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Changes in testosterone mediate the effect of winning on subsequent aggressive behaviour

Justin M. Carré *, Jocelyn A. Campbell, Elianna Lozoya, Stefan M.M. Goetz, Keith M. Welker

Wayne State University, United States

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Summary Testosterone concentrations rise rapidly in the context of competitive interactions and remain elevated in winners relative to losers. Theoretical models suggest that this divergent neuroendocrine response serves to mediate future dominance behaviours. Although research in animal models provides compelling support for this model, evidence for its applicability to human social behaviour is limited. In the current study, men and women were randomly assigned to experience a series of victories or defeats, after which aggressive behaviour was assessed using a well-validated behavioural measure. Winning produced elevated testosterone concentrations relative to losing in men, but not women. More importantly, testosterone reactivity to competition mediated the effect of winning on subsequent aggressive behaviour in men, but not women. We discuss limitations of the current study (e.g., the status manipulation may have affected other variables not measured in the study including competitiveness and physical activity expended), as well as discuss a potential neural mechanism underlying the effect of testosterone reactivity on aggressive behaviour.

1. Introduction

Testosterone plays a critical role in modulating aggressive behaviour in numerous animal species, yet its relationship to human aggression remains controversial (Eisenegger et al., 2011). Most human studies examining the association between testosterone and aggression have correlated testosterone concentrations obtained at a single point in time with aggressive behaviour measured using self-report, laboratory-based tasks, or court records. Meta-analyses of this work have revealed a small, yet significant association between baseline testosterone concentrations and various measures of human aggressive behaviour (see Archer et al., 2005; Archer, 2006 for meta analyses). A limitation of this work is that testosterone concentrations are not static, but rather fluctuate rapidly in the context of competitive interactions (see Archer, 2006 for review). Indeed, rapid fluctuations in androgens during competition are found across animal species including birds (Wingfield et al., 1990), fish (Oliveira, 2009), insects (Scott, 2006), non-human primates (Cavigelli and Pereira, 2000) and humans (Archer, 2006). It has been suggested that context dependent changes in

* Corresponding author at: Department of Psychology, Wayne State University, 5057 Woodward Avenue, Detroit, Michigan 48202, United States. Tel.: +1 519 995 6205.
E-mail address: jcarre14@gmail.com (J.M. Carré).

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testosterone may be a biological mechanism for rapidly adjusting dominance behaviour in the face of social challenges (Wingfield et al., 1990). Thus, it may be that acute fluctuations in testosterone, rather than baseline levels of testosterone, are more relevant to our understanding of individual differences in human aggressive behaviour (Carré et al., 2011).

A growing body of evidence also indicates that changes in testosterone concentrations during competition depend critically on the outcome, with testosterone concentrations typically rising in winners relative to losers (Archer, 2006). In humans, this pattern of testosterone reactivity has been observed in competitive athletes (Elias, 1981), laboratory-based competition tasks (Gladue et al., 1989), voters of political elections (Stanton et al., 2009), stock traders (Coates and Hebert, 2008) and sport spectators (Bernhardt et al., 1998). What evolutionary function does this divergent testosterone response pattern serve? Mazur's (1985) biosocial model of status suggests that rising testosterone in winners serves to increase subsequent dominance behaviours aimed at defending and/or gaining further social status, whereas decreasing testosterone in losers serves to increase submissive behaviours aimed at avoiding further threats to status. Given the fitness benefits of elevated status and the costs of failed attempts to gain status, a highly flexible neuroendocrine system capable of integrating status related contextual cues (e.g., victory or defeat) with behavioural output (e.g., dominant or submissive behaviour) might be adaptive in an ever-changing social environment.

