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When are low testosterone levels advantageous? The moderating role of individual versus intergroup competition

Pranjal H. Mehta [a,*], Elizabeth V. Wuehrmann [b], Robert A. Josephs [c]

[a] Columbia University, Graduate School of Business, 3022 Broadway, 702 Uris Hall, New York, NY 10027, USA
[b] State of Texas, USA
[c] The University of Texas at Austin, USA

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ABSTRACT

Although theory suggests that testosterone should facilitate competitive performance, empirical evidence has been mixed. The present study tested the hypothesis that testosterone's effect on competitive performance depends on whether competition is among individuals (individual competition) or among teams (intergroup competition). Sixty participants (50% women) provided saliva samples and were randomly assigned to complete an analytical reasoning test in individual or intergroup competition. Testosterone was positively related to performance in individual competition, but testosterone was negatively related to performance in intergroup competition. There were no sex differences in performance or in the magnitude of testosterone-performance relationships. These results are consistent with the hypothesis that high testosterone individuals are motivated to gain status (good performance in individual competition), whereas low testosterone individuals are motivated to cooperate with others (good performance in intergroup competition). Theoretical and practical implications are discussed.

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Across a variety of species, testosterone (T) levels regulate social dominance — a behavior intended to gain or maintain high status (Mazur and Booth, 1998). Higher T in humans is related to greater aggression and dominance motivation (Archer, 2006; Hermans et al., 2008; Josephs et al., 2003, 2006; Mazur and Booth, 1998; Mehta and Josephs, 2006; Mehta et al., 2008; van Honk et al., 2001; Wirth and Schultheiss, 2007), especially when social status is up for grabs (e.g., Josephs et al., 2003, 2006; Mehta et al., 2008). Although most research on T and behavior has been conducted in men, a growing literature indicates that T also influences social dominance in women (e.g., Bateup et al., 2002; Hermans et al., 2008; Josephs et al., 2003, 2006; Mehta et al., 2008; van Honk et al., 1999, 2001). Overall, the evidence suggests that high T individuals are more motivated to gain status than low T individuals.

If high T individuals are indeed motivated to gain status, are they more likely to perform better in competition? After all, competitions are an important means of determining status across many species. Although there is some evidence that T enhances competitive performance in animals (e.g., Trainor, Bird, and Marler, 2004), the evidence in humans is mixed. Some human studies show that T prior to competing predicts better competitive performance (females, Edward et al., 2006), others show no relationship between T and competitive performance (males, Edwards et al., 2006), and in some research, higher T actually predicts *worse* competitive performance (Carré et al., 2006; Gonzalez-Bono et al., 1999; Kivlighan et al., 2005; van Anders and Watson, 2007).

Two limitations of previous studies likely contribute to the inconsistent findings. First, most studies to date involved physical activity (sports competitions), which makes it difficult to tease apart the known physical effects of T on muscle mass and metabolism from the hypothesized psychological effects of T on the motivation to gain high status. Additional studies are needed to investigate the relationship between T and performance in non-physical domains, such as cognitive competitions (e.g., Mazur, Booth, and Dabbs, 1992; Josephs et al., 2006; van Anders and Watson, 2007).

Second, most previous studies have been conducted in naturalistic settings and therefore vary greatly in characteristics of the social environment. A growing literature shows that subtle changes in the social environment can affect T's influence on motivation and cognition (Josephs et al., 2003, 2006; Newman et al., 2005), so it is likely that the relationship between T and competitive performance is also context-dependent. Studies that systematically manipulate key aspects of the social environment may help clarify how and under what conditions T is related to competitive performance.

One environmental factor that could influence T and performance associations is whether a competition is among individuals (individual competition) or among teams (intergroup competition). Individual competition is a setting in which individuals compete in a zero-sum situation, and the person who wins gains status for him or herself (Stanne et al., 1999; Tauer and Harackiewicz, 2004). In contrast,

* Corresponding author. Fax: +1 212 854 3778.
E-mail address: pm2482@columbia.edu (P.H. Mehta).

