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Losing the battle but winning the war: Uncertain outcomes reverse the usual effect of winning on testosterone

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ABSTRACT

The biosocial model of status predicts a competition effect (or winner–loser effect), whereby winning a competition should cause a rise in testosterone relative to losing. However, its applicability to women and the role of contextual factors, such as a decisive versus close match, have been overlooked. In two studies of female competition, we tested whether the winner–loser effect generalizes to dominance contests that model unstable social hierarchies, namely in close competitions wherein the winner–loser distinction is unsettled (Study 1) and in competitions in which the outcome is uncertain (Study 2). In both studies we found evidence for a *reverse* winner–loser effect whereby losers experienced a net increase in testosterone compared to winners. Moreover, the rise in testosterone was stronger in those competitors who reported being more surprised by the loss (Study 2). These results represent some of the first empirical evidence for the reverse effect of what is predicted by the biosocial model of status. We interpret these findings in terms of the dominance motivation that testosterone might subserve within unstable status hierarchies.

1. Introduction

In women's tennis history one of the most famous rivalries took place between Steffi Graf and Arantxa Sanchez Vicario, who between January 1994 and July 1996 faced each other for no less than six Grand Slam finals. At the 1996 Wimbledon final, Graf dominated the entire match and won; Vicario later acknowledged the clear superiority of her opponent. A more memorable match, however, took place at the French Open final of the same year. Again, Graf emerged as victorious, but only after a riveting, back-and-forth final round that was one of the longest ever. Remarking on her narrow victory after the final game, Graf predicted victory for her rival on their next meeting; and apparently feeling poised to win, Vicario challenged Graf to a rematch. In short, it had become unclear which player was dominant. The underlying psychological and biological processes in close and uncertain competitions like the classic Graf–Vicario rivalry – in contrast to the unambiguous win–lose scenarios typically employed in studies of the "Competition Effect" – is the topic of the present research.

More than a century of research suggests that the steroid hormone testosterone regulates competitive and socially dominant behaviors across the animal kingdom, behaviors that are implicated in the pursuit of status within social hierarchies. One of the most influential theories of testosterone and social behavior – the biosocial model of status (BMS) – posits a dynamic, bidirectional relationship between testosterone and status (Mazur & Booth, 1998). According to the model, not only does testosterone encourage status-seeking behaviors, but changes in status should in turn alter testosterone concentrations. Specifically, the BMS predicts that winning a competition should cause a rise in testosterone relative to losing, and these testosterone changes should in turn guide individuals toward or away from future attempts at gaining status (Mazur & Booth, 1998). This model has garnered empirical support in many species ranging from mice to nonhuman primates and humans (for example, Bernstein, Rose, & Gordon, 1974; Lloyd, 1971; Zilioli & Watson, 2012). Most human studies have used sports competitions – such as soccer (Oliveira, Gouveia, & Oliveira, 2009), tennis (Mazur & Lamb, 1980), and volleyball (Edwards & Kurlander, 2010) – to model status dynamics and testosterone changes. Consistent with the predictions of the BMS, many of these studies show a *competition effect* (or winner–loser effect) whereby winners show

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an increase in testosterone for a few hours following the competition, while losers show a decrease in testosterone. Such effects are seen in competitors not only following their contests, but also when reviewing previous contests on video; in one example, hockey team members showed an increase in salivary testosterone after viewing a previous game that they had won (Carré & Putnam, 2010). Impressively, even purely vicarious competition effects have been observed, in the testosterone responses of sports fans witnessing wins or losses of their favorite teams. For example, in a study of soccer fans watching a World Cup match, fans that rooted for the winning team showed an increase in testosterone after the match relative to fans who rooted for the losing team (Bernhardt, Dabbs, Fielden, & Lutter, 1998). Similarly, on the night of the 2008 US presidential election, people who supported the losing candidate (McCain) dropped in testosterone relative to people who supported the winning candidate (Obama) (Stanton, Beehner, Saini, Kuhn, & LaBar, 2009). Together, these results support the BMS, showing that a rise in social status (victory) increases testosterone concentrations and a drop in social status (defeat) causes testosterone suppression.

Despite the broad appeal of the BMS, there are two important limitations in this area of research that have not been adequately addressed. First, the model has been tested primarily in men. Much more data in women are needed to determine the extent to which the model does or does not apply to female status dynamics. And second, although there are now many positive reports, the predicted winner–loser effect is not universally replicated (Gonzalez-Bono, Salvador, Ricarte, Serrano, & Arnedo, 2000; Suay et al., 1999), suggesting that unknown psychological and contextual factors besides competition outcome may affect testosterone responses (Bateup, Booth, Shirtcliff, & Granger, 2002; van Anders & Watson, 2007). Although researchers have recently begun to investigate some psychological factors such as personality traits (Schultheiss & Rohde, 2002) and cognitive appraisals (Gonzalez-Bono et al., 2000), the role of contextual factors in regulating testosterone responses to competition has been overlooked.