Evidence in animal models indicate that winning an aggressive interaction increases one's probability of winning subsequent interactions, while losing has the opposing effect (Dugaktin, 1997; Hsu and Wolf, 1999). Experimental work in animal models provides compelling support for the idea that testosterone reactivity mediates the effect of winning on subsequent competitive and aggressive behaviour. Specifically, an increase in testosterone after a victory is necessary to increase both future aggressive behaviour (Trainor et al., 2004; Gleason et al., 2009) and the animal's probability of winning a future competitive encounter against a novel opponent (Fuxjager et al., 2010; Gleason et al., 2009; Oliveira et al., 2009a). There is some evidence in studies of people demonstrating that testosterone reactivity to competition predicts subsequent willingness to compete again (Mehta and Josephs, 2006) and aggressive behaviour in men (Carré et al., 2009).

In the current experiment, we used a novel competition paradigm (Xbox Kinect video game) in which participants were able to fully immerse themselves in sport competition (see Supplementary Video S1 and S2). Unknown to participants, the game was rigged such that half of the participants were assigned to a win condition and half to a loss condition. Specifically, prior to participants' arrival to the laboratory, we programmed the Xbox video game such that participants played against a very difficulty or very easy computer opponent. After playing the video game, participants were taken to a separate room where they were paired with another same-sex opponent and played the point subtraction aggression paradigm (PSAP). Based on the animal literature (Fuxjager et al., 2010; Gleason et al., 2009; Oliveira et al., 2009b; Trainor et al., 2004) and predictions derived from the biosocial model of status (Mazur, 1985), we hypothesized that winners would demonstrate an increase in testosterone and would be more aggressive in a subsequent interaction relative to losers. Further, we predicted that testosterone responses to the video game would mediate the association between competition outcome (win vs. loss) and subsequent aggressive behaviour. That is, winning would produce a significant increase in testosterone, and this endocrine response would in turn be associated with increased aggressive behaviour. We also predicted that although mean levels of testosterone would decrease after a defeat, individual differences in testosterone reactivity among losers would be positively correlated with aggressive behaviour (e.g., Carré et al., 2009). In other words, individuals who did show a rise in testosterone after a defeat would be more aggressive than the majority of losers who decreased in testosterone. Finally, given the scarcity of research examining sex-dependent associations between testosterone and aggressive behaviour, we examined whether associations between testosterone reactivity, competition outcome, and aggressive behaviour would be found in men and women.

2. Methods

2.1. Participants

Undergraduate students ($N = 237$, 52% women, mean age = 21.73, $SD = 4.66$) were recruited from the Wayne State University (WSU) Research Participation Pool. Participants received partial research credit and a $10 honorarium for their participation. The WSU Institutional Review Board approved all procedures.

2.2. Procedure

Saliva samples were obtained from participants before and after they played an Xbox Kinect video game (between 11 am and 5 pm). Participants were randomly assigned to one of four experimental conditions that differed in the type of game played (boxing vs. volleyball) and the outcome of the game (win vs. loss). We included a competitive game with aggressive content (boxing) and one without aggressive content (volleyball) with the hypothesis that competitive games with aggressive content would elicit a more robust testosterone response and have a larger effect on subsequent aggressive behaviour. However, preliminary analyses indicated that type of video game (boxing vs. volleyball) did not influence testosterone reactivity or aggressive behaviour ($ps \geq 0.364$), nor did it interact with sex and/or game outcome to predict testosterone reactivity or aggression ($ps \geq 0.127$). Thus, all analyses were collapsed across type of video game. After the video game, participants completed a questionnaire assessing whether they found the game exciting, frustrating, difficult, enjoyable, and fast paced. Next, participants were paired with another same-sex participant (actually a computer program) and performed the point subtraction aggression paradigm (PSAP; Cherek et al., 2006; see Fig. 1 for experimental timeline). The PSAP is a well-validated behavioural measure of reactive aggression (see Cherek et al., 2006 for review) in which participants were told they were

