Available online at www.sciencedirect.com

ScienceDirect

Current Opinion in Behavioral Sciences

The dual-hormone hypothesis: a brief review and future research agenda

Pranjal H Mehta and Smrithi Prasad

The dual-hormone hypothesis posits that testosterone's role in status-relevant behavior should depend on concentrations of cortisol, a hormone released in response to physical and psychological stress. This paper (i) reviews evidence for the dual-hormone hypothesis on measures of dominance, aggression, social status, risk-taking, and economic decision-making; (ii) discusses contextual and individual difference moderators of dual-hormone associations with behavior; and (iii) outlines key directions for future research. Together, this review points to promising support for the dual-hormone hypothesis across multiple behavioral domains relevant to the pursuit and maintenance of social status.

Address
Department of Psychology, University of Oregon, United States

Corresponding author: Mehta, Pranjal H (mehta@uoregon.edu)

Current Opinion in Behavioral Sciences 2015, **3**:163–168

This review comes from a themed issue on **Social behavior**

Edited by **Molly J Crockett** and **Amy Cuddy**

For a complete overview see the Issue and the Editorial

Available online 12th May 2015

http://dx.doi.org/10.1016/j.cobeha.2015.04.008

Introduction

Prevailing theories propose that testosterone should directly enhance status-seeking behaviors such as dominance and aggression in a variety of species (for reviews, see [1–4]), but the precise role of this hormone in human social behavior remains controversial. Although some studies have demonstrated positive associations between testosterone and status-relevant behaviors such as dominance, aggression, and competitive behaviors, other studies have revealed null or weak effects. Further, meta-analyses indicate only a small positive relationship between baseline testosterone and human aggression [5]. Some scholars have attributed these weak and inconsistent results to methodological limitations of studies. However, another possibility is that testosterone may not directly impact aggressive and dominant behaviors as prevailing theories predict. There is a need for an updated theoretical perspective that can better explain testosterone's behavioral effects.

This paper reviews evidence for the *dual-hormone hypothesis*, a novel hypothesis that was recently proposed to account for the inconsistences in research on testosterone and human social behavior [6••,7]. In the sections below, we (i) review studies that have tested the dual-hormone hypothesis, (ii) discuss contextual and individual difference moderators, and (iii) highlight key directions for future research. We conclude that there is promising evidence for the dual-hormone hypothesis in numerous behavioral domains.

The dual-hormone hypothesis: testosterone × cortisol interactions and human social behavior

Traditional theories propose that testosterone should directly increase behaviors implicated in the pursuit of social status such as dominance. By contrast to these standard theories, the dual-hormone hypothesis proposes that testosterone's impact on status-seeking behaviors should depend on concentrations of cortisol — a hormone released during physical and psychological stress [6••,7]. Specifically, the dual-hormone hypothesis predicts that testosterone should interact with cortisol such that testosterone should be positively related to status-seeking behaviors only when cortisol concentrations are low. When cortisol concentrations are high, the model predicts that testosterone's impact on status-seeking behaviors should be blocked or inhibited. Testing the dual-hormone hypothesis requires measurements of testosterone, cortisol, and social behavior followed by analyses that test for a statistical interaction between testosterone and cortisol (for a review of statistical interactions, see [8]). Below we review emerging evidence in support of the dual-hormone hypothesis across multiple behavioral domains (see Table 1).

Dominant leadership behavior. In one study of 94 undergraduate students (approximately 50% males), participants provided an afternoon saliva sample and were videotaped in a leadership position [6••]. Research assistants watched the videotapes and rated the leaders on items that tap into dominance (e.g., assertive, confident, leader-like). Ratings were aggregated to create an overall index of dominant leadership behavior. In strong support of the dual-hormone hypothesis, there was a statistically significant basal testosterone × basal cortisol interaction such that testosterone was positively related to dominant leadership behavior only among low-cortisol individuals (see left panel, Figure 1). Among high-cortisol individuals, there was a non-significant association between

Table 1

Studies that provide empirical support for the dual hormone hypothesis.