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intergroup competition is a competitive setting that also involves cooperation; teammates work towards a common goal and share the status that comes with victory (Tauer and Harackiewicz, 2004). So although both settings are competitive, intergroup competition involves more cooperation than individual competition (Tauer and Harackiewicz, 2004).

Although research on T and social behavior has focused on T's relationship to dominance, some initial evidence suggests that T may be *negatively* associated with cooperation motivation. Indeed, lower T has been linked to affiliative and cooperative behaviors such as caring for offspring (Wingfield et al., 1990), preference for monogamous relationships (McIntyre et al., 2006), empathic behavioral responses (Hermans et al., 2006), and bonding with one's teammates (Kivlighan et al., 2005).Therefore, it seems plausible that low T individuals might prefer social settings that are more cooperative (e.g., intergroup competition), and in turn might perform better than high T individuals in them. Conversely, because high T individuals are motivated to gain status, they might prefer social settings that are more competitive (individual competition) and in turn might perform better than low T individuals in them. These ideas, however, have yet to be experimentally tested.

The present study tested for the first time whether individual versus intergroup competition moderates T's relationship to competitive performance. Pairs of same-sex participants provided saliva samples and were randomly assigned to complete an analytical reasoning test in individual or intergroup competition. Based on the literature linking higher T to dominance and based on initial evidence linking lower T to cooperation, we hypothesized that high T individuals would perform better than low T individuals in individual competition, whereas low T individuals would perform better than high T individuals in intergroup competition.

Method

Participants

Sixty students (30 men) enrolled in an introductory psychology course at the University of Texas at Austin participated in the study in exchange for credit toward a research requirement. Five participants provided saliva samples that were inadequate for salivary assay. Thus, complete data were available for 55 participants (29 men, 26 women). For the purposes of the present research, only these 55 participants were included in our analyses.

Procedure

Participants reported to the lab in same-sex pairs between 12 PM and 4 PM (Mean start time = 2:15 PM, SD = 68 min) to minimize the effects of circadian fluctuations in T levels (Touitou and Haus, 2000). The gender of the experimenter was matched to the gender of the participants because T may operate differently in same-sex and opposite-sex social interactions (Roney, Lukaszewski, and Simmons, 2007). We suspected that variance in how well participants knew each other could lead to differences in competition and cooperation motivation and in turn, performance. Therefore, we restricted our sample to participants who were not friends. All participants were instructed to sign up for an experimental session with a person that they did not know. Once participants arrived at the lab, they were asked if they knew each other. If they did, they were sent home and were asked to sign up for another session. Participants were seated at two separate desks in the same room, read and signed the consent form, and provided a 2 mL saliva sample. The samples were immediately transported to a freezer, where they were stored until later assay.

The two participants then moved to the same desk. They were told that they would first complete a warm-up task together in preparation for a test they would take later on. Pilot testing revealed that including this warm-up task led participants to care more about their performance during the subsequent analytical reasoning test. At the same time, this task allowed participants to get to know one another, and thus, served to strengthen the competition manipulation to follow. For the warm-up task, participants played a modified version of the popular SET card game (Set Enterprises, Fountain Hills, AZ). Twelve cards were laid out on the table, and participants were instructed to take turns to form as many sets as possible from the cards. When no more sets could be made, participants were instructed to lay down more cards. Participants worked on this task for about 10 min, after which the experimenter returned. Participants were then asked to return to their separate desks.

Next, participants were told that they were going to move on to the next task — an analytical reasoning test. Each pair of participants was randomly assigned to the individual or intergroup competition condition. These conditions differed only in the instructions participants were given. The experimenter first told all participants the following:

> "The test I'm going to give you today is a basic test of analytical reasoning. This test contains the type of questions that you will see in other tests like the LSAT for admission to law school, in tests for business school admissions and for graduate school. It's important that you try hard on these questions."