One contextual factor that may affect testosterone responses is whether a competition results in a clear, decisive victory or a close one, or even an uncertain one. Decisive victories model stable hierarchies where the winner clearly dominates the loser, and testosterone may rise or fall in alignment with the new hierarchy as the BMS predicts. In contrast, competitions in which the outcome is close or uncertain cause the status hierarchy to become unpredictable and unstable, and this instability may induce testosterone response profiles that diverge from the predictions of the BMS. This possibility is implied by animal and human research demonstrating different behavioral consequences of status in stable versus unstable hierarchies (Ellemers & Basrreto, 2000; Gust, Gordon, Hambright, & Wilson, 1993; Higham & Maestripieri, 2010; Magee & Galinsky, 2008; Nadler & Halabi, 2006; Sapolsky, 2005; Tauber & van Leeuwen, 2012). In stable hierarchies, high status is associated with more socially dominant, approach-oriented behaviors compared to low status. But in unstable hierarchies, these effects often reverse. Low status individuals in unstable hierarchies–seeing an opportunity to improve their status – show heightened dominance and approach behaviors compared to high status individuals. For example, subordinate male rhesus macaques form revolutionary coalitions and fight over dominance during period of rank instability (Higham & Maestripieri, 2010). Likewise, Gust et al. (1993) found that, compared to periods of stability, female rhesus monkeys displayed more physical aggression when the social rank was unstable. Interestingly, post-aggression reconciliatory behaviors also increased in this context. These active coping strategies are in sharp contrast with the inhibited ways low-status primates tend to respond when in stable social hierarchies (Sapolsky, 2005). In line with these observations, tennis player Arantxa Sanchez Vicario expressed enhanced status-seeking motivation after she barely lost to Graf in the 1996 French Open final, publicly challenging Graf to a rematch. Given testosterone's role in encouraging status-seeking behaviors, it is plausible that testosterone response profiles may show similar patterns to these prior behavioral findings in unstable hierarchies. Whereas the BMS predicts that attaining high status (victory) should increase testosterone relative to attaining low status (defeat) regardless of the nature of the hierarchy, an alternative *status instability hypothesis* predicts that possession of an unstable low status position (e.g., defeat in a close match) should enhance testosterone so as to encourage status-seeking behaviors in that opportunity-rich environment. Conversely, attainment of an unstable high status position (e.g., winning a close victory) might be associated with avoidance of further contests. Therefore, to return to our example, the status instability hypothesis predicts that after their close match Sanchez Vicario may have experienced elevated testosterone compared to Graf, not the other way around as the BMS predicts. The primary goal of the present research was to contrast these two opposing predictions – the predictions of the BMS versus the predictions of the status instability hypothesis, using laboratory competitions designed to model unstable, uncertain status hierarchies in females.

A second goal of our research was to explore the extent to which psychological states, such as mood, explain post-competition testosterone responses in unstable hierarchies. Theoretical models of testosterone fluctuations in response to social competition have proposed mood as a principal modulator (Chichinadze, Lazarashvili, Chichinadze, & Gachechiladze, 2012; Salvador & Costa, 2009), but empirical results have been inconclusive. Indeed, many studies show no associations between mood and testosterone fluctuations in competition (e.g., Gladue, Boechler, & McCaul, 1989; Mazur, Susman, & Edelbrock, 1997; Mehta & Josephs, 2006; but see, McCaul, Gladue, & Joppa, 1992). One possible explanation is that researchers have focused only on higher-order constructs such as global positive and negative mood and have neglected more specific aspects of mood that may be more closely associated with endocrine function in status hierarchies (for an example, see Zilioli & Watson, 2013). Thus, in addition to measuring global positive and negative affect in line with previous studies, the present research added a previously unstudied affective state relevant to unstable hierarchies: surprise. Unstable hierarchies are characterized by high uncertainty (Sapolsky, 2005), and therefore surprise may play a role in modulating biological processes in these contexts. We measured global positive mood, negative mood, and surprise in our studies and examined their relationships with testosterone changes. Given the mixed findings on mood and hormone changes in previous research, we did not make any specific predictions for these analyses.

Lastly, because testosterone secretion in women is equally split between the ovaries and the adrenal cortex (Burger, 2002), in both studies cortisol was also measured. This allowed us to understand the implication of the hypothalamic–pituitary–adrenal (HPA) axis in the anticipated androgenic response to a potentially stressful event such as social defeat.

2. Study 1

In Study 1, undergraduate women engaged in a competition with a female confederate. The contest was manipulated so that the competitors were always tied going into the final round (seven rounds in total). In each preceding round participants always just barely won or barely lost. We measured levels of testosterone before and after the manipulation. Surprise, positive affect and negative affect were assessed at the end of the competition.

3. Method

3.1. Participants and procedure

Seventy-two undergraduate women from the University of Texas at Austin (mean age = 18.61 years, SD = 1.13) participated in Study 1 for course credits. A target sample size of at least 50 participants for the final analysis was chosen based on prior research in this field (Mehta & Josephs, 2006; Schultheiss et al., 2005). The stopping rule for data collection was to collect data until the end of the semester. Four women provided inadequate saliva samples that could not be assayed for testosterone concentrations, and three participants indicated suspicion about the competition manipulation. The final sample thus included 65 women (32 winners). Fifty-seven percent of the participants identified themselves as White/Caucasian, 23% as Asian, 20% as other. All testing sessions began between 11:00 am and 4:00 pm to control for diurnal hormone fluctuations (Campbell, Walker, Riadfahmy, Wilson, & Griffiths, 1982). Upon arriving, participants were welcomed by a female research assistant, read and signed an informed consent form, completed trait personality questionnaires for approximately 20–25 min, and provided a 1.5 mL saliva sample. Participants were unaware that they would be involved in a later competition when providing this first saliva sample, eliminating potential anticipatory effects on testosterone concentrations. Participants next were introduced to the experimental manipulation, which entailed a competition on seven rounds of the Number Tracking Task (Mehta & Josephs, 2006) ostensibly against another participant. In reality, this person was a female confederate. We experimentally manipulated the outcome of competition such that the participant either narrowly won or narrowly lost the competition (details below).

