individuals high in baseline cortisol may have been especially vulnerable to the stress of a status loss. One possible mechanism suggested by previous work is that high baseline cortisol individuals, because of their high levels of psychological stress and anxiety (Brown et al., 1996), may have decreased in catecholamines in response to the stress of losing, which in turn, may have caused a drop in T (Sapolsky, 1986). Conversely, individuals low in baseline cortisol may have increased in catecholamines after the status loss, which in turn, may have caused a rise in T. The positive relationship between change in cortisol and change in T in losers may be explained by the fact that both cortisol and to a lesser extent T are secreted by the adrenal glands. Perhaps stress-induced cortisol increases in response to losing stimulated T secretion in the adrenal glands as well. Few studies have examined cortisol–T change interactions in human competition, and thus, our findings provide a new direction for future research (see Viau, 2002 for further research on cortisol–T interactions).

Previous research also provides support for our finding that baseline T predicted T drops in losers. Baseline T levels are correlated with implicit power motive, and individuals high in implicit power motive who lose in competitions tend to drop in T levels (Schultheiss et al., 2005). Applying these findings to the results of our study, perhaps the high power motive in high baseline T individuals led to greater frustration and disappointment with losing, which in turn, caused these individuals to decrease in T. Taken together, our findings linking baseline T and cortisol (both baseline and change) to post-competition T changes highlight the complex nature of the interactions among T, cortisol, and social status, and suggest the need for future research on this topic.

There are a number of additional directions that researchers can take to extend the present research and address its limitations. We have implied that T changes after losing may have had a direct causal influence on decisions to compete again, but due to our study's correlational design, it is possible that a third variable might have caused both T changes and decisions to compete again. We measured cortisol and affect and found that they did not explain the observed relationship between T changes and decisions to compete again, but other variables, such as attributions (Gonzalez-Bono et al., 1999) and implicit power motive (Schultheiss et al., 2005), may have played a role. Future research should measure such variables in order to determine their relationships with post-competition T changes and decisions to compete again.

In order to provide a direct test of causality, future research should attempt to experimentally increase or decrease post-competition T levels. Based on the findings from the present study, we would hypothesize that losers whose T levels are exogenously increased would choose to compete again, whereas losers whose T levels are exogenously suppressed (e.g., via a T antagonist such as flutamide, Sundblad et al., 2005) would choose not to compete again.

Consistent with most of the prior research on T and social behavior, our study included male participants only, but future research should test whether our findings extend to females. The few studies that have targeted females have found that T levels predict a variety of outcomes, including social dominance (Cashdan, 1995; Grant and France, 2001; Sellers et al., in press), cognitive performance (Josephs et al., 2003, 2006; Newman et al., 2005), attention to threatening faces (Van Honk et al., 1999), and physiological arousal (Van Honk et al., 2001). Other studies have found that women's T levels change from before to after competition (Edwards et al., 2006). These results demonstrate that T plays an important role in females, leaving open the possibility that the findings from the current study may replicate in women. However, some studies have also pointed out gender differences (e.g., Kivlighan et al., 2005), suggesting that T may operate differently in the two sexes. Clearly, more research examining the role of T in women is needed.

Finally, researchers should examine additional social behaviors beyond the behavior targeted in the present study. Our study measured decisions to compete again and found that T changes had predictive power, but many other outcomes are also likely to be influenced by changes in T. Future studies should build upon our findings and further investigate the effects of T changes on a variety of cognitive, emotional, and behavioral outcomes. Ultimately, we believe that research paradigms that examine T change both as an outcome variable and as a predictor are likely to yield the greatest insights into the role of T changes in social situations.

Acknowledgments

We are grateful to Amanda C. Jones, Matthew L. Newman, Oliver C. Schultheiss, Jennifer Guinn Sellers, and Richard B. Slatcher for their helpful comments on earlier drafts of the manuscript. We thank Dante Garcia, Kimberly Huang, and Manish Punjabi for their help in data collection, and we thank Yvon Delville and his graduate students for their assistance in conducting hormone assays. Finally, we thank the two anonymous reviewers for their helpful comments on previous versions of this manuscript. Preparation of this manuscript was supported by National Science Foundation Grant No. BCS0423405.

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