

Salivary testosterone change following monetary wins and losses predicts future financial risk-taking

Coren L. Apicella^{a,*}, Anna Dreber^b, Johanna Mollerstrom^{c,d}

^a Department of Psychology, 3720 Walnut Street, Philadelphia, PA 19104, United States

^b Department of Economics, Stockholm School of Economics, P.O. Box 6501, 113 83 Stockholm, Sweden

^c Program for Evolutionary Dynamics, Harvard University, 1 Brattle Square, Cambridge, MA 02138, United States

^d The Research Institute for Industrial Economics (IFN), P.O. Box 55665, 102 15 Stockholm, Sweden

Received 2 June 2013; received in revised form 23 September 2013; accepted 23 September 2013

KEYWORDS

Testosterone;
Winner–loser effect;
Risk aversion

Summary While baseline testosterone has recently been implicated in risk-taking in men, less is known about the effects of changing levels of testosterone on financial risk. Here we attempt to influence testosterone in men by having them win or lose money in a chance-based competition against another male opponent. We employ two treatments where we vary the amount of money at stake so that we can directly compare winners to losers who earn the same amount, thereby abstracting from income effects. We find that men who experience a greater increase in bioactive testosterone take on more risk, an association that remains when controlling for whether the participant won the competition. In fact, whether subjects won the competition did not predict future risk. These results suggest that testosterone change, and thus individual differences in testosterone reactivity, rather than the act of winning or losing, influence financial risk-taking.
© 2013 Published by Elsevier Ltd.

1. Introduction

National stock markets often suffer negative returns on days following a country's elimination from major sporting events (Edmans et al., 2007). While events such as this are not easily

explained by traditional economic theory, where actors are assumed to be rational, they may be understood using a behavioral endocrinological account. One candidate proximate mechanism mediating financial decision-making is the hormone testosterone. While baseline differences in testos-

* Corresponding author at: Department of Psychology, University of Pennsylvania, 3720 Walnut Street, Philadelphia, PA 19104, United States. Tel.: +1 215 898 9718; fax: +1 215 898 7301.

E-mail addresses: capicella@psych.upenn.edu, corenaticella@gmail.com (C.L. Apicella), anna.dreber@hhs.se (A. Dreber), jmollers@fas.harvard.edu (J. Mollerstrom).

terone explain some individual differences in financial risk-taking (Apicella et al., 2008; Stanton et al., 2011) and account for some of the observed sex differences in risk-taking (Sapientza et al., 2009), there is much reason to suspect that transient changes in testosterone may also influence financial risk-taking (Goudriaan et al., 2010). If so, these changes may help to explain documented behavioral phenomena such as the sensitivity of economic markets to sporting outcomes (Edmans et al., 2007).

While accumulating evidence over the past two decades has demonstrated widespread effects of circulating testosterone on the social behavior of males in many species, including its effects on aggression (Archer, 2006), mate-seeking (Roney et al., 2003), dominance (Kemper, 1990; Mazur and Booth, 1998) and profitability in men (Coates and Herbert, 2008) it has also, conversely, demonstrated that men's testosterone levels respond to their social milieu and status. For instance, testosterone rises during brief interactions with attractive women (Roney et al., 2003; Ronay and von Hippel, 2010) and with the anticipation of a social challenge or contest (Wingfield et al., 1990; Mazur and Booth, 1998). Also, winners of competitive challenges often experience a relative increase in testosterone compared to losers; a differential response that primarily occurs in men (Bateup et al., 2002) and applies to physical competitions, such as tennis (Booth et al., 1989), non-physical competitions, such as chess (Mazur et al., 1992) and political contests and chance-based competitions such as coin-tosses (McCaul et al., 1992).

Findings such as these suggest that testosterone acts as a physiological modulator of behavior, allowing male organisms to appropriately adjust their behavior to changing social environments (Oliveira, 2004). Males across a range of species engage in risky and competitive behaviors in response to increases in testosterone, particularly during the breeding season (Wingfield et al., 1990). As an example, mating calls by males are risky because they expose males to increased risk of predation, but they also attract more females. Indeed, recent work also suggests that testosterone has motivational effects on human males to compete and take risks. In athletes, pre-training concentrations of testosterone correlate with men's voluntary workloads during training sessions (Cook et al., 2013). Men are also more likely to perform physically risky stunts in the presence of attractive women and this increase in risky behavior is explained by rising levels of testosterone in the men (Ronay and von Hippel, 2010). These motivational effects of testosterone have also been noted in non-physical domains. For instance, an increase in testosterone following success in a cognitive spatial task against an opponent predicts men's willingness to participate in another competition against the same opponent (Mehta and Josephs, 2006). Finally, testosterone changes following a competitive line-tracing task also predict future aggressive behavior in men (Carré et al., 2009). In short, transient increases in testosterone work to promote socially competitive and risky behaviors in males, precisely when those behaviors are likely to be profitable and not when they are likely to be costly (Oliveira, 2004; Apicella and Cesarini, 2011; Eisenegger et al., 2011).