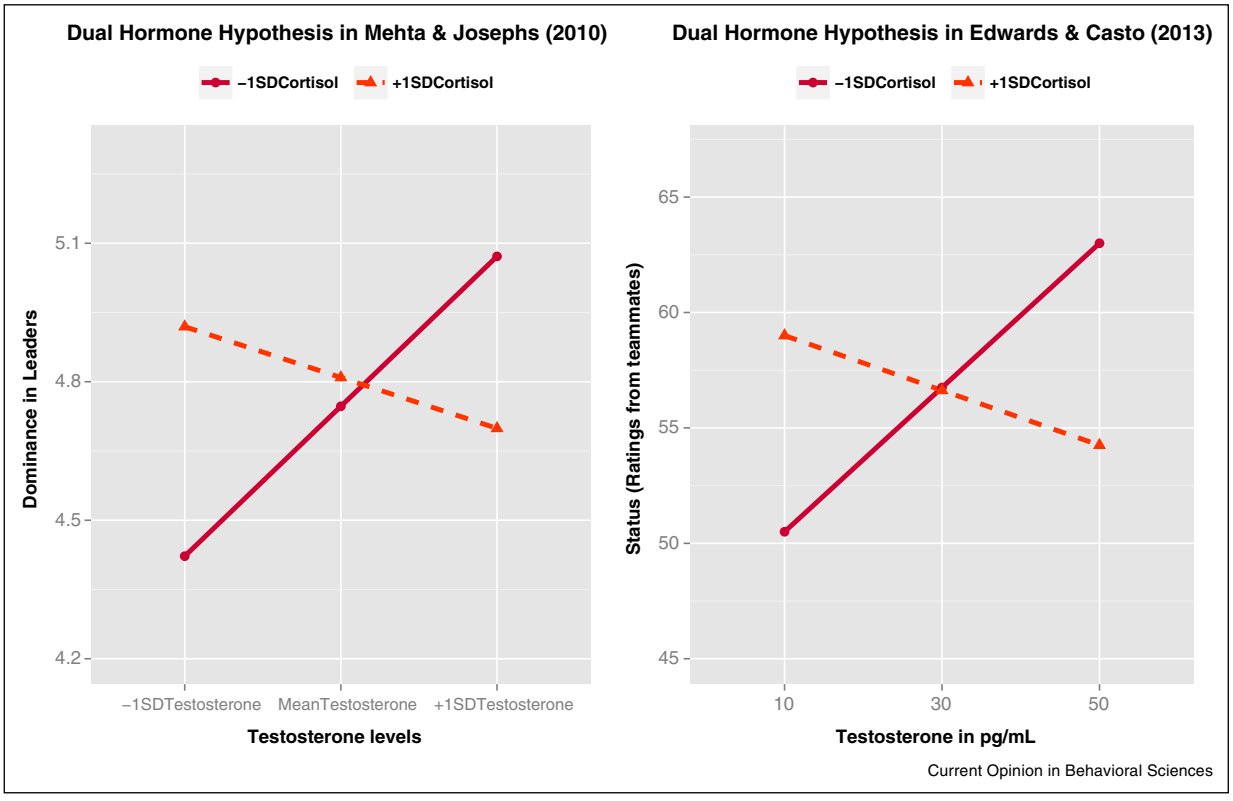
Year	Reference	Sample size	Sample characteristics	Dependent variable(s)	Context or individual difference moderator
Studies that report basal testosterone × basal cortisol interactions consistent with the standard predictions of the dual-hormone hypothesis					
1991	Dabbs *et al*.	113 M	Late-adolescent offenders in the U.S.	Real life crime/juvenile delinquency	–
2007	Popma *et al*.	103 M	12–14 year old delinquent adolescents in the Netherlands	Self-reported trait aggression	–
2010	Mehta and Josephs (study 1)	45 M|49 F	U.S. undergraduates	Dominant leadership behavior	–
2010	Mehta and Josephs (study 2)	57 M	U.S. undergraduates	Competitive decisions, testosterone change	Victory versus defeat
2011	Geniole *et al*.	74 M	Canadian undergraduates	Aggressive behavior	Social inclusion versus exclusion
2013	Edwards and Casto	74 F	U.S. Female athletes	Teammates' ratings of social status	–
2012	Zilioli and Watson	70 M	Canadian undergraduates	Testosterone change	Victory versus defeat
2013	Pfattheicher *et al*.	72 M	German students	Punishment in a public goods game	–
2013	van den Bos *et al*.	26 M	U.S. undergraduates	Overbidding	–
2014	Tackett *et al*.	47 M|57 F	13–18 year old adolescents in the U.S.	Externalizing behaviors	Personality traits (disagreeableness, emotional instability)
2014	Zilioli *et al*.	323M|146 F	U.S. MBA students	Empathy	–
2015	Mehta *et al*. (study 1)	53 M|62 F	U.S. undergraduates	Risk-taking (self report and informant report)	–
2015	Mehta *et al*. (study 2)	160 M	U.S. undergraduates	Risk-taking (balloon analog risk task)	–
Studies that report basal testosterone × basal cortisol interactions showing a reversal of the dual-hormone hypothesis					
2013	Denson *et al*.	53 F	Australian students	Aggressive behavior	–
2014	Welker *et al*.	114 M|123 F	U.S. undergraduates	Psychopathy	–
Studies that report acute testosterone change × cortisol change interactions					
2015	Mehta *et al*. (study 1)	38 M|26 F	U.S. MBA students	Final price negotiated in a competitive negotiation	Seller versus buyer
2015	Mehta *et al*. (study 2)	54 M|61 F	U.S. undergraduates and community members	Rejection of unfair offers in the ultimatum game	–

