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Testosterone responses to competition: The opponent's psychological state makes it challenging

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ABSTRACT

Testosterone (T) increases after competition have typically been attributed to winning, yet there is also evidence that being victorious is not in itself sufficient to provoke a T response. Instead, it has been proposed that T responses are moderated by psychological processes. Here, we investigated whether the opponent's psychological state affected hormonal changes in men competing face to face on a rigged computer task. The results show that, irrespective of outcome, the competition led to increases in heart rate and T levels. We found that the T levels of the participants increased more when their opponents had high self-efficacy and that T levels were not influenced by participants' own psychological state. Furthermore, the T levels of losers, but not winners, increased more when their opponent judged the competition to have low importance. The findings from this study are consistent with the challenge hypothesis. Both winners and losers were being challenged to compete for social status; therefore their T responses did not differ. In addition, the psychological state of the opponent makes a competition challenging and subsequently triggers T responses.

1. Introduction

Changes in testosterone (T) during competitive interactions have attracted a lot of attention in behavioural and endocrinological research (Salvador, 2005). Two main hypotheses have been proposed to explain the function of T in competition. These are the biosocial theory of status (Mazur, 1985; Mazur and Booth, 1998) and the challenge hypothesis (Wingfield et al., 1990; Archer, 2006).

According to the biosocial theory of status, the relationship between status and T is reciprocal. The model predicts that in physical or non-physical competition, winning and thereby gaining status causes an increase in T, while losing decreases T levels. Some studies have found support for these predictions in humans (Mazur and Lamb, 1980; Elias, 1981; Booth et al., 1989; Gladue et al., 1989; Mazur et al., 1992; McCaul et al., 1992), while others have found no different T change between winners and losers (Salvador et al., 1987; Gonzalez-Bono et al., 1999; Suay et al., 1999; Gonzalez-Bono et al., 2000; Filaire et al., 2001; Mehta and Josephs, 2006). Because of this mixed support it has been proposed that winning or losing is not in itself enough to cause T levels to shift, but that T responses in reaction to competition are moderated by psychological processes (Salvador, 2005; Salvador and Costa, 2009). In support of this it has been shown that a high motivation to win is positively related to T changes during competition (Suay et al., 1999) and a high power motivation predicts T increases among winners and decreases among losers (Schultheiss et al., 2005). Furthermore, it has been found that among winners a positive mood accompanies a T increase (Booth et al., 1989) and similarly, it has been shown that men who increase their T levels during a competition express a desire to compete again after social defeat but not after victory (Mehta and Josephs, 2006; Carré and McCormick, 2008).

From an evolutionary perspective, the challenge hypothesis (Wingfield et al., 1990; Archer, 2006) predicts that T levels should increase in challenging contexts that are relevant for reproduction. This hypothesis was originally focused on birds (Wingfield et al., 1990) but has also been applied to humans (Archer, 2006). Recent studies have found direct support for this hypothesis, showing that an informal encounter with a potential mate induces a T rise in men after 15 min of contact (Roney et al., 2007) or even as little as 5 min (van der Meij et al., 2008). The challenge hypothesis also predicts that T increases throughout a competitive interaction and may in the long-term cause a further rise of T in the winner of the competition. The outcome of such an interaction can be relevant for reproductive success, since it could affect the status, and thus the mating success of the winner. Therefore, according to the challenge

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hypothesis, in reaction to a challenging and evolving competition, T should first rise throughout the competition for both winners and losers and, only when considering a long-time interval, further increase among the winners.

Several non-human studies have looked at the impact of the opponent on T changes during competition. For example, cichlid fish (*Oreochromis mossambicus*) and Japanese quail (*Coturnix japonica*) do not increase their T levels when fighting against a mirror image of themselves but they do respond with increased androgen levels when fighting a real opponent (Oliveira et al., 2005; Hirschenhauser et al., 2008, 2004). To explain these findings it has been proposed that to mount a T response, information or feedback from the fighting ability of the opponent are necessary components (Hirschenhauser et al., 2008). In the experiment reported here, we tested this hypothesis in humans. Our aim was to investigate whether the characteristics of the opponent are a crucial component in provoking a T increase.