While the pathway through which testosterone produces its motivating and competitive effects are not clearly defined, research suggests that testosterone exerts positive

hedonic effects by activating mesolimbic dopaminergic pathways involved in incentive processing such as in the ventral striatum (Hermans et al., 2010) and more specifically the nucleus accumbens (Frye et al., 2002). Event-related functional magnetic resonance imaging research has implicated these same pathways in feelings of positive arousal and in anticipation of financial rewards (Knutson et al., 2001). In fact, greater activation of the nucleus accumbens is observed before individuals select risky relative to safe monetary gambles but this same activation is not observed prior to making safe relative risky monetary decisions (Matthews et al., 2004).

This behavioral plasticity to varying levels of testosterone likely evolved because it, on average, benefited males (Oliveira, 2004), but it is also possible that it could lead to irrational decision-making. This may be especially true in evolutionarily novel domains, such as financial decision-making or when changes in testosterone resulting from one event influence the behavior of an organism in a separate and independent event. Indeed, if changes in testosterone influence financial decision-making in men, this may help to explain a number of documented behavioral economic phenomena such as (a) the house money effect (an increase in risk-seeking following a prior gain) (Thaler and Johnson, 1990), (b) increases in financial risk-taking by men following physical contact with a woman (Levav and Argo, 2010) and (c) national stock market declines after a country's sports team experiences a defeat (Edmans et al., 2007).

While little work has examined whether changes in testosterone influence financial risk-taking, few studies have examined the relationship between testosterone on economic decision making more generally. For instance, correlations between financial risk-taking and baseline testosterone (Apicella et al., 2008; Stanton et al., 2011) and 2D:4D digit ratios (Sapientza et al., 2009; Branäs-Garza and Rustichini, 2011), a proxy for prenatal testosterone exposure, have been reported. However, the findings have been mixed. While Apicella et al. (2008) reported a linear relationship between salivary testosterone concentrations and the amount of money invested in a risky gamble, Stanton et al. (2011) found that men with both low and high levels of testosterone were risk neutral, whereas individuals with intermediate levels of testosterone were risk averse. Other studies have found no relationship between baseline testosterone and financial risk (Sapientza et al., 2009) and economic competitiveness (Apicella et al., 2011). Researchers have also examined the organizing effects of testosterone on the brain during critical periods of development. For example, a lower ratio between the second finger and fourth finger (2D:4D, digit ratio), which is thought to reflect greater exposure to testosterone in utero (Manning et al., 1998) has been associated with increased profits and risk taking in high-frequency traders (Coates et al., 2009; Coates & Page, 2009). Negative relationships between 2D:4D and financial risk have also been found in less specialized populations (Branäs-Garza and Rustichini, 2011; Dreber & Hoffman, 2007). Yet, some studies have also yielded null or mixed results. Apicella et al. (2008) did not find a relationship between 2D:4D and financial risk in an ethnically heterogeneous sample of men. Similarly, Sapientza et al. (2009) did not obtain a significant relationship between 2D:4D and financial risk-taking in a mixed-sex sample of students, though students with lower 2D:4D were more likely

to select financial risky careers. One possibility for these mixed findings is that transient changes in testosterone may also be important in mediating behaviors associated with risk. Yet, little work has examined this.

We contribute to this important body of research by focusing on the role of testosterone change in financial risk. Specifically, we investigate whether natural changes in testosterone, following wins and losses in a monetary competition, influence future financial risk-taking. Since there is much evidence that the magnitude of testosterone responses in men varies (Cohen et al., 1996; Pound et al., 2009) and that increases in testosterone influence other behaviors associated with competition and risk-taking, we hypothesize that individual differences in testosterone reactivity will be associated with financial risk-taking.

2. Method

2.1. Experimental procedures and design

The experiment and all procedures were approved by the Harvard University's Committee on the Use of Human Subjects in research. When arriving at the laboratory, participants immediately signed consent form and where thereafter seated in private cubicles in the lab. Before any instructions about the experiment were given, the first saliva sample was collected in 2 ml cryovials via passive drool. The second saliva sample was collected on average 30 min after the competition.

For the competition, participants played 15 rounds of Rock, Paper, Scissors (RPS) against an opponent. RPS is a chance-based game with no pure strategy Nash equilibrium, but a mixed-strategy equilibrium is to play randomly.¹ Participants were randomly paired with another participant and each pair was taken to an adjacent room by a female experimenter. They were seated at a table opposite one another and each were given three laminated cards with the RPS symbols from which to choose.