Immediately following the competition task, participants' affect was assessed using the PANAS (Watson, Clark, & Tellegen, 1988), which measures positive and negative mood. Each item corresponds to an adjective. Participants have to indicate to what extent they feel that specific emotional state (e.g., enthusiastic, interested, proud) at the moment of its administration. Surprise, which is absent in the list of the PANAS adjectives, was simply added as one of the items (the word "surprised" was added). At the same time that mood was assessed, participants completed additional questions related to enjoyment of the task, competitive motivation, and attributions of the contest outcome and then waited to provide a saliva sample at exactly 20 min after the end of the competition. Before leaving participants completed a demographic questionnaire and read the debriefing form.

3.2. Close competition task

The participant and one of two Asian female confederates were seated at separate desks facing opposite walls, and there was a timer on each desk. The Number Tracking Task consists of a series of puzzles containing a grid of numbers. The goal is to trace through the numbers in sequential order until a highlighted number is reached. The participant and the confederate competed on the same puzzles. Whoever completed each round in the least amount of time was declared the winner for that round. Seven rounds were played, and the context was manipulated so that the participants always completed each puzzle first and said "Done". The real participant was ostensibly randomly chosen to go first. The experimenter recorded and announced the time to complete the first puzzle, and then the confederate completed the same puzzle and announced "Done" upon competition. The experimenter again announced the time and declared the winner and loser in each round. The confederate was trained to either barely win or lose in each round of the competition by watching the timer in front of her. This was possible because the real participant completed the puzzle first in each round followed by the confederate. The competition was always tied at 3-3 going into the final round. The competition environment was tightly controlled in that participants were asked not to talk during the competition, and the margin of the victory and defeat in each round of the competition was experimentally manipulated. For participants randomly assigned to lose the contest, the confederate was trained to adjust win or lose times in each round by the following margins: win by 6 s, lose by 4 s, lose by 5 s, win by 3 s, lose by 2 s, win by 4 s, win by 2 s. For participants randomly assigned to win the contest, these margins were reversed: lose by 6 s, win by 4 s, win by 5 s, lose by 3 s, win by 2 s, lose by 4 s, and lose by 2 s. This protocol deviates from prior research on the Number Tracking Task in two important ways. First, prior research used two real participants who competed on the task at the same time (saying "Done" after competition of each puzzle) (Mehta & Josephs, 2006; Schultheiss et al., 2005) whereas the use of confederates in the current study allows for greater experimental control. Second, prior research on the Number Tracking Task experimentally manipulated the contest outcome by giving one participant an easier version of all puzzles than the other participant, but the difference in difficulty between the puzzles was substantial in order to guarantee random assignment to the victory or defeat condition. This procedure results in large margins between participants randomly assigned to win or lose the task with variability around these margins. For example, in the study reported in Mehta and Josephs (2006), the average time difference across six puzzles of the Number Tracking Task was 116 s (almost 2 min), whereas the average times between winners and losers in the present study was only a few seconds.

3.3. Hormone assays

Participants were instructed to abstain from eating, drinking, smoking, or brushing their teeth for 1 h before testing. Saliva samples were collected using passive drool. Samples were chilled immediately following collection, and then frozen within 1 h and held at −80 °C until assay. The saliva samples were shipped on dry ice to Yerkes Biomarkers Laboratory (Emory University, Atlanta, GA). The samples were analyzed in duplicate for testosterone concentrations using RIA and cortisol concentrations using EIA (Diagnostic Systems Laboratories – DLS, Webster, TX). For testosterone, the intra-assay coefficient of variation was 11.6%, and the inter-assay coefficient of variation averaged across high and low controls was 16.24%. Out of the 65 participants analyzed for this study, an additional two women had insufficient saliva to assay for cortisol. Thus, cortisol analyses were conducted for the remaining 63 women. For cortisol, the inter-assay coefficient of variation averaged across high and low controls was 3.50%, and the intra-assay coefficient of variation is expected to be approximately 9% based on information from another dataset. Due to a clerical error, the laboratory failed to provide intra-assay CVs for cortisol in this particular study, and electronic communication with the laboratory indicates that this information cannot be recovered along with a note that the all CVs were under 20%. Another study in the same population found an average cortisol intra-assay CV of 8.56% using this laboratory. Given all of this information, we remain confident that measurement reliability of cortisol in the present study was sufficient. Further corroborating the reliability of cortisol measurement in the present study, we found the expected positive correlation between basal testosterone and basal cortisol that has been reported in prior research ($r = 0.40$, $p = 0.001$) (Mehta & Josephs, 2010) as well as temporal stability of cortisol concentrations from time 1 to time 2 ($r = 0.65$, $p < 0.001$). Descriptive statistics for baseline and post-competition cortisol concentrations are presented in Table 1. Fig. 1 shows baseline and post-competition testosterone concentrations. Baseline testosterone and cortisol means are

Table 1
Descriptive statistics for cortisol in Study 1.

	Winners and losers ($n=63$)		Winners ($n=30$)		Losers ($n=33$)	
	M (SEM)	SD	*M* (SEM)	SD	*M* (SEM)	SD
Pre-competition cortisol (μg/dL)[a]	0.58 (0.03)	0.28	0.61 (0.06)	0.31	0.55 (0.04)	0.24
Post-competition cortisol (μg/dL)	0.40 (0.03)	0.2	0.42 (0.05)	0.25	0.38 (0.02)	0.14

[a] Basal levels of cortisol were not different between randomly assigned winners and losers [$t(63)=-0.898$, $p=0.373$].

similar to prior research that also used DSL kits (Mehta & Josephs, 2010).

4. Study 1: results and discussion

The BMS predicts that winners should show an increase in salivary testosterone relative to losers, whereas the *status instability hypothesis* predicts that in the case of the close competition examined in Study 1 – which models unstable status hierarchies – the reverse pattern may emerge, with losers experiencing an increase in testosterone relative to winners, presumably to motivate future status-seeking behavior.