In the individual competition condition, the experimenter followed these statements with:

> "As an incentive, we've decided to take the higher scoring person of the two of you and enter you into a drawing for a prize — $25 cash. So if you do better (score higher) than the other person does, you'll be entered into the drawing. The test takes 20 min and there are 15 questions. Are you ready?"

But in the intergroup competition condition, participants followed the initial statements with:

> "As an incentive, we've decided to add your scores together, and if you score higher than the next group that comes in you'll both be entered into a drawing for $25 cash for each of you. The test takes 20 min and there are 15 questions. Are you ready?"

Participants then completed 15 questions from the former Graduate Record Exam (GRE) — Analytical subsection. The questions selected were of medium difficulty. We chose this task because a similar task has been employed in previous research on T levels, cognitive performance, and the social environment (Josephs et al., 2006). Participants worked independently on the problems and were not able to communicate with each other. The door to the lab room was left ajar, and the experimenter waited just outside the room. The participants had 20 min to complete as many of the questions as possible. After the test, participants were debriefed as to the true nature of the study and were dismissed.

Hormone assays

Saliva samples were analyzed for T concentrations using enzyme immunoassays kits purchased from Salimetrics (State College, PA, USA). These assays were conducted in-house at the University of Texas at Austin. Samples were assayed in duplicate. The intra-assay coefficient of variation (CV) was 6%, and the inter-assay CVs averaged across low and high controls was 8.7%. The mean T level for men was 155 pg/mL, and the standard deviation was 112 pg/mL. The mean T level for women was 29 pg/mL, and the standard deviation was 28 pg/mL.

Data analysis strategy

We used SPSS 16.0 to analyze the data. The T distributions were skewed. Therefore, we log-transformed them, which yielded normal distributions. To control for sex differences in basal T, we standardized these distributions within sex by converting these log-transformed T scores to *z*-scores. High scores on this T distribution indicated high levels of T relative to other individuals of the same sex. This analytical strategy has been used in previous T research involving mixed-sex samples (Josephs et al., 2006; Mehta et al., 2008; Wirth and Schultheiss, 2007) and allows researchers to capitalize on statistical power and to test for sex differences in the predictive power of T levels. For all of our analyses, we employed these log-transformed, standardized scores as our measure of basal T.

Results

Time of day was marginally positively correlated with T levels ($r = .23$, $p < .10$), and therefore it was used as a covariate in our main analysis. Cognitive performance scores were calculated as the total number of correct items out of 15 on the GRE-Analytical test. Across all 55 individuals, the mean number of items correct was 8.76, and the standard deviation was 2.29.

The sex of the participant did not predict performance ($t(53) = .25$, $p > .80$), nor did it interact with competition condition ($F(1, 51) = .43$, $p > .50$) or T level (($F(1, 51) = .14$, $p > .70$) to predict performance. In addition, the sex × T × competition condition three-way interaction was also non-significant ($F(1, 47) = .33$, $p > .50$). Thus, participant sex was excluded from the following analysis.

To test whether T moderated the effect of the competition manipulation on performance, we ran a hierarchical regression analysis in which performance was entered as the dependent variable, time of day, competition condition and T were entered as predictors in Step 1, and the competition condition × T interaction was entered as a predictor in Step 2. This model revealed no main effects but a statistically significant interaction, $\Delta R^2 = 15.2\%$, $F(1, 50) = 9.29$, $p < .01$. To interpret this interaction, we ran regressions for participants in the individual and intergroup competition conditions separately, controlling for time of day (see Fig. 1). Consistent with our predictions, there was a positive relationship between T and performance in individual competition ($\beta = .45$, $t = 2.04$, $p = .05$), in contrast with a negative relationship between T and performance in intergroup competition ($\beta = -.48$, $t = -2.88$, $p < .01$).