Participants also had a pile of one-dollar bills placed on the table in front of them. The participant who won the most rounds of the game was declared the winner. In the event of a tie an additional round(s) was used to determine a winner. The pairs were assigned to one of two monetary treatments (5USD or 15USD). Depending on the treatment, each individual in the pair had either 5USD or 15USD placed in front of them. Each participant had the same amount of money in front of them as their opponent and in both conditions the participants could, over the course of the 15 rounds, either win 5USD or lose 5USD from/to their opponent. We specifically designed the study such that the winners from the 5USD condition, whose resulting income would be 10USD, could be directly compared to the losers from the 15USD, whose resulting income would also be 10USD. These conditions were put into place given the possibility that earnings could directly affect both testosterone and risk-aversion. Thus we compare the winners from the 5USD condition to the

losers from 15USD condition since both groups have the same resulting income of 10USD ($n = 49$).

After the competition, participants were escorted back to the computer lab where they participated in a non-incentivized filler task. Thereafter, risk attitudes were elicited by having participants make ten computerized choices between a certain amount of money that varied, in increments of 1USD, from 1USD to 10USD and a lottery with a 50 percent chance of winning 10USD. The lottery remained the same in all ten choices and was determined with a coin toss. The task was incentivized and participants were told that one of their choices would be selected at random to determine their earnings. This risk elicitation task is standard in the literature and follows Holt and Laury (2002). The number of times a participant chose the certain payoff is a standard measure of risk aversion and an average of 5.5 indicates risk neutrality, whereas a lower score indicates risk loving behavior and a higher score indicates risk aversion.

After having been paid their earnings from the experiment in private, participants filled out a questionnaire that contained questions about age, sexuality, relationship status and potential use of psychotropic or steroid medications.

All saliva samples were frozen immediately after collection and stored at -20°C . At the end of the data collection period, all samples were packed in dry ice and shipped via Fed Ex, overnight delivery, to Salimetrics LLC, State College, PA for assaying. Saliva samples were assayed for testosterone in duplicate using a highly sensitive enzyme immunoassay (Salimetrics). The test uses 25 μl of saliva per determination, has a lower limit of sensitivity of 1.0 pg/ml, standard curve range from 6.1 pg/ml to 600 pg/ml, an average intra-assay coefficient of variation of 4.6 percent and an average inter-assay coefficient of variation of 9.8 percent. Method accuracy determined by spike recovery average 104.3 percent and linearity determined by serial dilution average 102.4 percent. The serum and saliva correlation for males and females combined in this test is $r(26) = 0.96$, $p < 0.001$.

Salivary measures quantify bioactive or free testosterone concentration and research suggests that salivary testosterone levels in men are highly correlated with both serum free and total testosterone levels in males (Granger et al., 2004). While there are many benefits of using saliva to measure testosterone there are some limitations, including the possibility that testosterone-behavior correlations may be underestimated (for a review of limitations see Granger et al., 2004).

2.2. Subjects

Male participants were recruited through the Harvard Decision Science Laboratory, which has a subject pool consisting of students and other inhabitants in the Boston metropolitan area. The laboratory does not employ deception and makes this clear to subjects. In the recruitment processes, subjects were informed that they were not allowed to eat or drink

¹ This implies that winners and losers were randomly assigned in the RPS game. To confirm that this was actually the case, we test whether our winners were more likely to win compared to chance expectations. We ran 1000 simulations of our exact RPS game but where the outcomes were based on chance. We found no evidence that the number of rounds of RPS that was won by the winners in our study was greater than what would be expected by chance. The winners in our random simulation won by the same margin ($M = 2.62$, $S.D. = 1.84$) as the real winners in our game ($M = 2.80$; $S.D. = 2.25$), suggesting that winners and losers were randomly assigned (95% CI 2.38–2.90).

anything except water for at least an hour before the start of the experimental session for which they signed up. Subjects were again reminded of this rule on the day before their participation. Subjects were given a show up fee of 10USD.

Nineteen experimental sessions with a total of 108 men were conducted. Six men were excluded because they reported taking psychotropic or steroid medications. Four additional subjects were excluded from the analyses due to intoxication (1), reported food intake immediately before or during salivary collection (2) and visible contamination of the saliva sample with plasma due to a cut (1). These samples were not assayed. Due to our experimental design, where we control for income effects, data was analyzed for 49 subjects. Sessions lasted 45 min and participants earned on average 25.6USD. Sessions were conducted between 9.30am and 5.30pm during five consecutive weekdays. Of the subjects included in the analyses, ages ranged from 18 to 64 ($M = 35$, $S.D. = 14.9$). 38 percent of the subjects were students. The majority (64 percent) of the participants described themselves as white but other races were represented. These included black or African-American (9 percent), Hispanic (7 percent) and Asian (9 percent). The majority of subjects were also single (67 percent), whereas 16 percent were in a relationship but living alone and 18 percent were in a relationship living together. 84 percent of our subjects reported that they were heterosexual while 14 percent and 2 percent reported that they were homosexual and bisexual, respectively. Most of the participants did not have children though 9 percent of the participants reported having at least one child.