In order to investigate this possibility, we assessed the effect of the contest outcome on hormonal reactivity using an independent-groups *t*-test. Testosterone change was measured by saving unstandardized residuals after regressing post-manipulation concentrations onto basal concentrations (Mehta & Josephs, 2006). Results supported the status instability hypothesis, not the BMS: losers of the competition ($M=1.87$, $SD=8.7$) demonstrated an increase in testosterone compared to winners ($M=-1.93$, $SD=5.4$) [$t(63)=2.099$, $p=0.04$, $d=0.53$], suggesting that the absence of a clear winner led to a net increase in testosterone in barely defeated individuals (see Fig. 1 for mean pre- and post-competition testosterone concentrations). In particular, 57.6% of losers increased in testosterone compared to 40.6% in winners. Repeating this analysis with cortisol did not yield significant results (*M* losers $=-0.00414$, $SD=0.1196$; *M* winners $=0.00455$, $SD=0.1832$) [$t(61)=-0.225$, $p=0.823$, $d=0.056$].

Self-reported positive and negative affect had good internal consistency (Cronbach's alpha = 0.91 and 0.85, respectively). Self-reported positive mood did not statistically differ between the two conditions [$t(63)=-1.347$, $p=0.183$]. There was a marginally significant effect of competition outcome on negative mood such that losers showed less negative affect ($M=1.24$, $SD=0.35$) than winners ($M=1.47$, $SD=0.6$, $t(49.194)=-1.820$, $p=0.075$, $d=0.47$], but negative mood did not moderate the effect of competition outcome on testosterone reactivity [$\beta=-0.118$, $p=0.406$]. Also surprise did not differ between the two conditions [$t(63)=-0.308$, $p=0.759$] and did not further qualify the main effect of contest outcome on testosterone reactivity [$\beta=-0.172$, $p=0.162$].

5. Study 2

Study 1 provides evidence for a reverse winner–loser effect (for similar results, see Oliveira et al., 2013) in support of a status instability hypothesis. Study 2 extended Study 1 in three important ways. First, Study 2 participants were involved in a competition to emphasize another relevant aspect typical of unstable social hierarchies: uncertainty regarding relative performance during competition. Pairs of female undergraduates competed in two separate rooms on a modified version of a commercial videogame, Tetris. Throughout the competition no feedback was given,

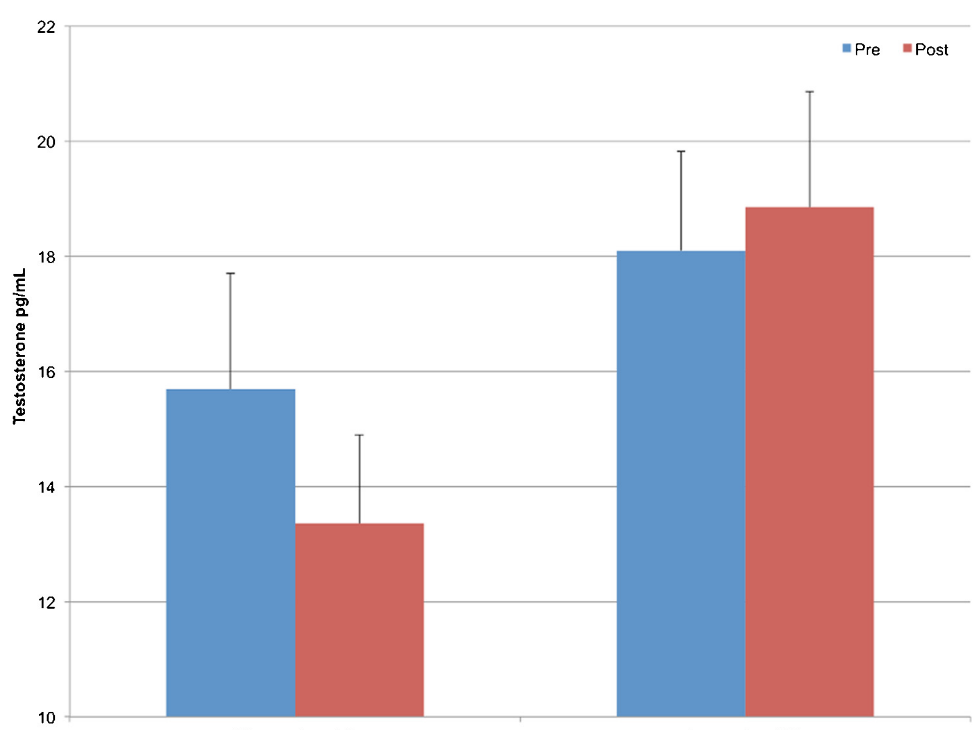

Fig. 1. Study 1 mean (SEM) salivary concentrations of testosterone before and after victory and defeat. The total number of participants per condition is reported in brackets. Basal levels of testosterone were not different between randomly assigned winners and losers [$t(63)=0.915$, $p=0.364$].

preventing both participants from assessing their performance relative to their opponents, and thereby creating uncertainty as to who the eventual winner would be. Second, information about use of oral contraceptives and information about the menstrual cycle (Puts, 2006, p. 120) was collected and controlled in the analyses. Third, surprise was not assessed through a single-item question, but rather through a more comprehensive standardized measure (Watson & Clark, 1994).