testosterone and leadership behavior. Further, there were no sex differences in this dual-hormone interaction. Indeed, a similar dual-hormone interaction pattern emerged when examining males and females separately.

Social status. Dominant behaviors are related to the attainment and maintenance of high-status positions [2,9]. Thus, the results from the previously discussed laboratory study on leadership behavior suggest that the dual-hormone hypothesis may extend to measures of social status in real-world groups. To test this possibility, one study examined the interactive effects of testosterone and cortisol on social status in collegiate female sports teams (soccer, softball, tennis, and volleyball teams) [10•]. Seventy-four female athletes provided saliva samples and rated their team members on perceived social status. Items on the social status measure included: 'She inspires her teammates to play at their highest level.' and 'Please provide an overall rating of the individual's abilities as a team leader.' Consistent with the results of the laboratory study on leadership behavior, there was a basal testosterone × basal cortisol interaction such that testosterone was positively related to social status only among low-cortisol athletes but not among high-cortisol athletes (see right panel, Figure 1).

Aggressive and violent behavior. The studies reviewed above suggest that testosterone interacts with cortisol to predict dominant leadership behaviors and higher status in students and athletes. However, the behavioral mechanisms of status attainment may vary across different populations. In samples of prisoners and delinquent adolescents, for example, violent behavior may be a key behavioral route to status attainment and reputation management. Two studies tested the dual-hormone hypothesis on measures of aggression and violent behavior in such populations. In one study, hormone profiles in 113 late-adolescent male offenders were used to predict criminal violence [11•]. In a second study, hormone profiles in 103 12–14-year-old delinquent male adolescents in the

Figure 1



The dual hormone hypothesis interaction pattern across two studies: (1) Mehta and Josephs [6••]: dominance in leaders as a function of the interactive effects of testosterone and cortisol (left panel); (2) Edwards and Casto [10•]: perceived status as a function of the interaction between testosterone and cortisol levels (right panel). The interactions have been graphed following standard procedures for interpreting statistical interactions in regression [8].

Netherlands were used to predict self-reported overt aggression (e.g., 'When I lose my temper, I am capable of slapping someone.') [12•]. In both studies, there were basal testosterone × cortisol interactions such that testosterone was positively related to aggression/violent crime only among low-cortisol individuals but not among high-cortisol individuals.

Antisocial economic punishment in a public goods game. Another study (72 male students at a German university) tested the interactive effects of testosterone and cortisol on antisocial economic punishment in a public goods game [14•]. In support of the dual-hormone hypothesis, there was a basal testosterone × basal cortisol interaction such that testosterone was associated with higher antisocial punishment among low-cortisol but not high-cortisol individuals.

Empathy. In another study 469 MBA students (323 males) provided afternoon saliva samples and completed self-reported empathy [15•]. Items on the self-report scale included: 'I often have tender, concerned feelings for people less fortunate than me.' There was a statistically significant testosterone × cortisol interaction consistent with the dual-hormone hypothesis. Higher testosterone was related to lower self-reported empathy only among low-cortisol individuals.

Overbidding in auctions. Overbidding is the tendency to bid more than the estimated utility of a good when competing for an item in an auction (cf. [15•]). The motivation to attain higher status (i.e., the desire to 'win') is likely a key psychological factor involved in overbidding. In one study 26 male participants provided saliva samples in the late afternoon or early evening and made decisions in a laboratory auction task [16•]. There was a basal testosterone × basal cortisol interaction such that testosterone was positively related to overbidding among low-cortisol individuals but not high-cortisol individuals.