3. Results

Baseline testosterone does not differ between winners and losers (t -test $p = 0.5407$). There was an overall rise in testosterone in 73 percent of the participants before and after the competition (the average change in testosterone looking at all subjects is 27.82 pg/ml, corresponding to an increase of 26 percent). This is, to our knowledge, the first time increases in testosterone have been associated with a financial challenge. The change in testosterone was also associated with the outcome of the competition, though and as expected from previous studies (Pound et al., 2009), there is substantial inter-individual variation in the change. On average, winning men's testosterone levels increased 12 percent more than losing men (see Table 1). For men who won by a tighter margin that increase was even greater; the closer the final scores were between the participants or the more fierce the competition, the greater the increase. In a regression analysis (OLS) controlling for the difference in score between the player and his opponent, winning leads to a significantly greater increase in testosterone compared to losing (coeff = 44.92, $p = 0.020$).

Changes in testosterone significantly predict risk aversion (see Fig. 1A). In a regression analysis (OLS, see Table 2) we find that men who experience an increase in testosterone are less risk-averse (coeff = -0.015 , $p = 0.009$). To isolate the importance of changes in testosterone on risk-aversion following the competition, we also include a control for the binary winner variable. We still find that the greater the testosterone increase, the lower the risk aversion

Table 1 Summary statistics of all subjects, winners and losers.

Variable	All men	Winners	Losers
Baseline T (pg/ml)	$M = 106.14$ $S.D. = 41.84$ $N = 49$	$M = 102.51$ $S.D. = 30.50$ $N = 25$	$M = 109.92$ $S.D. = 51.51$ $N = 24$
Change in T (pg/ml)	$M = 27.82$ $S.D. = 41.52$ $N = 49$	$M = 33.00$ $S.D. = 29.42$ $N = 25$	$M = 22.43$ $S.D. = 51.33$ $N = 24$
Year of birth	$M = 1976$ $S.D. = 14.90$ $N = 45$	$M = 1976$ $S.D. = 14.63$ $N = 23$	$M = 1977$ $S.D. = 15.49$ $N = 22$
Heterosexual (1 = yes)	$M = 0.84$ $S.D. = 0.37$ $N = 43$	$M = 0.86$ $S.D. = 0.36$ $N = 21$	$M = 0.82$ $S.D. = 0.39$ $N = 22$
Risk aversion score	$M = 6.29$ $S.D. = 1.84$ $N = 49$	$M = 6$ $S.D. = 1.5$ $N = 25$	$M = 6.58$ $S.D. = 2.12$ $N = 24$

(coeff = -0.014 , $p = 0.020$). Whether participants won or lost in this model does not predict risk-aversion (coeff = -0.44 , $p = 0.404$), providing strong evidence that it is changes in testosterone that influence risk-taking in men and not the act of winning or losing itself or other biological mechanisms that are orthogonal to T .

The result is also robust when we control for both the winner variable and the difference in score between the competing pair (coeff = -0.016 , $p = 0.022$), and when we include additional control variables to the previous regression (coeff = -0.021 , $p = 0.011$). As an additional robustness check, we also perform the complete analyses using Tobit regressions and ordered probit regressions. The results are very similar to those from the OLS both qualitatively and in terms of statistical significance.

On average, participants made choices exhibiting more risk aversion than the risk neutral, profit maximizing choices. However, participants in the quintile with the largest testosterone increase made decisions that were risk neutral and profit-maximizing. Conversely, participants in the quintile with the largest testosterone decrease had a risk aversion score almost 40 percent higher than the risk neutral score (see Fig. 1B). Our results suggest that testosterone reactivity to competitive outcomes influences risk-aversion in men in ways that influence their financial payoffs.