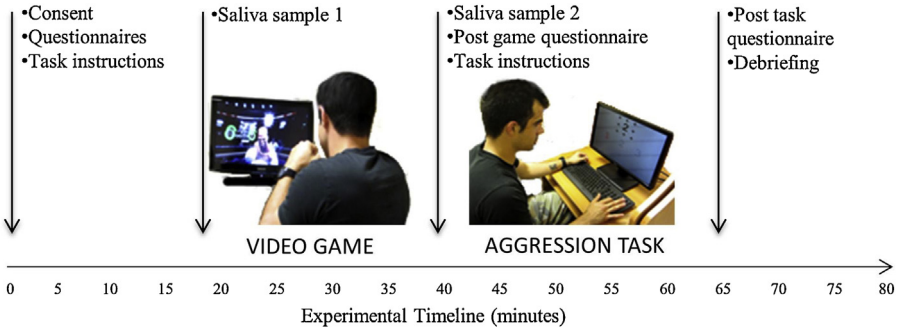

Figure 1 Experimental timeline.

playing the game with another same-sex participant and the goal of the task was to earn as many points as possible, which were later exchangeable for money. Participants had three response options: button 1 earned points after a hundred consecutive presses; button 2 stole points after ten consecutive presses; and button 3 protected points after ten consecutive presses. Throughout the task, points were randomly stolen from participants and this was attributed to their partner who got to keep all the points. Participants could steal points back, but were told they had been assigned to the experimental condition whereby they did not get to keep stolen points. Participants were told that at the end of the game, they would be paid based on how many points they accumulated during the task and that their game partner would be paid based on how many points he/she accumulated during the task. The PSAP consisted of three blocks, each lasting 7 min. Because of the parameters of the PSAP, aggressive responses are correlated with both Reward and Protection responses (accounting for 53% of the variance in aggressive behaviour in the current study). Given our specific interest in aggressive behaviour, we computed aggressive behaviour by regressing average aggressive responses onto average Reward and average Protection responses and saved the unstandardized residuals. This procedure removes variance in aggression that is explained by Reward and Protection responses, enabling us to investigate how much additional variance in aggression is uniquely explained by sex, competition outcome and testosterone reactivity.

2.3. Testosterone measurement

Saliva samples were collected in polystyrene tubes via unstimulated passive drool and stored at −20 °C until assayed. Intra-assay coefficient of variation for male samples was 9.30% and for female samples was 12.47%. Testosterone concentrations were higher in men (M_{pre} = 93.83 pg/ml, SE = 3.80) compared to women (M_{pre} = 41.09 pg/ml, SE = 1.86; $p < 0.001$, Cohen's d = 1.71). In accordance with other human research examining competition induced testosterone dynamics (e.g., Mehta and Josephs, 2006; Carré et al., 2009; Schultheiss et al., 1999) testosterone reactivity was measured by regressing post-video game testosterone concentrations onto pre-video game testosterone concentrations and saving the unstandardized residuals. We also computed testosterone reactivity as a percent change from baseline ([post-testosterone − pre-testosterone]/pre-testosterone) and absolute change from baseline (post-testosterone − pre testosterone) to examine whether these different methods of computing testosterone change would produce comparable results.

2.4. Statistical analyses

Aggression data from 11 participants were lost due to computer malfunction and 8 participants did not provide sufficient saliva for testosterone analyses. Four univariate outliers were identified and their values were winsorized to ±3 SDs.[1] Analyses of variance (ANOVAs) were performed with post-video game questionnaire responses, changes in testosterone and aggressive behaviour as dependent variables and sex (male vs. female) and outcome (win vs. loss) as between-subject variables. Also, mediation analyses using bootstrapping, which is recommended for small samples (Shrout and Bolger, 2002) with 5000 resamples were computed to generate 95% bias corrected confidence intervals for indirect effects (Preacher and Hayes, 2008). Significant indirect effects are indicated by confidence intervals that do not contain 0.