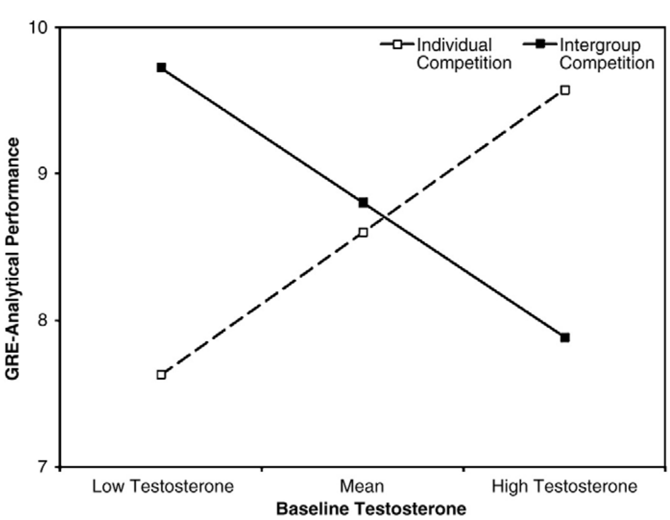

Fig. 1. GRE-Analytical performance (number of items correct out of 15) as a function of competition condition and testosterone level (log-transformed and standardized within sex), controlling for time of day. Low testosterone = 1 standard deviation below mean, high testosterone = 1 standard deviation above mean. Standardized Beta's: individual competition, $\beta = .45$*, intergroup competition, $\beta = -.48$**. **$p < .01$, *$p = .05$.

Even though participant sex did not interact with T and the experimental condition to predict performance, this non-significant effect could have been due to insufficient statistical power. Thus, we decided to examine men and women separately to be sure that similar patterns emerged. Because of the limited sample size, we did not expect statistically significant effects in these separate analyses. We ran separate hierarchical regressions in men and women. In these two models we entered cognitive performance as the dependent variable, T and competition condition as predictors in Step 1, and the T × competition condition interaction as a predictor in Step 2. The results in men alone showed no main effects but a statistically significant interaction, $\Delta R^2 = 21.3\%$, $F(1, 25) = 6.88$, $p < .05$; T was positively associated with performance in individual competition ($\beta = .35$), but T was negatively associated with performance in intergroup competition ($\beta = -.60$). The results in women alone showed no main effects but a marginally significant T × competition condition interaction, $\Delta R^2 = 14.7\%$, $F(1, 22) = 3.91$, $p = .06$; T was positively associated with performance in individual competition ($\beta = .41$), but T was negatively associated with performance in intergroup competition ($\beta = -.36$). Overall, these follow-up analyses are consistent with the main analysis and demonstrate that the pattern of data was strikingly similar in men and women.

Discussion

The present study provides evidence that T levels predict competitive performance, but only when attention is paid to the social environment. We demonstrated for the first time that individual versus intergroup competition moderates the relationship between T and performance. There was a positive relationship between T and performance in individual competition, but there was a negative relationship between T and performance in intergroup cooperation. Research has generally shown inconsistent relationships between T and competitive performance, and the results of this study provide one explanation for why that might be — specifically, it seems that the association between T and competitive performance depends on whether a competition is among individuals (individual competition) or among teams (intergroup competition). These findings dovetail nicely with recent studies showing context-dependent effects of T on a variety of emotional, cognitive, physiological, and behavioral outcomes (Jones and Josephs, 2006; Josephs et al., 2003, 2006; Mehta et al., 2008; Newman et al., 2005).

The results of our study provide greater support for the hypothesis that T levels serve as a biological marker for an individual's motivation to gain status. Presumably, high T individuals performed well in individual competition out of a strong desire to gain high status, but low T individuals performed poorly in this setting because they do not have a strong drive for status (Josephs et al., 2003; Newman et al., 2005; Mehta et al., 2008) or because they may be motivated to avoid high status (Josephs et al., 2006). This interpretation is consistent with past research demonstrating the differential effects of high and low status on high and low T individuals (Jones and Josephs, 2006; Josephs et al., 2003, 2006; Mehta et al., 2008; Newman et al., 2005). It is also consistent with the larger literature linking higher T levels to dominance (Archer, 2006; Mazur and Booth, 1998).