4. Discussion

There is ample heterogeneity in economic preferences both within and between individuals – an observation that has motivated a large body of research to try to explain why these differences exist. Despite considerable efforts, individual differences in economic decision-making remain largely unexplained (Camerer, 2003). One possible reason is that traditional attempts to understand economic behavior have been made under the assumption that preferences are stable within individuals (Stigler and Becker, 1977). While relatively stable individual differences do exist, it is clear that pre-

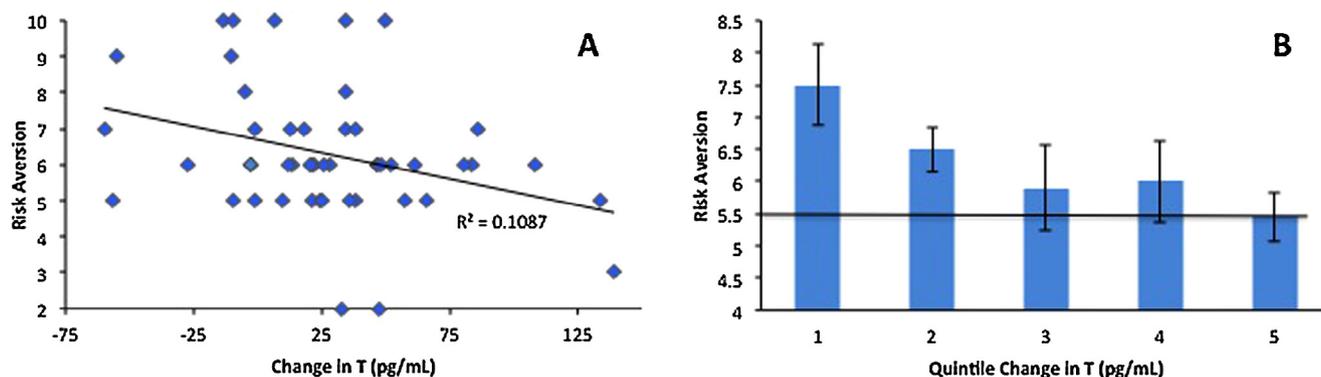


Figure 1 (A) Scatterplot of testosterone change by risk aversion. Line is least square fit. (B) Quintile of testosterone change and risk aversion. Line represents risk neutrality. $N = 49$.

ferences are flexible with the most extreme occurrence being preference reversal (Tversky and Thaler, 1990). The failure to find robust correlates to variation in economic preferences suggests that other factors, largely independent of socio-demographics, such as biological, psychological and situational sources, as well as their interactions, account for some of the variation between and within individuals. Here we demonstrated that individual differences in testosterone reactivity in response to a situational event are associated with financial risk-taking. Our result challenges the classical assumption in economics that preferences are stable within individuals and leads to testable predictions of how preferences may vary within an individual (and in groups) depending on context.

The extent to which biological factors mediate differences in economic decision-making is a current source of investigation (e.g. Burnham, 2007). While previous research suggests that baseline differences in testosterone may account for differences in risk preferences between men (Apicella et al., 2008; Stanton et al., 2011) and that male traders' profits increase on days when their testosterone is

highest (Coates and Herbert, 2008), our findings are the first to directly link individual differences in testosterone reactivity to financial risk in men. Moreover, we provide strong evidence that it is testosterone change, rather than the act of winning or losing money, that influences future financial risk; a result that indicates that variation in risk preferences can be explained by individual variation in testosterone reactivity to social events, such as winning or losing money in a competition.

While our results support the theoretical framework that changes in testosterone in men should modulate risky and competitive behaviors we cannot rule out that another variable correlated with testosterone could jointly or independently affect men's willingness to take risks. Of particular concern is the potential role of cortisol, the end product of the hypothalamic-pituitary-adrenal (HPA) axis, whose primary task is to modulate stress reactions. It is possible that the outcome of RPS game could have influenced cortisol levels in men, which could have directly affected men's willingness to take risks. It is also possible that changes in cortisol resulting from the game may have indirectly influenced risk-taking through its effects on testosterone. The HPA and the hypothalamic-pituitary-gonadal (HPG) axes are not independent of one another and increases in testosterone can inhibit cortisol and similarly rises in cortisol can work to inhibit testosterone (Viau, 2002). Furthermore, previous research has documented changes in cortisol with winning and losing competitions (Mehta et al., 2008; Jiménez et al., 2012; Aguilar et al., 2013). However, it is worth noting that recent research has not found a relationship between baseline levels of cortisol and a measure of economic competitiveness (Apicella et al., 2011). Similarly, a study examining cortisol levels in high frequency traders found no relationship between cortisol levels and profits and losses but did find that cortisol rises when the variance in trading results are high (Coates and Herbert, 2008). Still, there is very little research examining the role of cortisol on financial risk-taking and thus, any conclusions drawn from this limited body of work would be premature. Future work should examine the simultaneous influence of cortisol and testosterone on economic decision-making including risk.

Future work employing direct manipulations of testosterone on financial risk-aversion would also be a useful next step. A recent study employing the exogenous administration

Table 2 OLS regression analysis.

Dependent variable: risk aversion				
	(1)	(2)	(3)	(4)
ΔT	-0.015*** (0.005)	-0.014** (0.006)	-0.016** (0.007)	-0.021** (0.008)
Winner		-0.44 (0.52)	0.29 (0.87)	0.75 (0.83)
Scorediff			-0.12 (0.11)	-0.15 (0.11)
Controls	No	No	No	Yes
N	49	49	49	43
R^2	0.11	0.12	0.14	0.41

OLS. Robust standard errors. Controls include age, sexual orientation, and time of day.