Possible psychological processes of special significance include the motivation and perceived self-efficacy of the opponent. Perceived self-efficacy refers to beliefs in one's capabilities to organize and execute the courses of action required to manage prospective situations (Bandura, 1995). An opponent who has a strong sense of efficacy exerts greater effort to master a challenge (Bandura, 1982), and may more easily provoke a competitive interaction and augment T levels in the individual with whom it is interacting. We therefore predicted that T increases during a non-physical contest in men are enhanced when the opponent reports a high self-efficacy, expects to win and perceives the competition as important. According to the biosocial theory of status, these moderating effects could depend on the outcome of the competition. However, based on the challenge hypothesis, we expected that these moderating effects would be similar for winners and losers, as this hypothesis states that the competitive interaction in itself is relevant, and only in the long-term the outcome can be relevant for T levels.

We performed an experiment in which pairs of men engaged face to face in a competitive computer task. This task was designed to intensify the competitive nature of the interaction and to be sensitive to changes in social status. The outcome of the competition was rigged, so that we could assess the direct effect of winning or losing without any confounding influence of the participants' true abilities. The psychological effects produced by the competition were analyzed by measuring mood changes and situational appraisal. To investigate the physiological reaction to the competition we recorded heart rate and collected saliva samples to measure T.

2. Methods

2.1. Participants

Eighty-four male students, aged 18–29 years (21.2 ± 0.31), participated in this study in exchange for €10. We assessed participants' body mass and measured subjective socio-economic status (Adler et al., 2000) to provide some general characteristics of our sample. The participants had a mean body mass index of 23.4 (±0.44) and they reported a mean subjective socio-economic status of 6.6 (±0.09). The participants were recruited from cafeterias and classrooms of the University of Valencia. All were first interviewed and asked to complete a questionnaire, on the basis of which we excluded those enrolled in a psychology degree, smoking more than 5 cigarettes a day, or reporting a serious medical or psychological problem or drug abuse. Participants were also excluded if they were using any medication directly related to cardiac, emotional or cognitive function, or one that was able to influence hormonal levels, such as glucocorticoids or β-blockers.

Up until 1 day before the experiment, the participants were asked to maintain their typical habits, including sleeping for as long as usual. Additionally, they were instructed to refrain from alcohol consumption and any heavy physical activity the day before the session, and during 2 h immediately beforehand to drink only water and avoid any stimulants, such as coffee, cola, caffeine, tea or chocolate. All the participants received verbal information about the study and signed an informed consent form. This study was approved by the ethical committee of the Faculty of Psychology (University of Valencia).

2.2. The competition

Each participant competed with another participant on a computer task. Unknown to them, the outcome of this task was actually manipulated by the experimenter, with participants randomly assigned to the winner or loser conditions. The participants were told that the test used in this experiment was an important test that was commonly used by companies and psychologists to assess if a person is intelligent or not. To intensify the competition, the participants were informed that the winner of the competition would receive €10 and the loser €5, but at the end of the study they all received €10, since the result was manipulated.

The competitive task consisted of items similar to those used in intelligence tests. To familiarise themselves with the task, the participants first completed a practice session with feedback indicating the correct answer. During the subsequent task, they were simultaneously presented with the same item and within 30 s had to choose the correct answer from four, five or six possibilities. They were informed that they would win an item if they were the first to enter the correct answer, but in reality the computer task determined for every item which of the contestants won and lost. During the task the participants were seated roughly 1 m apart on opposite sides of the same table, each behind their own computer screen and facing their opponent. The experimenter remained clearly visible to the participants and observed the progress of the task.