At the same time, the negative relationship between T and performance in intergroup competition (a competitive setting that also involves cooperation) raises new theoretical questions about a possible function of T levels in regulating cooperation. The literature to date has focused almost exclusively focused on T's relationship to aggression and dominance, but the present findings suggest that low T levels might also be a potent predictor of *cooperation motivation*. The finding that low T individuals performed especially well in intergroup competition fits well with initial human studies showing that low T individuals are motivated to bond with their teammates in intergroup competition (Kivlighan et al., 2005), to enter into monogamous relationships (McIntyre et al., 2006), and to show empathic behaviors (Hermans et al., 2006) (but see Edwards et al., 2006 for a different pattern of results on T and bonding in intergroup competition). Clearly, more research on T and cooperation is needed.

There are some limitations of the present research that should be addressed in future studies. First, although we have interpreted our findings to suggest that high T individuals are motivated to gain high status (better performance in individual competition) and low T individuals are motivated to cooperate with others (better performance in intergroup competition), our study could not directly test these mechanisms. Future studies can incorporate additional psychological and biological measures in order to examine the processes that explain the present results (e.g., implicit power and affiliation motives, Schultheiss et al., 2005; attention to status, Josephs et al., 2006; approach motivation, Josephs et al., 2006; interest in bonding and competing, Bateup et al., 2002; Edwards et al., 2006; Kivlighan et al., 2005; interpersonal enthusiasm/attraction, Stanne et al., 1999, Tauer and Harackiewicz, 2004; cardiovascular reactivity, Josephs et al., 2006; Newman et al., 2005, van Honk et al., 2001; neuroendocrine reactivity, Mehta et al., 2008; neural activity, Mehta and Beer, under review).

Second, our experimental design only allowed us to compare individual competition to intergroup competition. This design showed that a very subtle change in the competitive environment affected T's relationship to performance. It would be useful, however, to extend the present findings with experiments that incorporate a pure cooperation condition (e.g., Stanne et al., 1999; Tauer and Harackiewicz, 2004). A negative relationship between T and performance in a purely cooperative setting would provide further support that low T individuals are motivated to cooperate with others. Further, competition was only implicit in the intergroup competition condition because the other competitors were not physically present. A future study should also include an intergroup competition condition in which competition is made more explicit, such as having two participants compete with two other participants who are physically present.

Third, we cannot be certain that T levels directly caused the performance differences we observed because we measured endogenous levels of T. Future studies can provide greater evidence of causality by experimentally manipulating T levels (e.g., Hermans et al., 2006). It is also possible that other hormones that show functional cross-talk with androgens (e.g., cortisol, Mehta & Josephs, 2008; Popma et al., 2007) may interact with T to predict performance. Future studies can measure other hormones as well and examine their relationships with performance.

Fourth, our results demonstrated that T levels prior to competing interacted with the social setting to predict performance, but it is also possible that short-term changes in T before, during, or after a social event might also be associated with performance. Indeed, there is evidence that a short-term rise in T prior to a competitive context can facilitate psychological focus (Bateup et al., 2002) and performance (Salvador et al., 2003), and animals studies demonstrate that experimental rises in T following a win in competition can lead to better performance in a second competition (Trainor et al., 2004). Future research should continue to examine both baseline and short-term changes in T as predictors of performance.

Fifth, participants in the current study completed a warm-up task that involved social interactions, but they were instructed not to communicate with each other during the competitive task. These instructions were included so that we could examine the effects of a subtle change in the social environment on individual motivation and performance. In the real world, however, individual and intergroup competitions often involve social interactions (e.g., verbal communication among competitors or teammates, cheering or booing from the audience, social interactions with coaches). It is unclear in the present study how the social warm-up task prior to the competition or how the absence of social interaction during the competition may have affected competitive performance. Future research should systemically examine how social processes before and during competitive encounters might influence T and performance associations. Future research should also determine whether our findings extend to *means interdependent tasks*, in which performance is dependent on multiple people (e.g., a collaborative group project, Stanne et al., 1999) as well as other types of cognitive tasks (mental rotation, verbal fluency, Newman et al., 2005; math performance, Josephs et al., 2003, 2006).