*Level of significance: $p < 0.1$.

** Level of significance: $p < 0.05$.

*** Level of significance: $p < 0.01$.

of estradiol and an aromatase inhibitor to manipulate concentrations of testosterone and estradiol in men found that men whose intervention resulted in both high-normal testosterone and low-normal estrogen levels became more risk-taking (Goudriaan et al., 2010). However men whose intervention resulted in low-normal testosterone and high estradiol did not exhibit an increase in risk-taking. While this change in risk preferences was only found for one risk task involving unknown probabilities and not for another task, involving known probabilities, the authors state they were unable to account for the simultaneous variation in estradiol. Wibrál et al. (2012) find that men who receive testosterone become less likely to cheat in a task with economic consequences compared to men who receive placebo. Zethraeus et al. (2009) examined the effects of testosterone administration over four weeks on risk aversion in a sample of postmenopausal women but did not find an effect. However, it is not clear that men and women should react similarly to circulating levels testosterone. Compared to men, women have less androgen-responsive neurons, rendering them less responsive to the behavioral influences of testosterone (Wood and Newman, 1999). Likewise, critical periods of exposure to testosterone, such as in utero, are thought to have organizing effects on the brain affecting how individuals respond to the activating effects of testosterone (as shown in e.g. Montoya et al., 2013 on moral decision making). Accordingly, research examining the effects of testosterone change on behavior should ultimately be wedded with research involving testosterone exposure during other periods of development.

The significance of our results not only depend on how closely tied men's risk preferences are to changes in their testosterone levels, but also to how readily changeable testosterone is within men. If testosterone were stable in men, our findings would bear little significance. However, testosterone levels are not static and vary in predictable ways. Changes in testosterone have been linked to exercise (Weiss et al., 1983), mate-seeking (Roney et al., 2003), competitive challenges (Wingfield et al., 1990; Mazur and Booth, 1998), victories and defeats (Booth et al., 1989; Mazur et al., 1992; McCaul et al., 1992) as well as major life events such as marriage and fatherhood (Gray et al., 2002; Gettler et al., 2011). Likewise, many of these events have also been linked to changes in risk-taking in ways that are consistent with what we would expect if the phenomena were mediated by testosterone.

Our findings also offer an important complement to current theories of financial risk-taking, such as prospect theory, by showing how independent and unrelated events may influence financial decision-making in men through their actions on testosterone. Indeed, this may help to explain a number of documented behavioral economic phenomena, such as the house money effect (Thaler and Johnson, 1990), increased financial risk in men following physical contact with a woman (Levav and Argo, 2010) and national stock market declines after a country's sports team experiences a defeat (Edmans et al., 2007). To the extent to which we can predict events that influence testosterone levels in individuals and in groups, we would be in a better position to predict the behavior of not only individual investors but also market economies. Many instances of unexplained collective phenomena, such as crowd effects or herd behavior have

been documented in financial markets and it is possible that changes in testosterone at the group level may help us to better understand these observations. We look forward to research investigating these possibilities further and note that one important part of this future research is to address the differences and similarities in the role of testosterone for both men's and women's risk taking.

Role of funding sources

This work was supported by the Mind Brain Behavior Interfaculty Initiative at Harvard University and the Jan Wallander and Tom Hedelius Foundation (Handelsbankens forskningsstiftelser). This research was not funded by any of the funding bodies that have agreements with Elsevier.

Conflict of interest

None declared.

Acknowledgments

We thank Magnus Johannsson and Burkhard Schipper for helpful comments and feedback. This work was supported by the Mind Brain Behavior Interfaculty Initiative at Harvard University and the Jan Wallander and Tom Hedelius Foundation (Handelsbankens forskningsstiftelser).