There were 27 items in all, divided into three sets of nine items each (visual–spatial, mathematics and analogies) and taking a total of 18 min to complete. After contesting a given item, the message "*you win!*" appeared on the winner's screen, while the loser's screen showed "*you lose!*", and the loser's specific buzzer was loudly heard. The participant with the most wins at the end of the competition was declared the overall winner. During the first part the participants in the loser condition won five items, for the second part they won only two items and in the last part they did not win any items at all. Both contestants could constantly see their score and that of their opponent in the right corner of their screen. After the first part of the competition the experimenter encouraged the participants by telling them "*the both of you are doing really well*". After the second part the experimenter commented to the winner "*you are doing really well*" and to the loser "*you can still beat him*". At the end of the task their screen showed them a message with their end score, together with a statement of whether they had lost or won and the amount of money they could expect to receive (€10 for the winner, €5 for the loser).

2.3. Procedure

Upon arrival at the laboratory the participants were greeted by the male experimenter and were briefed on the general procedure of the study. Unknown to themselves, half of the participants were randomly assigned to the loser condition and the other half to the winner condition. They filled in an informed consent form, their height and weight was measured and a heart-rate monitor was put on. All participants were alone in a separate room when they filled in the questionnaires of this study to avoid any social influence of their opponent while answering the questionnaires.

Ten minutes after arrival at the laboratory the participants provided their first saliva sample (T1) for the measurement of their basal T level. Immediately after this, they were seated at opposite sides of the same table and individually practiced on the computer task (duration 10 min). Next, they went to a separate room where they filled in a questionnaire concerning their psychological state and a questionnaire measuring their mood (duration 5 min). Then the competitive task took place (duration 18 min).

After the competition they each went to a separate room and filled in questionnaires concerning their mood and situational appraisal (duration 10 min). After these questionnaires (10 min after the competition and approximately 45 min after T1), the participants provided a second saliva sample (T2). Finally, they were debriefed about the true nature of the experiment and each received €10. The whole procedure lasted 1 h and sessions were held from 16.00 to 19.00 h to control for circadian fluctuations in T (Dabbs, 1990).

2.4. Questionnaires and scales

2.4.1. Psychological state

Before the computer task, the self-efficacy (Bandura, 1997) of the participants was measured. This study operationalised self-efficacy with the following two items, both on a scale from 1 (none) to 100 (very much): (i) What do you think is your capacity to win this competition? (ii) How much confidence do you have that you will win this competition? The scores on both items were averaged and had a Cronbach's alpha of 0.88. Motivation was measured by asking (again on a scale from 1 to 100): How important is it for you to win this competition? Finally, they were asked about their expectancy: do you expect a victory (1) or a defeat (2)?

2.4.2. Situational appraisal

After the competition participants completed five questions regarding the perception of the competition. They were asked about their perceived frustration, effort, importance, difficulty and stress (e.g. *How much effort did the task require?*). These questions were formulated based on a previous study by Baggert et al. (1996). Participants answered each question on a 5-point Likert scale (1 = not at all, 5 = extremely).

2.4.3. Mood

We measured the positive and negative mood of the participants before and after the competition by using the Spanish version (Sandín et al., 1999) of the PANAS questionnaire (Watson et al., 1988). The scale consisted of 10 items describing positive mood (e.g. enthusiastic, activated) and ten describing negative mood (e.g. ashamed, irritable), for each of which the participants were required to indicate the extent to which it corresponded with their current mood. For negative feelings we found a Cronbach's alpha of 0.87 before the competition and an alpha of 0.80 afterwards; for positive feelings the figures were 0.85 beforehand and 0.89 afterwards.