3. Results

3.1. Post-video game questionnaire responses

To investigate if sex and competitive outcomes affected participants' perceptions of the game, a 2 (sex: male vs. female) × 2 (outcome: win vs. loss) MANOVA was conducted on the video game questionnaire items. This analysis revealed main effects of outcome, indicating that losers reported the game as less enjoyable ($F(1, 212) = 11.24$, $p = 0.001$, $\eta_p^2 = .05$) and more frustrating ($F(1, 212) = 172.78$, $p < 0.001$, $\eta_p^2 = .45$), difficult ($F(1, 212) = 438.39$, $p < 0.001$, $\eta_p^2 = .67$), and fast paced ($F(1, 212) = 13.91$, $p < 0.001$, $\eta_p^2 = .06$). Losers also reported the game as marginally less exciting ($F(1, 212) = 3.03$, $p = 0.083$, $\eta_p^2 = .01$). Women found the game marginally more difficult ($F(1, 212) = 3.52$, $p = 0.062$, $\eta_p^2 = .02$) and fast paced ($F(1, 212) = 2.78$, $p = 0.097$, $\eta_p^2 = .01$). There were no other main

[1] The significance of the results from the main analyses remained the same when using non-winsorized data and/or when removing the univariate outliers from the analyses.

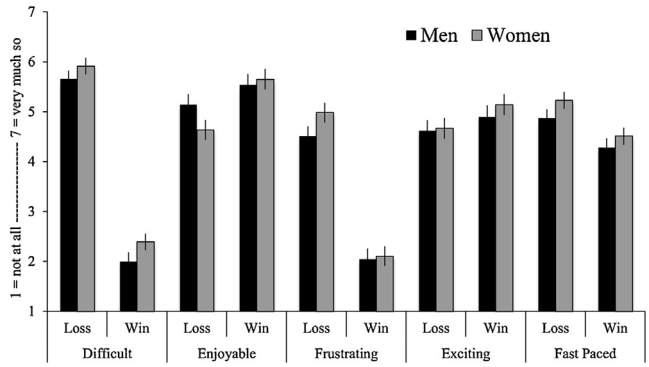

Figure 2 Post-video game self-report responses as a function of sex and outcome. Error bars represent SEM.

effects of sex (all $ps \geq 0.189$) or significant sex × outcome interactions (all $ps \geq 0.133$) (see Fig. 2).

3.2. Association between baseline testosterone concentrations and aggressive behaviour

There were no relationships between baseline testosterone concentrations and aggressive behaviour in men ($r = .01$, $p = 0.906$) or women ($r = -.02$, $p = 0.836$). Moreover, when analyses were performed for winners and losers separately, there were no associations between testosterone and aggression for male or female winners or losers (all $ps \geq 0.382$).

3.3. Testosterone reactivity as a function of sex and outcome

Results from a 2 (sex: male vs. female) × 2 (outcome: win vs. loss) ANOVA revealed that testosterone reactivity (unstandardized residualized score) to the game was influenced by sex ($F(1, 214) = 6.99$, $p = 0.009$, $\eta_p^2 = .03$), outcome ($F(1, 214) = 11.66$, $p = 0.001$, $\eta_p^2 = .05$), and by a sex × outcome interaction ($F(1, 214) = 16.89$, $p < 0.001$, $\eta_p^2 = .07$). Conditional simple effects tests indicated that male winners demonstrated increased testosterone residuals ($M = 12.51$, $SE = 2.59$) relative to male losers ($M = -5.81$, $SE = 2.42$; $F(1, 214) = 26.78$, $p < 0.001$, Cohen's $d = .71$; see Fig. 3a). There were no differences in testosterone reactivity patterns between female winners ($M = -3.93$, $SE = 2.37$) and losers ($M = -2.24$, $SE = 2.35$; $F(1, 214) = 0.26$, $p = 0.613$, Cohen's $d = .06$). Notably, the sex × outcome interaction (and associated simple effects) was significant when using percent testosterone response and absolute testosterone response as the dependent variables. Also, given that winners and losers differed on the post-game self-report measures (see Fig. 2), we included these variables as covariates in the model to examine the extent to which to which effects of competition outcome would remain significant after controlling for these variables. Importantly, the effect of competition outcome on testosterone reactivity (assessed using residualized scores, percent change, and absolute change) remained statistically significant even after controlling for variability in ratings of difficulty, enjoyment, frustration, excitement, and pace.