Sixth, the current study is not intended to establish a complete model of all factors influencing competitive performance. Although we found that individual versus intergroup competition moderated T's association with performance, a number of additional psychological factors (e.g., personality, coping style, appraisal, attribution), physical factors (age, body mass index), and environmental factors (e.g., home versus away games, task structure, social interactions) may also be involved in competitive performance (see Carré et al., 2006; Salvador, 2005; Salvador and Costa, 2009; Stanne et al., 1999). These additional variables should be examined in future research on the neuroendocrinology of competition.

The present study also paves the way for more practical research on ways to improve the effectiveness of performance in real-world social settings. If some individuals seem to thrive in individual competition, while others seem to thrive in intergroup competition as the findings from our study suggest, then perhaps the social environment should be tailored to each individual. The current study showed that T predicts whether individual or intergroup competition will lead to better performance. But it is up to future research to identify other biological systems and other environmental factors that will help determine the best fit between the person and their social situation.

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References

Archer, J., 2006. Testosterone and human aggression: an evaluation of the challenge hypothesis. Neurosci. Biobehav. Rev. 30 (3), 319–345.
Bateup, H.S., Booth, A., Shirtcliff, E.A., Granger, D.A., 2002. Testosterone, cortisol, and women's competition. Evol. Hum. Behav. 23, 181–192.
Carré, J., Muir, C., Belanger, J., Putnam, S., 2006. Pre-competition hormonal and psychological levels of elite hockey players: relationship to the 'home advantage'. Physiol. Behav. 89 (3), 392–398.
Edwards, D.A., Wetzel, K., Wyner, D.R., 2006. Intercollegiate soccer: saliva cortisol and testosterone are elevated during competition, and testosterone is related to status and social connectedness with teammates. Physiol. Behav. 87, 135–143.
Gonzalez-Bono, E., Salvador, A., Serrano, M.A., Ricarte, 1999. Testosterone, cortisol, and mood in a sports competition. Horm. Behav. 35, 55–62.
Hermans, E.J., Putman, P., van Honk, J., 2006. Testosterone administration reduces empathetic behavior: a facial mimicry study. Psychoneuroendocrinology 31 (7), 859–866.
Hermans, E., Ramsey, N., van Honk, J., 2008. Exogenous testosterone enhances responsiveness to social threat in the neural circuitry of social aggression in humans. Biological Psychiatry 63 (3), 263–270.
Jones, A.C., Josephs, R.A., 2006. Interspecies hormonal interactions between man and the domestic dog (*Canis familiaris*). Horm. Behav. 50 (3), 393–400.
Josephs, R.A., Newman, M.L., Brown, R.P., Beer, J.M., 2003. Status, testosterone, and human intellectual performance: stereotype threat as status concern. Psychol. Sci. 14 (2), 158–163.
Josephs, R.A., Sellers, J.G., Newman, M.L., Mehta, P.H., 2006. The mismatch effect: when testosterone and status are at odds. J. Pers. Soc. Psychol. 90 (6), 999–1013.
Kivlighan, K.T., Granger, D.A., Booth, A., 2005. Gender differences in testosterone and cortisol response to competition. Psychoneuroendocrinology 30 (1), 58–71.
Mazur, A., Booth, A., 1998. Testosterone and dominance in men. Behav. Brain Sci. 21 (3), 353–397.