2.5. Heart rate

During the session the heart rate of the participants was recorded at 5-s intervals using a Polar heart-rate monitor. This technique provides a valid measure of heart rate (Goodie et al., 2000). Artefacts were manually removed from the heart-rate register. To analyze these data, we divided the heart-rate register into five phases: baseline, the first, middle and last parts of the competition and a recuperation phase. Not all phases were of equal length, so we took from each phase the middle 3 min and used these to calculate an average heart rate for the phase. Five participants were excluded from this analysis: three had an incomplete heart-rate register and two outliers whose heart-rate average differed by more than three standard deviations from the mean.

2.6. Hormonal assays

Participants provided two saliva samples by depositing 5 ml of saliva into plastic vials. The samples were frozen at −20 °C and shipped to the endocrinology laboratory at the University Medical Centre Utrecht, the Netherlands. Depending on the starting time of the session, the first saliva sample (T1) was approximately taken at 16.10 or 18.10 and the second saliva sample (T2) was taken at approximately 16.55 or 18.55. Second saliva samples were taken 10 min after completing the competition since psychological stimulation needs some time to affect T levels (Hellhammer et al., 1985). The saliva samples were tested using radio-immunoassays. Salivary T was determined with the double antibody T kit (DSL-4100) from Diagnostic Systems Laboratories Inc. (Webster, TX), according to the modifications of Granger et al. (1999). The detection limit was 4 pmol/L. The mean inter-assay coefficient of variation was 7.5% (±0.90) and the mean intra-assay coefficient was 5.3% (±1.30). Two outliers were removed, since one participant had an extremely low baseline T level of 28 pmol/L (differed 2.8 standard deviations below the mean, including this outlier did not influence the overall conclusions of the study) and another participant's T measurements differed by more than three standard deviations from the mean.

2.7. Statistical analysis

We first performed several independent *t*-tests to assess if there were any differences between the winning and the losing conditions for the socio-demographic variables and the psychological and physiological measures taken. We used a Pearson correlation and an independent *t*-test to investigate if baseline T was related to the opponent's psychological state. To investigate if the T change of opponents were related we performed a Pearson correlation. Spearman's Rho was performed to investigate if T levels were related to the sampling times.

To investigate if the competition and its outcome provoked any changes in positive and negative mood, we performed two repeated-measures ANOVAs with outcome (winner or loser) as a between-subjects factor and positive and negative mood as within-subject factors (before versus after the competition). To examine if the competition influenced heart rate we performed another repeated-measures ANOVA with outcome (winner or loser) as a between-subjects factor and phase (baseline, first competitive, middle competitive, last competitive and recuperation) as a within-subject factor. To investigate if the competition produced any difference in T levels we performed a repeated-measures ANOVA, with outcome (winner or loser) as a between-subjects factor and moment (first or second T measurement) as a within-subject factor. When a significant effect was found for any of these ANOVAs, post hoc planned comparisons were performed using the Bonferroni adjustments for the *p*-values. Where the assumption of sphericity was violated, we used the Greenhouse-Geisser adjustment.

To test for an interaction between the effects of the outcome of the competition and the opponent's psychological state on the change in T, we used regression analyses following Aiken and West (1991). Using forward stepwise regression, separate moderator regression analyses were performed for the participant's own and the opponent's self-efficacy, perceived importance of the competition and expectancy. The outcome of the competition was dummy-coded as 0 for losing and 1 for winning. Following Mehta et al. (2008), we entered T2 as dependent variable, in Step 1 we entered T1 as a covariate, in Step 2 we entered outcome and psychological state and in Step 3 we entered the interaction term psychological state × outcome. When Step 3 was significant, post hoc significance tests of the slopes were performed with dependent variable the unstandardized residuals scores from regressing T1 on T2.No violation of the normality assumption was found in the *T* values, so there was no need to transform them. A value of $p < 0.05$ (two-tailed) was considered statistically significant. Statistical tests were performed with SPSS version 15.0. When not otherwise specified values are mean ± SEM.