References

- Aguilar, R., Jiménez, M., Alvero-Cruz, J.R., 2013. Testosterone cortisol and anxiety in elite field hockey players. *Phys. Behav.* 119, 38–42.
- Apicella, C.L., Dreber, A., Campbell, B., Gray, P., Hoffman, M., Little, A.C., 2008. Testosterone and financial risk preferences. *Evol. Hum. Behav.* 29, 384–390.
- Apicella, C.L., Cesarini, D.A., 2011. Testosterone and the biology of politics: experimental evidence from the 2008 Presidential Election. In: Hatemi, P.K., McDermott, R. (Eds.), *Man is by Nature a Political Animal: Evolution, Biology, and Politics*. University of Chicago Press, Chicago, pp. 261–272.
- Apicella, C.L., Dreber, A., Gray, P.B., Hoffman, M., Little, A.C., Campbell, B.C., 2011. Androgens and competitiveness in men. *J. Neurosci. Psychol. Econ.* 4, 54–62.
- Archer, J., 2006. Testosterone and human aggression: an evaluation of the challenge hypothesis. *Neurosci. Biobehav. Rev.* 30, 319–345.
- Bateup, H., Booth, A., Shirtcli, E., Granger, D., 2002. Testosterone cortisol, and women's competition. *Evol. Hum. Behav.* 23, 181–192.
- Booth, A., Shelley, G., Mazur, A., Tharp, G., Kittok, P., 1989. Testosterone and winning and losing in human competition. *Horm. Behav.* 23, 556–571.
- Branas-Garza, P., Rustichini, A., 2011. Organizing effects of testosterone and economic behavior: not just risk taking. *PLoS ONE* 6, e29842.
- Burnham, T., 2007. High-testosterone men reject low ultimatum game offers. *Proc. R. Soc. B: Biol. Sci.* 274, 2327–2330.
- Camerer, C., 2003. *Behavioral Game Theory: Experiments in Strategic Interaction*. Princeton University Press, Princeton.
- Carré, J., Putnam, S., McCormick, C., 2009. Testosterone response to competition predict future aggressive behaviour to a cost to reward in men. *Psychoneuroendocrinology* 34, 561–570.