3.4. Aggressive behaviour as a function of sex and outcome

Results from a 2 (sex: male vs. female) × 2 (outcome: win vs. loss) ANOVA indicated a marginal effect of sex ($F(1, 214) = 3.11$, $p = 0.080$, $\eta_p^2 = .01$), indicating that men tended to be more aggressive than women ($M = 6.78$, $SE = 6.52$ and $M = -9.01$, $SE = 6.15$, respectively). There was no main effect of outcome ($F(1, 214) = 0.08$, $p = 0.804$, $\eta_p^2 = .00$). Though the sex × outcome interaction was not statistically significant ($F(1,214) = 2.45$, $p = .119$, $\eta_p^2 = .01$), simple effects tests indicated that male winners were more aggressive ($F(1,214) = 6.28$, $p = .022$) than female winners ($M = 15.03$, $SE = 9.52$ and $M = -14.78$, $SE = 8.74$, respectively, Cohen's $d = .31$). In contrast, aggressive behaviour

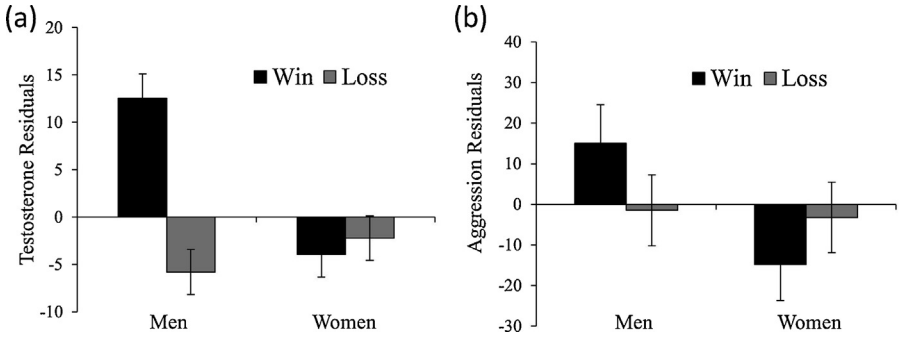

Figure 3 (a) Testosterone reactivity (unstandardized residuals, pg/mL) and (b) Aggressive behaviour as a function of sex and game outcome. Error bars represent SEM.

did not differ for male losers ($M = -1.46$, $SE = 8.90$) and female losers ($M = -3.23$, $SE = 8.66$, $F(1,214) = .02$, $p = .887$, Cohen's $d = .02$; see Fig. 3b).

3.5. Mediation analyses

Although competition outcome was not associated with aggressive behaviour, this direct effect need not be met for testosterone to mediate the effects of competitive outcomes on aggression (Zhao et al., 2010). To investigate mediation, we used a bootstrapped mediation analysis as described in Preacher and Hayes (2008) with 5000 random samplings of the data with replacement, with competition outcome as the independent variable, testosterone reactivity as the mediator, and aggressive behaviour as the dependent variable. Mediation analysis revealed that for men, testosterone reactivity (unstandardized residual score) mediated the effect of competition outcome on subsequent aggression (95% CI: 3.12, 29.35, $k^2 = .10$; Fig. 4). The kappa squared (k^2) value of .10 is consistent with a medium effect size (Preacher and Kelley, 2011). For women, the indirect effect of testosterone reactivity was non-significant (95% CI: −3.45, 2.96, $k^2 < .001$). The mediation effect in men was also significant when using percent testosterone response or absolute testosterone response. Additionally, testing mediation using the more conservative Sobel Z-test revealed that testosterone reactivity mediated the effect of outcome on aggression in men ($Z = 2.16$, $p = .031$), but not in women ($Z = -.01$, $p = .992$). Importantly, the mediating effect of testosterone reactivity (residualized score, percent change, and absolute change) on the relationship between competition outcome and aggressive behaviour remained statistically significant even after controlling for variability in ratings of difficulty, enjoyment, frustration, excitement, and pace.