3. Results

3.1. Preliminary analysis

There were no differences between the winning and losing conditions for the following variables: age, height, weight, BMI, subjective socio-economic status, educational level, average weekly physical activity and alcohol use (*t*-tests, all $p \geq 0.10$). Before the competition there were no differences between the conditions for positive and negative mood or psychological state ($p \geq 0.14$). Baseline heart rate and T did not differ between winners and losers ($p \geq 0.67$). Baseline T was not correlated with the opponent's perceived importance of the competition ($r = -0.097$, $p = 0.388$), but was higher when their opponent reported a lower self-efficacy, $r = -0.295$, $p = 0.007$, and expected a defeat instead of a victory, $t(80) = -2.55$, $p = 0.013$. The T change (T2–T1) of opponents was not correlated ($r = 0.127$, $p = 0.434$). The time of saliva collection was not correlated with T1 ($r = 0.065$, $p = 0.562$), T2 ($r = 0.037$, $p = 0.742$) nor with the T change (T2–T1), $r = -0.053$, $p = 0.633$.

3.2. Psychological effects of the competition

3.2.1. Situational appraisal

Losers perceived the competition as more frustrating than winners, $t(71.68) = -7.68$, $p = 0.003$, and afterwards viewed it as less important than winners did, $t(82) = 2.70$, $p = 0.008$. No differences were found for perceived effort, perceived stress or perceived difficulty of the task (*t*-tests, all $p \geq 0.16$).

3.2.2. Mood

There was a significant interaction between moment of measuring positive mood and outcome of the competition, $F(1,82) = 24.64$, $p < 0.001$. Among winners, positive mood did not change, $F(1,82) = 1.41$, $p = 0.239$, whereas among losers, positive mood decreased $F(1,82) = 34.04$, $p < 0.001$. There was also a significant interaction between moment of measuring negative mood and outcome of the competition, $F(1,82) = 15.36$, $p < 0.001$. Among winners, negative mood decreased, $F(1,82) = 26.59$, $p < 0.001$, while among losers, negative mood did not change $F(1,82) = 0.15$, $p = 0.701$.

3.3. Physiological effects of the competition

3.3.1. Heart rate

There was a significant effect of phase on heart rate, $F(2.03,156.27) = 67.95$, $p < 0.001$, but no interaction between outcome and phase on heart rate, $F(2.03,156.26) = 0.60$, $p = 0.553$. Overall, heart rate was higher in the three competitive phases than at baseline levels (all $p < 0.001$), and during the recuperation phase it decreased to below baseline levels ($p = 0.006$). The mean heart rate was 76.5 bpm (±1.4) at baseline, in the first competitive phase 82.2 bpm (±1.5), in the middle competitive phase 82.5 bpm (±1.4), in the last competitive phase 79.3 bpm (±1.4) and in the recuperation phase 74.6 bpm (±1.3). Heart rate was highest in the middle phase of the competition, with an average increase of 8.2% (±0.8) over baseline levels.

3.3.2. Testosterone

There was a significant effect of moment of collecting the saliva sample on T, $F(1,80) = 14.74$, $p > 0.001$, but no interaction between the outcome of the competition and moment of collecting the saliva sample on T, $F(1,80) = 0.70$, $p = 0.406$. Overall, the T levels of the participants increased on average by 16.4% (±3.9) between the first and second measurement, from 266.4 pmol/L (±8.5) to 300.6 pmol/L (±10.5). For descriptive purposes we reported the *T* values for winners and losers separately (see Fig. 1). Losers increased their T