6. Method

6.1. Participants and procedure

Fifty-six female undergraduates from Simon Fraser University (mean age = 20 years, SD = 2.7) served as participants for course credits, following elimination of one pair whose experimental session was not run properly. Fifty-five percent of the participants identified themselves as Asian, 29% as White/Caucasian, 16% as other. As in Study 1, in order to reduce diurnal hormone variability, test sessions were conducted between 13:30 h and 18:30 h. Upon arriving, each pair of competitors was greeted by a female experimenter and completed an informed consent. Participants were directed to separate small testing rooms. Before collecting the first saliva sample (T1) participants completed the BIS/BAS questionnaire (Carver & White, 1994) (intended for a different study), answered a few questions about the upcoming competition and a self-report measure of experience playing videogames (adjusted from Terlecki & Newcombe, 2005). After collection participants were given instructions for the competition task and were informed that there would be a cash prize – to further intensify the contest the winner would receive 10 dollars. Five minutes after the collection of the T1 saliva sample participants were instructed to begin the game on the experimenter's signal, after which doors to the two participants' rooms were shut for the duration of the experimental task. This consisted of a rigged competition on a modified version of a well-known commercial videogame, Tetris (see below). Following the competition participants' mood was assessed through the PANAS-X (Watson & Clark, 1994). *Surprise* is one of the scales of PANAS-X and contains the following adjectives: amazed, surprised and astonished. Participants also filled out an attribution questionnaire designed to obtain feedback about the experiment up to that point and a cognitive test. A neutral video (a documentary about Ireland) served as a filler task prior to collection of the second saliva sample, which was taken at exactly 20 min following completion of the competition. Participants completed a demographic questionnaire and read a debriefing form at the end of the experimental session.

6.2. Competition task

Pairs of participants believed they were competing against each other via two linked computers, but in reality they were interacting only with the computer. The game difficulty was the same for both the win and lose conditions, and throughout the competition no feedback was given, so participants were unable to assess their performance relative to their opponents. At completion of the contest, the message "you win!" on a colorful background was displayed on the winner's screen, while the loser's screen displayed "you lose!" on a drab background. No participant reported suspicion about the rigged nature of the competition; however, in the post-competition questionnaire two winners reported no understanding of the Tetris instructions and one loser reported impaired hand mobility. For these reasons, the final sample was reduced to 53 women (26 winners).

Study 1 tightly controlled the relative performance of competitors throughout the competition to model a close victory or defeat. Unlike this prior study, participants in Study 2 had no information about their opponent's performance throughout the task, suggesting that participants would use their own task performance and task expertise to derive expectations about the competition outcome (and, presumably, drive their neuroendocrine responses). The average Tetris score was 3739.45 points (SD = 2522.75) for a 15-min game, but there was a cluster of four very low-performing women (two winners) who likely did not understand the task instructions (score less than 100 points). Because this extreme low-performance group may have had a radically different experience of the game, we conducted separate analyses both with and without this group of participants.

6.3. Hormone assays

Participants were instructed to abstain from eating, drinking, smoking, or brushing their teeth for 1 h before testing. Saliva samples were collected using Salimetrics oral swabs (SOS) placed under the tongue. Samples were chilled immediately following collection, and then frozen within 1 h and held at −20 °C until assay in our laboratory at SFU. On the day of the assay, frozen samples were first warmed to room temperature and then centrifuged (3000 rpm) for 15 min in order to extract saliva from the swabs. Samples were then assayed in duplicate using ELISA for testosterone and cortisol (Salimetrics). For testosterone, the average intra-assay coefficient of variation was 4.4% and the inter-assay coefficient was 8.4%. For cortisol, the intra-assay coefficient of variation was 6.5%, and the inter-assay coefficient of variation averaged across high and low controls was 6.1%. Descriptive statistics for baseline and post-competition cortisol concentrations are presented in Table 2. Fig. 2 shows baseline and post-competition testosterone concentrations. Baseline testosterone and cortisol means are similar to prior research that also used Salimetrics kits (Kuzawa, Gettler, Huang, & McDade, 2010). Consistent with Study 1, testosterone and cortisol change was measured by saving unstandardized residuals after regressing post-manipulation concentrations onto basal concentrations (Mehta & Josephs, 2006). On average, participants dropped in testosterone consistent with circadian rhythms in testosterone (see Fig. 2). Thus, any difference in hormone change scores between conditions should be interpreted as resisting circadian decline in the condition with higher hormone changes scores (for a similar example, see Stanton et al., 2009).

7. Study 2: results and discussion

Similarly to a head-to-head contest, where the outcome is decided at the very end and where a clear winner–loser distinction is lacking, participants in Study 2 were engaged in a competition characterized by uncertainty. We tested whether this aspect of competition leads to the same pattern of testosterone response observed in Study 1. We first tested our hypothesis excluding the cluster of four extremely low-performing participants. This analysis replicated the reverse win–lose effect shown in Study 1 [*M* winner = −3.55, SD = 12.3; *M* loser = 3.41, SD: 10.7; $t(47) = 2.108$, $p = 0.04$, $d = 0.60$, but note that this effect should be interpreted as losers resisting circadian decline, see Fig. 2 for mean pre- and post-competition testosterone concentrations, see also Stanton et al., 2009]. This finding remained significant when controlling for menstrual cycle [$F(1,42) = 4.478$, $p = 0.040$, this information was missing for four women]. Seven women reported using hormonal contraceptives; however, in accordance with previous work on women competition (Edwards & O'Neal, 2009; Oliveira et al., 2013), controlling for this variable did not change the pattern of

Table 2
Descriptive statistics for cortisol in Study 2.