Mazur, A., Booth, A., Dabbs Jr, J., 1992. Testosterone and chess competition. Soc. Psychol. Q. 55, 70–77.
McIntyre, M., Gangestad, S.W., Gray, P.B., Chapman, J.F., Burnham, T.C., O'Rourke, M.T., et al., 2006. Romantic involvement often reduces men's testosterone levels—but not always: the moderating role of extrapair sexual interest. J. Pers. Soc. Psychol. 91 (4), 642–651.
Mehta, P.H., and Beer, J.S., (under review). Neural mechanisms of the testosterone-aggression relation: the role of orbitofrontal cortex.
Mehta, P.H., Josephs, R.A., 2008. The Testosterone-behavior Relation Depends on Cortisol: Convergent Evidence in the Domains of Competition and Leadership. Talk presented at the Society of Personality and Social Psychology conference, Albuquerque, NM.
Mehta, P.H., Josephs, R.A., 2006. Testosterone change after losing predicts the decision to compete again. Horm. Behav. 50, 684–692.
Mehta, P.H., Jones, A.C., Josephs, R.A., 2008. The social endocrinology of dominance: basal testosterone predicts cortisol changes and behavior following victory and defeat. J. Pers. Soc. Psychol. 94 (6), 1078–1093.
Newman, M.L., Sellers, J.G., Josephs, R.A., 2005. Testosterone, cognition, and social status. Horm. Behav. 47 (2), 205–211.
Popma, A., Vermeiren, R., Geluk, C.A.M.L., Rinne, T., van den Brink, W., Knol, D.L., et al., 2007. Cortisol moderates the relationship between testosterone and aggression in delinquent male adolescents. Biol. Psychiatry 61 (3), 405–411.
Roney, J.R., Lukaszewski, A.W., Simmons, Z.L., 2007. Rapid endocrine responses of young men to social interactions with young women. Horm. Behav. 52 (3), 326–333.
Salvador, A., 2005. Coping with competitive situations in humans (2005). Neurosci. Biobehav. Rev. 29 (1), 195–205.
Salvador, A., Costa, R., 2009. Coping with competition: neuroendocrine responses and cognitive variables. Neurosci. Biobehav. Rev. 33 (2), 160–170.
Salvador, A., Suay, F., González-Bono, E., Serrano, M., 2003. Anticipatory cortisol, testosterone and psychological responses to judo competition in young men. Psychoneuroendocrinology 28 (3), 364–375.
Schultheiss, O.C., Wirth, M.M., Torges, C.M., Pang, J.S., Villacorta, M.A., Welsh, K.M., 2005. Effects of implicit power motivation on men's and women's implicit learning and testosterone changes after social victory or defeat. J. Pers. Soc. Psychol. 88 (1), 174–188.
Stanne, M., Johnson, D., Johnson, R., 1999. Does competition enhance or inhibit motor performance: a meta-analysis. Psychol. Bull. 125 (1), 133–154.
Tauer, J.M., Harackiewicz, J.M., 2004. The effects of cooperation and competition on intrinsic motivation and performance. J. Pers. Soc. Psychol. 86, 849–861.
Touitou, Y., Haus, E., 2000. Alterations with aging of the endocrine and neuroendocrine circadian system in humans. Chronobiol. Int. 17 (3), 369–390.
Trainor, B.C., Bird, I.M., Marler, C.A., 2004. Opposing hormonal mechanisms of aggression revealed through short-lived testosterone manipulations and multiple winning experiences. Horm. Behav. 45, 115–121.
van Anders, S., Watson, N., 2007. Effects of ability- andchance-determined competition outcome on testosterone. Physiology and Behavior 90 (4), 634–642.
van Honk, J., Tuiten, A., Verbaten, R., van den Hout, M., Koppeschaar, H., Thijssen, J., et al., 1999. Correlations among salivary testosterone, mood, and selective attention to threat in humans. Horm. Behav. 36 (1), 17–24.
van Honk, J., Tuiten, A., Hermans, E., Putnam, P., Koppeschaar, H., Thijssen, J., et al., 2001. A single administration of testosterone induces cardiac accelerative responses to angry faces in healthy young women. Behav. Neurosci. 115 (1), 238–242.
Wingfield, J.C., Hegner, R.E., Dufty, A.M., Ball, G.F., 1990. The 'challenge hypothesis': theoretical implications for patterns of testosterone secretion, mating systems, and breeding strategies. Am. Nat. 136, 829–846.
Wirth, M.M., Schultheiss, O.C., 2007. Basal testosterone moderates responses to anger faces in humans. Physiol. Behav. 90, 496–505.