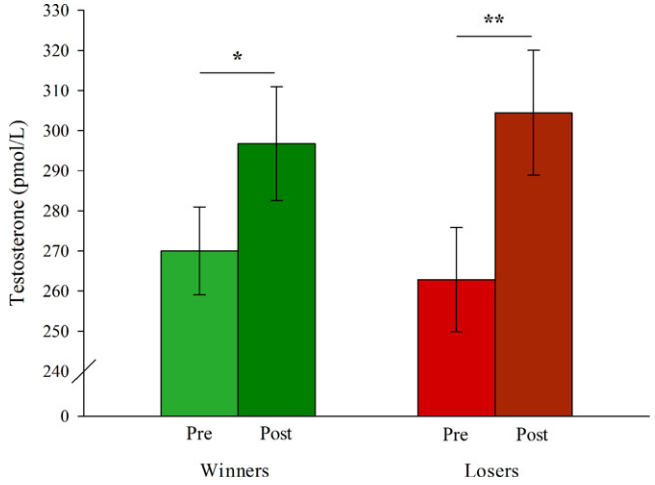

Fig. 1. Mean (±SEM) testosterone levels before (pre) and after (post) the competition separated for winners and losers. $^{*}p < 0.05$, $^{**}p \leq 0.001$.

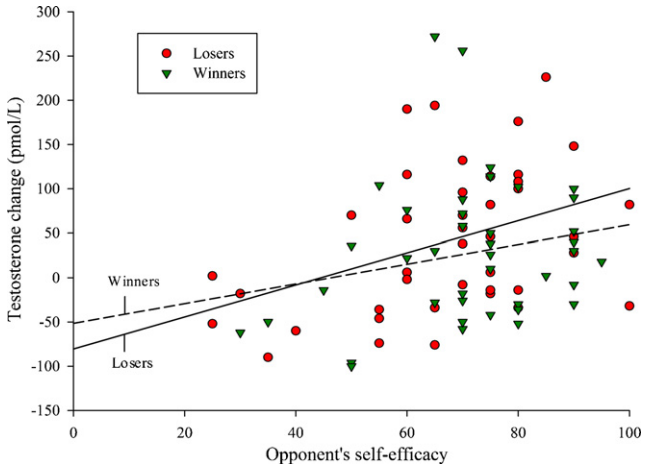

Fig. 2. The relationship between testosterone changes and the opponent's self-efficacy, plotted for winners and losers.

levels on average by 20.5% (±6.0) in response to the competition, $F(1,80) = 10.92$, $p = 0.001$, whereas winners increased their T levels by 12.2% (±4.9), $F(1,80) = 4.51$, $p = 0.037$.

3.4. Participant's own and opponent's psychological state as a moderator of a T response

3.4.1. Participant's own psychological state

Three different moderator regressions analysis were performed for each variable measuring the psychological state of the participants. T2 was used as dependent variable and in Step 1 baseline T was entered as a covariate. Entering Step 2, including outcome and participant's own psychological state as predictors (either: self-efficacy, importance, or expectancy), did not increase the amount of variance explained in T2 for any of the three regressions analysis ($p \geq 0.381$). Finally, entering Step 3, including the interaction term (outcome × psychological state) as predictor, did not increase the amount of variance explained in T2 for any of the three regressions analysis ($p \geq 0.606$).

3.4.2. Opponent's self-efficacy

After controlling for T1 in Step 1, entering Step 2 in the model, including outcome and the opponent's self-efficacy as predictors, increased the amount of variance explained in T2, $\Delta F(2,78) = 3.106$, $p = 0.050$, adjusted $R^2 = 36.0\%$, $\Delta R^2 = 4.9\%$. No main effect was found for outcome ($\beta = -0.091$, $p = 0.314$), but we did find a main effect of opponents reported self-efficacy, $\beta = 0.222$, $p = 0.020$. Fig. 2 shows that the T change was bigger when their opponent reported a higher self-efficacy. Entering the interaction term in Step 3 did not increase the amount of variance explained in T2, $\Delta F(1,77) = 0.87$, $p = 0.355$.