- Coates, J., Herbert, J., 2008. Endogenous steroids and financial risk taking on a London trading floor. *Proc. Natl. Acad. Sci. U.S.A.* 105, 6167–6172.
- Coates, J., Gurnell, M., Rustichini, A., 2009. Second-to-fourth digit ratio predicts success among high-frequency financial traders. *Proc. Natl. Acad. Sci. U.S.A.* 106, 623–628.
- Coates, J., Page, L., 2009. A note on trader Sharpe ratios. *PLoS ONE* 4, e8036.
- Cohen, D., Nisbett, R., Bowdle, B., Schwarz, N., 1996. Insult, aggression, and the southern culture of honor: an 'experimental ethnography'. *J. Pers. Soc. Psychol.* 70, 945–960.
- Cook, C.J., Crewther, B.T., Kilduff, L.P., 2013. Are free testosterone and cortisol concentrations associated with training motivation in elite male athletes? *Psych. Sports Exerc.* 14, 882–885.
- Dreber, A., Hoffman, M., 2007. Portfolio Selection in Utero. Mimeo/Stockholm School of Economics, Stockholm, Sweden.
- Edmans, A., Garcia, D., Norli, O., 2007. Sports sentiment and stock returns. *J. Finance* 62, 1967–1998.
- Eisenegger, C., Haushofer, J., Fehr, E., 2011. The role of testosterone in social interaction. *Trends Cogn. Sci.* 15, 263–271.
- Frye, C.A., Rhodes, M.E., Rosellini, R., Svare, B., 2002. The nucleus accumbens as a site of action for rewarding properties of testosterone and its 5 α -reduced metabolites. *Pharmacol. Biochem. Behav.* 74, 199–127.
- Gettler, L., McDade, T., Feranil, A., Kuzawa, C., 2011. Longitudinal evidence that fatherhood decreases testosterone in human males. *Proc. Natl. Acad. Sci. U.S.A.* 108, 16194–16199.
- Goudriaan, A.E., Lapauw, B., Ruige, J., Feyen, E., Kaufman, J.-M., Brand, M., Vingerhoets, G., 2010. The influence of high-normal testosterone levels on risk-taking in healthy males in a 1-week letrozole administration study. *Psychoneuroendocrinology* 35, 1416–1421.
- Granger, D.A., Shirtcliff, E.A., Booth, A., Kivlighan, K.T., Schwartz, E.B., 2004. The trouble with salivary testosterone. *Psychoneuroendocrinology* 29, 1229–1240.
- Gray, P., Kahlenberg, S., Barrett, E., Lipson, S., Ellison, P., 2002. Marriage and fatherhood are associated with lower testosterone in males. *Evol. Hum. Behav.* 23, 193–201.
- Hermans, E.J., Bos, P.A., Ossewaarde, L., Ramsey, N.F., Fernández, G., van Honk, J., 2010. Effects of exogenous testosterone on the ventral striatal BOLD response during reward anticipation in healthy women. *Neuroimaging* 52, 277–283.
- Holt, C.A., Laury, S.K., 2002. Risk aversion and incentive effects. *Am. Econ. Rev.* 92, 1644–1655.
- Jiménez, M., Aguilar, R., Alvero-Cruz, J.R., 2012. Effects of victory and defeat on testosterone and cortisol response to competition: evidence for same response patterns in men and women. *Psychoneuroendocrinology* 37, 1577–1581.
- Kemper, T.D., 1990. *Social Structure and Testosterone: Explorations of the Socio-bio-social Chain*. Rutgers University Press, New Brunswick, NJ.
- Knutson, B., Adams, C.M., Fong, G.W., Hommer, D., 2001. Anticipation of increasing monetary reward selectively recruits nucleus accumbens. *J. Neurosci.* 21, RC159.
- Levay, J., Argo, J., 2010. Physical contact and financial risk taking. *Psychol. Sci.* 21, 804–810.
- Manning, J.T., Scutt, D., Wilson, J., Lewis-Jones, D.I., 1998. The ratio of 2nd to 4th digit length. A predictor of sperm numbers and concentrations of testosterone, lutenizing, hormones and oestrogen. *Hum. Reprod.* 13, 3000–3004.
- Matthews, S.C., Simmons, A.N., Lane, S.D., Paulus, M.P., 2004. Selective activation of the nucleus accumbens during risk-taking decision making. *Neuroreport* 15, 2123–2127.
- Mazur, A., Booth, A., Dabbs Jr., J.M., 1992. Testosterone and chess competition. *Soc. Psychol. Q.* 55, 70–77.
- Mazur, A., Booth, A., 1998. Testosterone and dominance in men. *Behav. Brain Sci.* 21, 353–363.
- McCaul, K., Gladue, B., Joppa, M., 1992. Winning losing, mood, and testosterone. *Horm. Behav.* 26, 486–504.
- 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, 1078–1093.
- Montoya, E.R., Terburg, D., Bos, P.A., Will, G.J., Buskens, V., Raub, W., van Honk, J., 2013. Testosterone administration modulates moral judgments depending on second-to-fourth digit ratio. *Psychoneuroendocrinology* 38, 1362–1369.
- Oliveira, R., 2004. Social modulation of androgens in vertebrates: mechanisms and function. *Adv. Stud. Behav.* 34, 165–239.
- Pound, N., Penton-Voak, I., SurrIDGE, A., 2009. Testosterone responses to competition in men are related to facial masculinity. *Proc. R. Soc. B: Biol. Sci.* 276, 153–159.
- Ronay, R., von Hippel, W., 2010. The presence of an attractive woman elevates testosterone and physical risk taking in young men. *Soc. Psychol. Pers. Sci.* 1, 57–64.
- Roney, J., Mahler, S., Maestripieri, D., 2003. Behavioral and hormonal responses of men to brief interactions with women. *Evol. Hum. Behav.* 24, 365–375.
- Sapienza, P., Zingales, L., Maestripieri, D., 2009. Gender differences in financial risk aversion and career choices are affected by testosterone. *Proc. Natl. Acad. Sci. U.S.A.* 106, 15268–15273.
- Stanton, S.J., Mullette-Gillman, O., McLaurin, R., Kuhn, C., LaBar, K., Platt, M., Huettel, S., 2011. Low- and high-testosterone individuals exhibit decreased aversion to economic risk. *Psychol. Sci.* 22, 447.
- Stigler, G., Becker, G., 1977. De gustibus non est disputandum. *Am. Econ. Rev.* 67, 76–90.
- Thaler, R., Johnson, E., 1990. Gambling with the house money and trying to break even: the effects of prior outcomes on risky choice. *Manage. Sci.* 36, 643–660.
- Tversky, A., Thaler, R., 1990. Anomalies: Preference reversals. *J. Econ. Perspect.* 4, 201–211.
- Via, V., 2002. Functional cross-talk between the hypothalamic–pituitary–gonadal–adrenal axes. *J. Neuroendocrinol.* 14, 506–513.
- Weiss, L., Cureton, K., Thompson, F., 1983. Comparison of serum testosterone and androstenedione responses to weight lifting in men and women. *Eur. J. Appl. Physiol. Occup. Physiol.* 50, 413–419.
- Wibral, M., Dohmen, T., Klingmüller, D., Weber, B., Falk, A., 2012. Testosterone administration reduces lying in men. *PLoS ONE* 7, e46774.
- Wingfield, J., Hegner, R., Dufty Jr., A., Ball, G., 1990. The 'challenge hypothesis': theoretical implications for patterns of testosterone secretion mating systems, and breeding strategies. *Am. Nat.* 136, 829–846.
- Wood, R., Newman, S., 1999. Androgen receptor immunoreactivity in the male and female Syrian hamster brain. *J. Neurobiol.* 39, 359–370.
- Zethraeus, N., Kocoska-Maras, L., Ellingsen, T., von Schoultz, B., Hirschberg, A., Johannesson, M., 2009. A randomized trial of the effect of estrogen and testosterone on economic behavior. *Proc. Natl. Acad. Sci. U.S.A.* 106, 6535.