	Winners and losers ($n=53$)		Winners ($n=26$)		Losers ($n=27$)	
	M (SEM)	SD	*M* (SEM)	SD	*M* (SEM)	SD
Pre-competition cortisol (μg/dL)[a]	0.21 (0.02)	0.16	0.20 (0.03)	0.14	0.22 (0.03)	0.18
Post-competition cortisol (μg/dL)	0.13 (0.01)	0.06	0.12 (0.01)	0.05	0.13 (0.01)	0.06

[a] Basal levels of cortisol were not different between randomly assigned winners and losers [$t(51)=-0.533$, $p=0.597$].

results [$F(1,46)=4.48$, $p=0.040$]. Lastly, similarly to Study 1, cortisol reactivity was not different between the two conditions (*M* losers = −0.00502, SD = 0.0456; *M* winners = −0.00523, SD = 0.0385) [$t(47)=0.848$, $p=0.401$, $d=0.005$]. Thus, across two studies, we demonstrate a reverse win–lose effect on testosterone responses to competition.

We next conducted analyses including the cluster of four extreme low-performing women. Consistent with our expectations that this cluster of low-performing participants experienced a different pattern of neuroendocrine responses, the reverse win–lose effect was again evident, but with reduced strength [$t(51)=1.682$, $p=0.099$, $d=0.46$]. In particular, 40% of losers increased in testosterone compared to only the 12.5% in winners. A similar pattern emerged when controlling for menstrual cycle [$F(1,46)=2.870$, $p=0.097$] and hormonal contraceptives use [$F(1,50)=2.728$, $p=0.105$]. This pattern suggests that variability in psychological responses to the competition may explain reverse win–lose effects, which we explore in our next set of analyses.

Contests in which dominance is not clearly established are characterized by uncertainty. Uncertainty can be accompanied by a psychological state of surprise when expectations about the competition outcome deviated from expectations. In our sample, the *Surprise* scale had good internal consistency (Cronbach's alpha = 0.76) and losers reported experiencing this state less than winners at the end of the competition [$t(47)=-2.357$, $p=0.023$]. To test the hypothesis that surprise would moderate testosterone reactivity we ran a linear multiple regression with testosterone unstandardized residuals as the dependent variable and the following variables as predictors: competition outcome (−1 for losers and 1 for winners), self-reported surprise (centered) and the competition outcome × surprise interaction term. The overall regression model was significant [$R^2=0.204$, adjusted $R^2=0.151$, $F(3,45)=3.852$, $p=0.015$] and a significant competition outcome × surprise interaction emerged [$\beta=-0.313$, $p=0.025$] indicating that surprise moderated the influence of competition outcome on testosterone changes. Simple slope analyses (Aiken & West, 1991) revealed that competitors who were most surprised by the outcome of the competition showed the strongest evidence of a reverse win–lose effect [1 SD above the mean: $\beta=-0.704$, $p=0.002$]. We also computed simple slopes between surprise and testosterone response in winners and losers separately. There was a positive slope between surprise and testosterone responses in losers [$\beta=0.535$, $p=0.016$], but there was a null association between surprise and testosterone responses in winners [$\beta=-0.126$, $p=0.502$] (Fig. 3). These results indicate that it was especially the individuals who lost and experienced surprise who showed an increase in testosterone, relative to individuals who lost and were not surprised. The competition outcome × surprise interaction remained significant when the analyses were extended to the cluster of four extreme low-performing women [$\beta=-0.291$, $p=0.034$], after controlling for hormonal contraceptives use [$\beta=-0.287$, $p=0.034$] or menstrual cycle [$\beta=-0.342$, $p=0.019$].

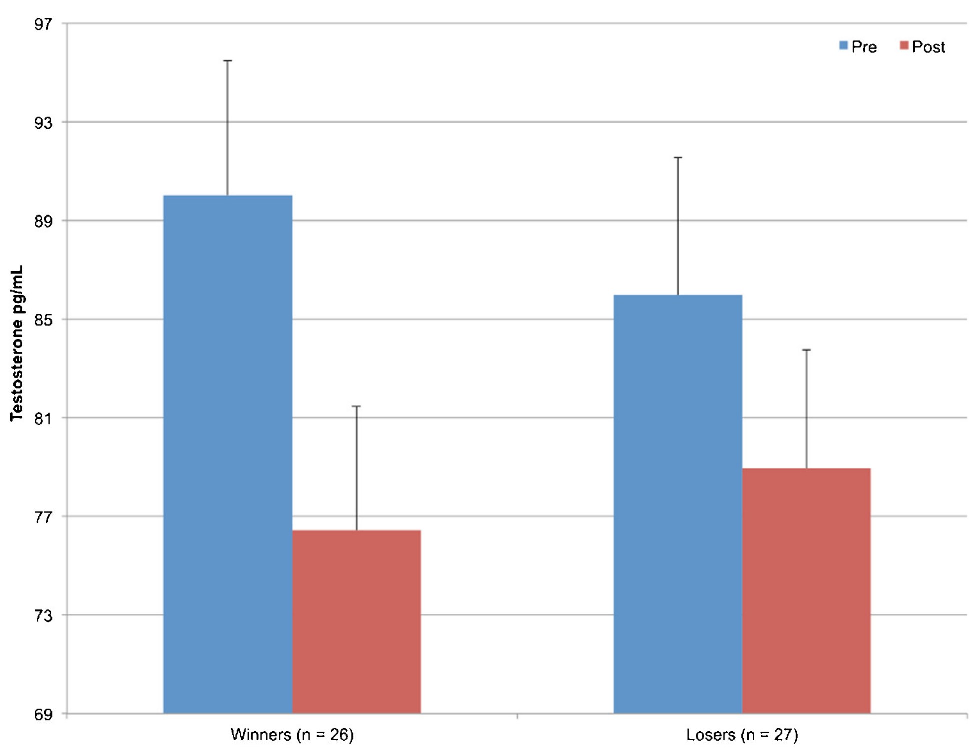

Fig. 2. Study 2 mean (SEM) salivary concentrations of testosterone before and after victory and defeat. The total number of participants per condition is reported in brackets. Basal levels of testosterone were not different between randomly assigned winners and losers [$t(51)=-0.520$, $p=0.606$].