3.4.3. Opponent's perceived importance of the competition

After controlling for T1 in Step 1, entering Step 2, including outcome and opponent's perceived importance of the competition as predictors, did not increase the amount of variance explained $F(2,78) = 0.53$, $p = 0.592$. Entering the interaction term in Step 3 increased the amount of variance explained, $\Delta F(1,77) = 7.75$, $p = 0.007$, adjusted $R^2 = 37.3\%$, $\Delta R^2 = 6.0\%$. In this step there was a significant main effect of outcome ($\beta = -0.661$, $p = 0.005$) and perceived importance of the competition ($\beta = -0.358$, $p = 0.011$). However, these main effects were qualified by a significant 2-way interaction between opponent's perceived importance of the competition and outcome, $\beta = 0.672$, $p = 0.007$ (see Fig. 3 for absolute values). Using unstandardized residuals scores to test the slopes, revealed that, among losers, T increased more when the opponent thought the competition was of low importance, $\beta = -0.44$, $t(37) = -2.62$, $p = 0.011$, but among winners, how important the opponent the competition perceived did not affect T levels, $\beta = 0.17$, $t(37) = 1.23$, $p = 0.221$.

3.4.4. Opponent's expected result

After controlling for T1 in Step 1, entering Step 2, including outcome and the opponent's expectancy as predictors, did not increase the amount of variance explained, $\Delta F(2,78) = 1.78$, $p = 0.176$. Entering the interaction term in Step 3 did not increase the amount of variance explained, $\Delta F(1,77) = 0.39$, $p = 0.533$.

4. Discussion

Our study shows that the T responses during a competitive interaction between two men are moderated by the opponent's perceived self-efficacy, and is not influenced by one's own psychological state. We found that T levels increased when the opponent felt more capable and confident. This extends the evidence that the hormone T plays an important role in many human social behaviours (van Anders and Watson, 2006), indicating that the opponent's state is a crucial element in provoking a T response.

Our results complement some of the findings in the literature on non-human animals. In some species feedback of the oppo-

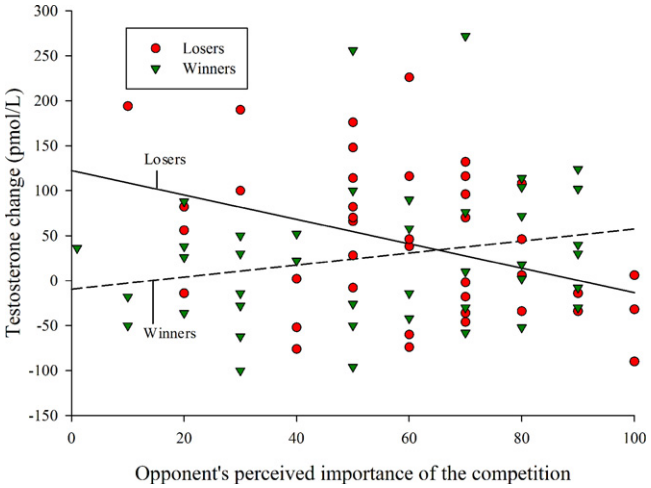

Fig. 3. The relationship between testosterone changes and the opponent's perceived importance of the competition, plotted for winners and losers.

nent is essential to provoke T changes during competition (Oliveira et al., 2005; Hirschenhauser et al., 2008). Here we have shown that in humans the influence of the opponent's feedback is also present, although it is in a different form. Humans most likely deduce information about their opponent's competitive ability from behavioural cues shown by that opponent. Opponents scoring high on self-efficacy probably exhibited non-verbal behaviour that implied their engagement and likewise made the competition challenging, which provoked an increase in T levels among competitors. During the competition, participants were seated at opposite sides of the same table and it was therefore relatively easy for them to deduce their opponent's psychological state by observing their reactions to the competition. Behaviours that provided information about the psychological state of the opponent have to have been non-verbal since participants were not allowed to talk during the competition. According to Bandura (1982), high self-efficacy causes behaviours such as persistence, assuredness and protesting, whereas low self-efficacy causes resignation, despondency and apathy. In our study, opponent's behaviours that could be an indicator of self-efficacy could have been: an active vs. depressed body-posture, apathy vs. attentiveness during the task and confidence vs. doubt during answering the items. To confirm this interpretation, research in the future should directly measure behaviour while linking it to T changes and the opponent's psychological state.