Risk-taking. Evolutionary theories propose that risk-taking may have evolved as a behavioral strategy for status attainment. Thus, the dual-hormone hypothesis may extend beyond competition, dominance, and status to measures of risk-taking as well. In two studies (N = 280), the dual-hormone hypothesis was tested across

self-reported, informant-reported, and behavioral measures of risk-taking [17•]. Both studies found a positive association between basal testosterone and risk-taking only for individuals with low basal cortisol, but not for individuals with high basal cortisol.

Contextual and individual differences moderators of the dual-hormone interaction

The studies reviewed above provide compelling empirical support for the dual-hormone hypothesis. However, a few other studies that measured basal hormones and social behavior revealed non-significant dual-hormone interactions on measures of aggression and violence (e.g., [18,19]). Methodological differences may account for some of these non-significant effects (e.g., morning instead of afternoon hormone measures in [19]), but another possibility is that these two hormones may further interact with the social context or psychological individual differences to modulate status-relevant behavior. Below we review evidence for context and personality moderators of the dual-hormone interaction.

Victory-defeat context. In one study of 57 undergraduate males, participants reported to the lab in pairs and provided afternoon saliva samples [6••]. Then participants competed in a cognitive contest in which the winner and loser were rigged. After the competition, participants chose whether or not to compete again against the same opponent in a second competition. There was a basal testosterone × basal cortisol × victory-defeat context interaction on competitive decision-making. Testosterone interacted with cortisol to predict complete decisions only after defeat, such that testosterone was related to a greater propensity to compete again among low-cortisol individuals but not high-cortisol individuals (see also [20•]). These results suggest that testosterone and cortisol may interactively regulate the desire to compete again after facing a loss of status (social defeat), presumably as a strategy to regain status in the social hierarchy [6••].

Social inclusion-exclusion context. Seventy-four undergraduate males reported to the lab and provided afternoon saliva samples [21•]. Then they were randomly assigned to a social inclusion or exclusion condition in a ball-tossing computerized task (Cyberball). After this experimental context manipulation, participants completed a laboratory task designed to measure aggressive behavior. There was a marginally significant basal testosterone × basal cortisol × inclusion-exclusion context interaction on aggressive behavior. Decomposing the interaction revealed a testosterone × cortisol interaction pattern consistent with the standard predictions of the dual-hormone hypothesis *only* in the social inclusion condition (testosterone was positively related to aggressive behavior among low-cortisol but not high-cortisol individuals). Collectively, these two studies involving context manipulations suggest that the interactive effect of testosterone and cortisol on status-relevant behaviors depends on key contextual factors relevant to social status (victory-defeat, social inclusion-exclusion).

Personality. Not only is the dual-hormone interaction effect dependent on context factors but also on personality factors. In one study, 104 13–18 year-old adolescents (47 boys) provided saliva samples and were assessed for externalizing problems (aggression, rule-breaking behaviors) and personality pathology traits (disagreeableness and emotional instability) [22•]. There were statistically significant personality trait × basal testosterone × basal cortisol interactions on externalizing problems. Specifically, the testosterone × cortisol interaction was statistically significant only for individuals high in personality pathology traits (high disagreeableness, high emotional instability). For these individuals, the pattern of the interaction was consistent with the standard predictions of the dual-hormone hypothesis — testosterone was positively related to externalizing problems in low-cortisol individuals but not high-cortisol individuals. This study demonstrates that the dual-hormone interaction on aggressive and rule-breaking behaviors depends on psychological individual differences (personality pathology traits).

Future directions

This paper has summarized recent evidence in support of the dual-hormone hypothesis, but there are many remaining questions to address in future research.

Acute hormone change interactions and ratio effects. Research to date has tested the dual-hormone hypothesis primarily with 'trait' hormone parameters (basal hormone profiles), but two recent studies show that 'state' testosterone and cortisol changes interactively track bargaining outcomes [27•]. Additional studies should test the dual-hormone hypothesis with measures of dynamic hormone fluctuations. Further, the dual-hormone hypothesis predicts testosterone × cortisol interactions on behavior, but other theories propose that the testosterone/cortisol ratio should predict behavior [39]. More studies are needed that compare hormonal ratio and interaction effects.