In addition to exploring whether testosterone reactivity mediated the effect of competition outcome on subsequent aggression, we also examined whether the association between individual differences in testosterone reactivity and aggressive behaviour would differ for winners and losers. Hierarchical regression analyses were computed in which aggressive behaviour was regressed onto testosterone reactivity and competition outcome (Step 1) and competition

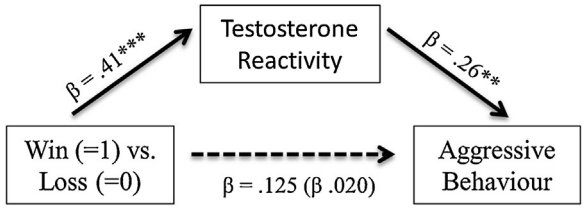

Figure 4 In men, testosterone reactivity (unstandardized residuals, pg/mL) mediates the association between game outcome and aggressive behaviour. *Note*: The regression slope in parenthesis indicates the relationship between outcome and aggression, controlling for variability in testosterone reactivity (*$p < .05$, **$p < .01$, ***$p < .001$).

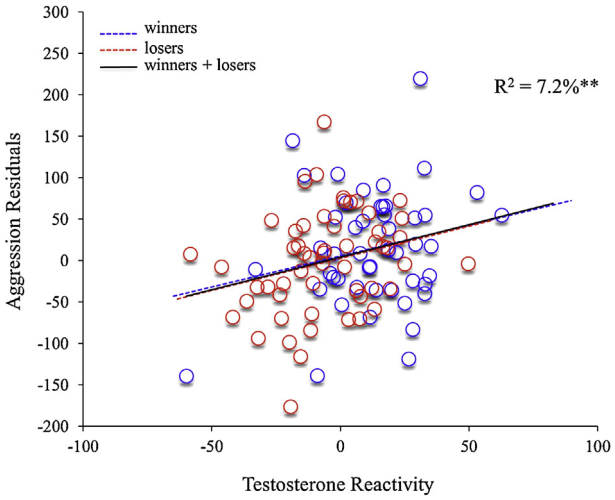

Figure 5 In men, testosterone reactivity (unstandardized residuals, pg/mL) is associated with aggressive behaviour in both winners and losers (**$p < .01$).

outcome × testosterone reactivity interaction (Step 2). For men, testosterone reactivity was associated with aggressive behaviour ($R^2 = 7.2\%$, $p = 0.024$), but there was no outcome × testosterone reactivity interaction ($p = .957$). Using percent testosterone response or absolute testosterone response yielded the same results. As seen in Fig. 5, the slopes for the relationship between testosterone reactivity and aggressive behaviour are essentially identical for male winners and losers. For women, there were no main effects or interactions (all $ps > .15$).

Given that winners and losers differed in post-video game questionnaire responses, we also examined whether ratings of game difficulty, enjoyment, frustration, pace, and excitement may underlie the effect of outcome on aggressive behaviour. Bootstrapping analyses performed separately for women and men indicated that none of the post-video game questionnaire items (enjoyment, difficulty, frustration, pace) mediated the effects of competition outcome on subsequent aggression (all CIs included zero). Notably, the latter finding is not surprising given that post-video game items were not predictive of aggressive behaviour (all $ps \geq 0.072$).

4. Discussion

Across the animal kingdom, testosterone concentrations fluctuate rapidly in the context of competitive interactions, with winners demonstrating increased testosterone concentrations relative to losers (see Oliveira, 2009 and Archer, 2006 for reviews). Researchers have long speculated that such divergent neuroendocrine responses may serve to guide subsequent human competitive and aggressive behaviours (Mazur and Booth, 1998; Archer, 2006; Carré et al., 2011; Mazur, 1985). Although compelling evidence for this hypothesis has been obtained in animal models (Trainor et al., 2004; Gleason et al., 2009; Fuxjager et al., 2010; Oliveira et al., 2009a), the current experiment is the first (to our knowledge) to demonstrate that testosterone responses mediate the effect of winning on subsequent aggressive behaviour in men (but see limitations below).