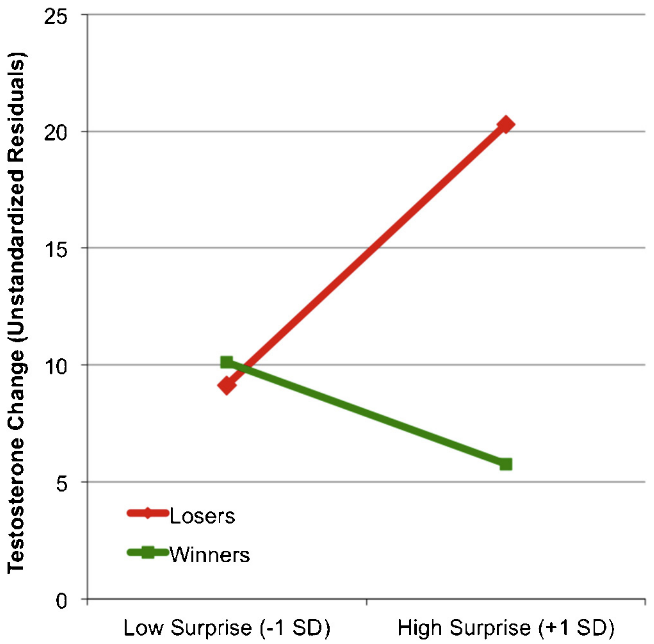

Fig. 3. Testosterone changes (unstandardized residuals) in winners and losers (victory vs. defeat) as a function of surprise in Study 2.

Similar analyses were run using positive and negative mood as covariates instead of surprise (Cronbach's alpha = 0.86 and 0.84 respectively). Although there was a statistically difference in negative affect [M winner = 1.53, SD = 0.47; M loser = 1.87, SD: 0.67; $t(43.109) = 2.045$, $p = 0.047$, $d = 0.59$] and a marginally significant difference in positive affect [M winner = 2.94, SD = 0.72; M loser = 2.54, SD: 0.79; $t(47) = -1.866$, $p = 0.068$, $d = 0.53$] between winners and losers at the end of the competition, we found no evidence for a moderating role of these higher order affective constructs on testosterone responsiveness [competition outcome × positive affect, $\beta = -0.166$, $p = 0.243$; competition outcome × negative affect $\beta = 0.011$, $p = 0.942$].

8. Internal meta-analysis

As a final analytical step, we conducted an internal meta-analysis across both studies to capitalize on statistical power and to estimate the aggregate effect size of the reverse win–lose effect. Testosterone change was measured by saving standardized residuals after regressing post-manipulation concentrations onto basal concentrations keeping the two studies separate. This analysis revealed a statistically significant reverse win–lose effect (M winner = −0.244, SD = 0.86; M loser = 0.236, SD: 1.08; $t(116) = 2.708$, $p = 0.008$] with an estimated effect size of $d = 0.5$. The combined p value, calculated following Rosenthal (Rosenthal, 1991), was equal to 0.007.

We also estimated the aggregate effect size of the Competition Outcome × Surprise interaction (surprise scores were centered using the overall mean across the two studies) on testosterone reactivity across both studies. This analysis revealed a statistically significant Competition Outcome × Surprise interaction when data were aggregated across both studies [$\beta = -0.213$, $p = 0.020$]. Simple slope analyses (Aiken & West, 1991) revealed that competitors who were most surprised by the outcome of the competition showed the strongest evidence of a reverse win–lose effect [1 SD above the mean: $\beta = -0.495$, $p < 0.001$]. We also computed simple slopes between surprise and testosterone response in winners and losers separately. There was a positive slope between surprise and testosterone responses in losers [$\beta = 0.262$, $p = 0.056$], but there was a non-significant negative association between surprise and testosterone responses in winners [$\beta = -0.168$, $p = 0.168$].

9. General discussion

The BMS (Mazur & Booth, 1998) has been the predominant theory for explaining how the outcome of dominance contests influences testosterone responses. However, its applicability to women is a matter of a current debate (Salvador & Costa, 2009), and the role of contextual factors has been overlooked. The aims of this research were thus: (1) to test whether the BMS can be generalized to those contests that model unstable social hierarchies, namely close competitions wherein the winner–loser distinction is unsettled (Study 1) or uncertain competitions in which no performance feedback is given (Study 2); and, (2) to shed light on the psychological states that might accompany endocrine responses. In both studies we found evidence for a reverse winner–loser effect, whereby losers increased in testosterone relative to winners. Moreover, in Study 2 we found that the emotional state of surprise moderated the reverse winner–loser effect such that participants who were more surprised about their defeat experienced larger increases in testosterone. An internal meta-analysis across both studies suggested a statistically reliable reverse win–lose effect that was stronger among competitors who were surprised by the outcome. In both studies, this effect seemed to be specific to the hypothalamic–pituitary–gonadal (HPG) axis as no significant changes in cortisol were observed.

A possible explanation of this pattern of results resides in the status instability hypothesis, the idea that attaining an unstable lower dominance position (narrow defeat) should result in increased testosterone, so as to encourage dominance-seeking behaviors, in contrast to individuals in unstable higher dominance positions (narrow victory). Insecure dominance ranks may lead individuals with unstable high status to actively avoid further competition in order to maintain their higher yet potentially vulnerable social rank (Ellemers & Basrreto, 2000; Nadler & Halabi, 2006; Sapolsky, 2005). Testosterone therefore could function as a biological agent in status-seeking behaviors after uncertain loss of status (Mehta & Josephs, 2006).