Mechanisms. The mechanisms that explain dual-hormone interactions remain poorly understood. Cortisol inhibition of the gonadal axis [13,28–31]; interactive effects of testosterone and cortisol on subsequent hormone release [6••,20•]; neural mechanisms involving threat (e.g., amygdala), reward (e.g., ventral striatum), and prefrontal (e.g., orbitofrontal cortex) regions [32–40]; as well as psychological processes involving approach-inhibition, dominance-submission, and challenge-threat are all candidate mechanisms to investigate in future studies [6••,7,12•,13,42,27•,41].

Experimental designs. The dual-hormone hypothesis has been tested primarily in correlational studies. Experimental designs are needed in which hormone concentrations

are exogenously manipulated (e.g., pharmacological designs that simultaneously increase testosterone and suppress cortisol). Research designs in which hormone concentrations are altered through psychological manipulations will also be important for testing the dual-hormone hypothesis (social stress manipulations that increase cortisol [43]).

Reversal of the dual-hormone hypothesis. Two studies demonstrated testosterone × cortisol interactions in a *reverse* pattern from the standard predictions of the dual-hormone hypothesis ([42,44]; see also social exclusion condition in [21•]). Testosterone was positively related to aggression and psychopathy among *high*-cortisol but not low-cortisol individuals. Although researchers have speculated about possible explanations (e.g., presence vs. absence of social provocation, [42]), further research is required to identify the precise mechanisms for this novel reversal effect.

Sex differences. The dual-hormone hypothesis has been tested in both males and females. Some studies have shown non-significant associations in females [44], whereas others have shown dual-hormone interaction patterns that are similar in males and females [6••,17•,22•,45]. Future research with larger mixed-sex samples is needed to determine whether there are sex differences in dual-hormone interaction effects. Future studies should also examine female reproductive hormones (estradiol, progesterone) to determine if they also interact with cortisol to modulate female social behavior (see [45] for recent evidence in support of the dual hormone hypothesis with estradiol).

Conclusion

Recent research has provided promising support for the dual-hormone hypothesis across a variety of status-relevant behaviors, including dominance, competitive behavior, aggression, risk-taking, economic decision-making, and social status. Future studies are needed to test the dual-hormone hypothesis with experimental designs and to identify mechanisms and moderators. Research on the dual-hormone hypothesis is still in its early stages, but the discoveries that have already emerged are expected to have practical applications. For example, the findings suggest that interventions that boost testosterone and reduce cortisol may enhance status-seeking behaviors and lead to higher status, whereas interventions in which testosterone and cortisol increase simultaneously may actually undermine status. Some possible interventions include specific diets, exercise programs, or psychological interventions [46], but the precise intervention techniques that are associated with these patterns of testosterone and cortisol changes will require additional studies. This new wave of research on reproductive and stress axis interactions may also inform interventions aimed at reducing social conflict, improving professional outcomes, and promoting mental and physical health.

Conflicts of interest statement

The authors declare no conflicts of interest.

Acknowledgments

We thank Jeffrey Whitaker for assistance. Preparation for this manuscript was supported by an NSF grant awarded to PHM.

References and recommended reading

Papers of particular interest, published within the period of review, have been highlighted as:

- • of special interest
- •• of outstanding interest

1. Wingfield JC, Hegner RE, Dufty AM Jr, Ball GF: **The"challenge hypothesis": theoretical implications for patterns of testosterone secretion, mating systems, and breeding strategies**. *Am Nat* 1990:829-846.

2. Mazur A, Booth A: **Testosterone and dominance in men**. *Behav Brain Sci* 1998, **21**:353-363.

3. Archer J: **Testosterone and human aggression: an evaluation of the challenge hypothesis**. *Neurosci Biobehav Rev* 2006, **30**:319-345.

4. Eisenegger C, Haushofer J, Fehr E: **The role of testosterone in social interaction**. *Trends Cogn Sci* 2011, **15**:263-271.

5. Archer J, Graham-Kevan N, Davies M: **Testosterone and aggression: a reanalysis of Book, Starzyk, and Quinsey's (2001) study**. *Aggr Violent Behav* 2005, **10**:241-261.