Importantly, the relationship between individual differences in testosterone reactivity and aggressive behaviour was remarkably similar in male winners and losers. Indeed, although the majority of male losers demonstrated a decrease in testosterone, some experienced an increase, and this was associated with higher aggressive behaviour. Similarly, although a majority of winners demonstrated an increase in testosterone, some experienced a decrease, and this was associated with more passive behaviour on the PSAP. At first glance, these results appear to be at odds with other evidence suggesting that testosterone responses to defeat (not victory) predict individual differences in subsequent competitive (Mehta and Josephs, 2006) and aggressive behaviour (Carré et al., 2009). One crucial methodological difference is that previous studies (Mehta and Josephs, 2006; Carré et al., 2009) gave participants the opportunity to compete or aggress against an individual for whom they had previously defeated or lost against. Although speculative, it may be that for winners, a rise in testosterone does not translate into more competitive or aggressive behaviour against a lower status person. Indeed, the costs of re-engaging in competition with an individual that one just defeated may far outweigh the benefits of reinforcing one's status. In contrast, a rise in testosterone in losers may serve to motivate competitive/aggressive behaviours aimed at reclaiming lost status (Mehta and Josephs, 2006). For the current study, and similar to studies in animal models (Trainor et al., 2004; Gleason et al., 2009; Fuxjager et al., 2010; Oliveira et al., 2009b), winners and losers engaged in a subsequent interaction with a novel opponent, and thus, no information regarding the status of their opponent was made available to them. In this case, a rise in testosterone among both winners and losers influenced subsequent aggressive behaviour.

Our findings highlight the important role of social context (i.e., victory vs. defeat) in modulating testosterone reactivity (in men), but they also suggest that there is substantial variability in testosterone reactivity among winners and losers that may have important effects on subsequent behaviour. Although it is currently unclear what variables underlie individual differences in testosterone reactivity during competition, some potential factors include personality traits (e.g., power motive, Schultheiss et al., 1999), genetics (e.g., androgen receptor CAG repeat polymorphism, Roney et al., 2010), cultural upbringing (e.g., 'culture of honor', (Cohen et al., 1996) or causal attributions to the outcome of the competition (Salvador, 2005). Future research will clearly be needed to delineate the factors that give rise to individual differences in testosterone reactivity to competition.

Although the temporal sequence of our design affords us the opportunity to speculate that acute changes in testosterone drive subsequent aggression, the correlational nature of the current experiment prohibits us from making strong causal claims. Nevertheless, to the extent that testosterone reactivity is causally linked to aggressive behaviour, the current findings suggest that testosterone would accomplish this through a rapid non-genomic mechanism. Indeed, such rapid effects of testosterone on neural and behavioural processes (including aggression) have been documented in numerous animal species (see Oliveira, 2009 and Nyby, 2008 for reviews). In studies of young women, pharmacological challenge work indicates that testosterone administration increases amygdala reactivity to angry facial expressions (Hermans et al., 2008; van Wingen et al., 2008). In one of the studies, the effects were observed within 45 min of testosterone administration (van Wingen et al., 2008), suggesting that testosterone can have rapid, non-genomic effects on the amygdala, a critical neural structure involved in mediating physiological and behavioural responses to threat (Davis and Whalen, 2001). Notably, heightened amygdala reactivity to angry faces has also been observed among individuals at risk for engaging in aggressive behaviour in response to social provocation (e.g., Coccaro et al., 2007; Carré et al., 2013). Collectively, these findings suggest that one possible neural mechanism underlying the effect of testosterone reactivity on aggressive behaviour is through heightened amygdala reactivity to social provocation (Carré et al., 2011), which in turn modulates downstream structures mediating reactive aggression (e.g., hypothalamus, PAG; Siegel et al., 2007).