Our study did not find support for the biosocial theory of status since our results do not show a reciprocal relationship between T and winning, in contrast to some other studies (Gladue et al., 1989; Mazur et al., 1992). Ten minutes after the competition T had increased not only among winners but also among losers. This discrepancy can be explained in two ways. One possibility is that the observed T response did not reflect an actual change in social status. However, care was taken to make the competition sensitive to status alterations. For example, the non-physical competition used was especially designed to be as confrontational and competitive as possible, hence the close physical proximity of the participants, the monetary incentive and the observing experimenter. Furthermore, although the competition was non-physical, the heart rate of the participants increased substantially and the mood changes and subsequent perception were outcome-specific. Another explanation is perhaps more likely, since several authors have argued that perceived outcome is more relevant than real or objective outcome (Gladue et al., 1989; Gonzalez-Bono et al., 1999; Serrano et al., 2000). Although this study did not measure perceived outcome but real outcome, it could be that winning is not in itself enough to provoke a T increase, but it rather depends on the social context and on cognitive variables (Salvador, 2005). In support of this last notion, we found that only the opponent's, and not so much their own, perceived self-efficacy was an important cognitive factor that influenced the change in T.

The main findings of this study can also be interpreted from an evolutionary viewpoint. The competitive situation in this study was designed to provoke a challenge for social status, and according to the challenge hypothesis (Archer, 2006), T levels should then increase to meet this challenge. Although we did not measure competitiveness directly, our findings do suggest that a confident and capable-feeling opponent augments competitiveness and therefore increase the possible gains or losses in social status. An adaptive response to the increased value of the outcome is to increase competitiveness and consequently increase T levels even further.

The observed T rise may not only be explained by the challenge hypothesis, but also by reward processing since all participants received a monetary reward. Animal studies have shown that T has rewarding properties, for example, rats and mice prefer environments which are previously paired with T injections (Alexander et al., 1994; Arnedo et al., 2002, 2000). Therefore, it could be that those participants that increased their T levels learned that the competition was pleasant and worth repeating (Mehta and Josephs, 2006). Following this rationale, one might expect that the T increase would be greater in winners than in losers since they were informed that winners would receive double the money. However, our results did not show a stronger T response for winners than for losers. Therefore, it seems that reward processing is limited in explaining our findings.

Another important finding of this study was that, the T response provoked by the competition was moderated by an interaction between status, i.e. the outcome of the competition, and the opponent's perceived importance of the competition. The T levels of winners were not significantly affected by how important their opponent thought the competition was, but in losers T increased when their opponent did not perceive the competition to be important. This result seems to be at odds with the results mentioned earlier, but can actually be explained by the competitive nature of our competition. Losing to an opponent who is not motivated, in that he perceives the competition to be unimportant, probably provoked a larger loss of social status, since despite the low motivation of the opponent a loss could not be avoided. Behaviours that could have indicated a lack of motivation among winners are: emotional indifference upon winning an item and paying little attention to the task. It could be the case that this situation frustrated and challenged losers and as a reaction T increased to augment competitiveness and regain social status. In support of this explanation is the finding that losers judged the competition as more frustrating than winners, and that losers dropped significantly in their positive mood. In addition, there is evidence that the relationship between T and cognitive factors can be different for winners and losers. For example, Gonzalez-Bono et al. (1999) found that a T response was negatively related to external attribution in winners, but positively related in losers.

To our knowledge, this is the first study showing a moderating influence of the opponent's psychological state on T responses to competition. Our results fit with the view that when trying to identify the role of T in competition, one must control for a wide range of context-dependent factors. One such important factor is the interaction between T and the psychological state of the opponent.

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