Recent findings in social psychology echo this notion (Jordan, Sivanathan, & Galinsky, 2011; Lammers, Galinsky, Gordijn, & Otten, 2008; Scheepers & Ellemers, 2005; Scheepers, 2009). Scheepers and Ellemers (2005), for example, reported that high status group members showed an increase in blood pressure – a physiological response that is often associated with a psychological state of threat and associated with behavioral avoidance (Blascovich & Mendes, 2000) – when faced with the possibility of losing their position. Convergent findings are reported in the study of Lammers et al. (2008), which investigated whether positions of status (i.e., power) obtained legitimately – e.g., perceived as fair and stable by the individual – led to the same behavioral consequences as positions of status that were obtained illegitimately. Across four experiments, it was found that people assigned to legitimate high status positions (i.e., powerful individuals) showed more behavioral approach (Carver & White, 1994; Keltner, Gruenfeld, & Anderson, 2003) than people assigned to legitimate low status position (i.e., powerless individuals). However, when status was experienced as illegitimate, the association between power and behavioral approach was reversed, with powerless individuals displaying more approach than powerful individuals (Lammers et al., 2008). In our Study 1, status was manipulated so as to appear precarious. The decrease in testosterone that we observed in winners might reflect the psychological/behavioral state of avoidance/inhibition. Complementary to this, the testosterone increase in participants who narrowly lost might subserve approach behaviors such as those reported by Lammers et al. (2008).

The status instability hypothesis offers also a conceptual framework that agrees with an additional finding of Study 2, namely the positive association in losers between the emotional state of surprise and testosterone reactivity. Social hierarchies in which dominance is not clearly established or is perceived as illegitimate are characterized by uncertainty (Bettencourt, Charlton, Dorr, & Hume, 2001; Nadler & Halabi, 2006; Sapolsky, 2005). In turn, uncertainty can be accompanied by a psychological state of surprise when expectations are violated. For example, defeated individuals might experience surprise and discomfort about their status conferral if during the competition they felt in control and/or confident about their performance or if they perceive that the asymmetries between them and their opponent were small. Acutely increased testosterone may thus serve as a modulator for the motivational drive to regain status after an unexpected surprising defeat (Mazur & Booth, 1998; Mehta & Josephs, 2006). The idea that testosterone increases after losing status might be preparatory for future encounters has been recently proposed by Oliveira et al. (2013), who recently ran an experiment very similar to those reported here. In a sample of 34 women, the authors used the Number Tracking Task (three rounds, four duels per round) as their competition task and manipulated it such that participants would have the same number of victories and defeats before entering the third round. In the last round, the winner was assigned to win all four duels, while the loser was assigned to lose all of four duels. Although the score difference between losers and winners in Oliveira et al.'s study (four duels) was higher than the difference in our study (one duel), the progression of the game was somehow comparable as in both studies participants entered the final round with the same amount of victories. The authors found that losers of the competition had an increase in testosterone (but not cortisol) compared to winners, and that this androgenic response was particularly pronounced in those losers who reported a less degree of familiarity with the opponent and experienced the defeat as more threatening (Oliveira et al., 2013). This introduces the possibility that various facets of the transient emotional state (e.g., feelings of threat) along with surprise modulate testosterone responses to competitive interaction.

To our knowledge, the only previous study that investigated the impact of victory type (Close vs. Decisive) on men's testosterone changes was run by Gladue et al. (1989). The authors found that winners had higher post-competition testosterone than losers, regardless of how they won (Close vs. Decisive). Thus, although the status instability hypothesis is appealing, it awaits further confirmatory evidence before being generalized to men. Furthermore, more studies are needed in both males and females that experimentally manipulate the stability versus instability of the social hierarchy in the same study in order to test the status instability hypothesis more directly (e.g., comparing close versus decisive competitions in the same study, comparing competitions in which relative performance is given throughout the competition versus withheld until the end of the competition).

The present research brings up several additional questions that remain important topics for future research. First, recent research suggests that merely asking participants to report on psychological states such as mood after an emotion manipulation can influence subsequent cardiovascular changes (Kassam & Mendes, 2013). There is no empirical evidence that the presence or absence of reporting psychological states influences subsequent neuroendocrine changes in competition, and this is not a likely explanation for the reverse winner–loser effects identified in the present research because prior studies also ask participants to report psychological states after competing (Mehta & Josephs, 2006; Oliveira et al., 2013; Schultheiss et al., 2005). Nevertheless, it would be interesting for future experiments to manipulate whether or not psychological states such as mood are or are not reported after competing to determine to what extent this manipulation influences hormone changes. Second, variables that may impact hormone concentrations such as menstrual cycle, BMI, and medication use were not recorded in Study 1 as they were in Study 2. These factors are unlikely to explain hormone response patterns in Study 1 due to random assignment and because the effects conceptually replicated Study 2, but follow-up studies are needed to confirm this conclusion.

In summary, across two studies we found that women who lost competitive interactions either without a clear cut triumph (Study 1) or characterized by uncertainty (Study 2) – both typical aspects of unstable social hierarchies – experienced an increase in salivary testosterone compared to winners. Moreover, in Study 2, this effect was stronger in those women who reported greater surprise about the verdict of the contest. These results provide some of the first empirical evidence for a reversal of the predictions of the BMS and are interpreted in term of the emotional-motivational states toward dominance that testosterone might subserve in competitors subjugated within unstable status hierarchies. Further research is required to clarify whether this hypothesis exclusively applies to female status dynamics or can be extended to males' dominance interactions as well.

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