The relationship between testosterone reactivity and aggressive behaviour was only found for men. This finding is consistent with other behavioural work in which acute changes in testosterone predict subsequent aggression in men, but not women (Carré et al., 2009) and highlights the importance of including men and women in studies of the neuroendocrine correlates of aggressive behaviour (Josephs et al., 2011). It could be argued that the absence of a mean increase in testosterone concentrations in women could explain the lack of an association between testosterone reactivity and aggressive behaviour. However, this is an unlikely possibility as a positive correlation between testosterone reactivity to competition and subsequent aggressive behaviour can occur in the absence of a mean increase in testosterone concentrations (e.g., Carré et al., 2009). Although testosterone reactivity was unrelated to aggressive behaviour in the current study, it may be related to other forms of status-seeking behaviours that were not assessed in the current study. For instance, previous work indicates that testosterone administration in women increases fair offers made in the ultimatum game (UG; Eisenegger et al., 2009) and cooperation in a public goods game (PGG; van Honk et al., 2012). These findings have been interpreted from a social status perspective whereby testosterone administration may modulate cooperative behaviour through increasing one's concerns for social status (Eisenegger et al., 2009, 2012). Specifically, in the UG, testosterone administration may render the thought of a rejected offer more aversive, and thus, motivate more generous offers aimed at avoiding threats to status (i.e., rejection; Eisenegger et al., 2009). In the PGG, participants typically confer higher status to cooperative group members (Hardy and Van Vugt, 2006), and as such, increased contributions to the public good after testosterone administration may also be related to one's concerns for social status (Eisenegger et al., 2012). These exogenous administration studies suggest that testosterone influences status seeking in women as well, but that this may be accomplished through building trust and cooperation rather than engaging in aggression. Importantly, however, our study was not designed to assess this alternative possibility and thus, future work will be needed to examine the extent to which testosterone reactivity to competition may function to promote trust and cooperation in the context of status-seeking. An important area for future research will be

to examine the extent to which testosterone administration in men also promotes these forms of cooperative behaviours (assessed in the UG and PGG) aimed at status attainment. Furthermore, it will be critical that future research in this area examine the causal role of testosterone in promoting aggressive behaviour using novel pharmacological challenge probes developed for use in men (e.g., Eisenegger et al., 2013).

For women, testosterone was not influenced by the outcome of the video game. The lack of an effect of competition outcome on testosterone reactivity in women is consistent with earlier work in various forms of competition (e.g., Mazur et al., 1997; Kivlighan et al., 2005; Edwards et al., 2006; Stanton et al., 2009). However, more recent evidence has emerged indicating that female winners have elevated testosterone relative to losers (Oliveira et al., 2009a; Jimenez et al., 2012; Costa and Salvador, 2012; Denson et al., 2013). The extent to which women naturally gravitate to these types of competitive video games may be smaller than for men and may in part explain the lack of winner-loser effects observed in women. Thus, future research examining different types of competitive interactions that may be more relevant for women will be an important area for future research. Another possibility is that the use of oral contraceptives and/or menstrual cycle phase moderates the effect of competition outcome on testosterone release. This possibility is also unlikely given that additional analyses including only women who did not use oral contraceptives yielded the same null findings.

One limitation of the current study is that although we experimentally manipulated competition outcome, this manipulation also produced robust effects on the extent to which winners and losers experienced the game as difficult, enjoyable, fast paced, and frustrating. Although the main findings remained significant after controlling for such differences, winners and losers may also have differed on other characteristics not measured in the current study including how much the participants found the games competitive and also the physical activity expended during the competition. Future research may benefit by manipulating the outcome of competitive interactions and holding all other factors constant (e.g., level of competitiveness, difficulty and physical activity).

In summary, the current findings provide further empirical support for the idea that testosterone fluctuations to competition may function to fine-tune subsequent aggressive behaviour in men. Although our findings were specific to aggressive behaviour, an interesting question for future work will be to examine the extent to which competition-induced changes in testosterone may modulate other forms of social behaviour including mate-seeking and risk-taking (Coates and Hebert, 2008; van der Meij et al., 2012).

Role of the funding source

Funding from this project was provided by Wayne State University. WSU played no further role in data collection, analysis, and interpretation.

Conflict of interest

None of the authors report any conflict of interest.

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Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at http://dx.doi.org/10.1016/j.psyneuen.2013.03.008.

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