6. •• Mehta PH, Josephs RA: **Testosterone and cortisol jointly regulate dominance: evidence for a dual-hormone hypothesis**. *Horm Behav* 2010, **58**:898-906.
This paper provides novel empirical support for the dual-hormone hypothesis in the domains of leadership (study 1) and competition (study 2). In Study 1, basal testosterone interacted with basal cortisol to predict dominant leadership behaviors. In study 2, the context of victory-defeat moderated the dual-hormone interaction effect on competitive behavior. Only in the defeat condition did basal testosterone interact with basal cortisol to predict the decision to compete again against the same opponent in a second competition. Basal testosterone and basal cortisol also interacted to predict changes in testosterone in the defeat condition.

7. Carré JM, Mehta PH: **Importance of considering testosterone–cortisol interactions in predicting human aggression and dominance**. *Aggr Behav* 2011, **37**:489-491.

8. Leona S Aiken, Stephen G West, Raymond R Reno: *Multiple Regression: Testing and Interpreting Interactions*. Sage; 1991.

9. Cheng JT, Tracy JL, Foulsham T, Kingstone A, Henrich J: **Two ways to the top: evidence that dominance and prestige are distinct yet viable avenues to social rank and influence**. *J Personal Soc Psychol* 2013, **104**:103.

10. • Edwards DA, Casto KV: **Women's intercollegiate athletic competition: cortisol, testosterone, and the dual-hormone hypothesis as it relates to status among teammates**. *Horm Behav* 2013, **64**:153-160.
In this study, basal testosterone interacted with basal cortisol to predict social status in collegiate female sports teams (soccer, softball, tennis, and volleyball teams).

11. • Dabbs JM Jr, Jurkovic GJ, Frady RL: **Salivary testosterone and cortisol among late adolescent male offenders**. *J Abnormal Child Psychol* 1991, **19**:469-478.
Basal testosterone interacted with basal cortisol to predict criminal violence among late-adolescent male offenders.

12. • Popma A *et al.*: **Cortisol moderates the relationship between testosterone and aggression in delinquent male adolescents**. *Biol Psychiatry* 2007, **61**:405-411.
Basal testosterone interacted with basal cortisol to predict self-reported overt aggression among 12–14-year-old delinquent male adolescents.

13. Viau V: **Functional cross-talk between the hypothalamic-pituitary-gonadal and -adrenal axes**. *J Neuroendocrinol* 2002, **14**:506-513.

14. • Pfattheicher S, Landhäußer A, Keller J: **Individual differences in antisocial punishment in public goods situations: the interplay of cortisol with testosterone and dominance**. *J Behav Decision Making* 2013, **27**:340-348.

Basal testosterone interacted with basal cortisol to predict antisocial economic punishment in a public goods game.

15. • Zilioli S, Ponzi D, Henry A, Maestripieri D: **Testosterone, cortisol and empathy: evidence for the dual-hormone hypothesis**. *Adaptive Hum Behav Physiol* 2014:1-13.

Basal testosterone interacted with basal cortisol to predict self-reported empathy.

16. • Van Den Bos W, Golka PJ, Effelsberg D, McClure SM: **Pyrrhic victories: the need for social status drives costly competitive behavior**. *Front Neurosci* 2013:7.

Basal testosterone interacted with basal cortisol to predict overbidding in an auction.

17. • Mehta P, Welker KM, Zilioli S, Carré JM: **Testosterone and cortisol jointly modulate risk-taking**. *Psychoneuroendocrinology* 2015, **56**:88-99.

Basal testosterone interacted with basal cortisol to predict self-reported trait risk-taking (study 1), informant-reported trait risk-taking (study 1), and risk-taking behavior (study 2).

18. Geniole SN, Busseri MA, McCormick CM: **Testosterone dynamics and psychopathic personality traits independently predict antagonistic behavior towards the perceived loser of a competitive interaction**. *Horm Behav* 2013, **64**: 790-798.

19. Mazur A, Booth A: **Testosterone is related to deviance in male army veterans, but relationships are not moderated by cortisol**. *Biol Psychol* 2014, **96**:72-76.

20. • Zilioli S, Watson NV: **The hidden dimensions of the competition effect: basal cortisol and basal testosterone jointly predict changes in salivary testosterone after social victory in men**. *Psychoneuroendocrinology* 2012, **37**:1855-1865.

This paper demonstrates that basal testosterone interacts with basal cortisol to predict testosterone changes after social victory.

21. • Geniole SN, Carré JM, McCormick CM: **State, not trait, neuroendocrine function predicts costly reactive aggression in men after social exclusion and inclusion**. *Biol Psychol* 2011, **87**:137-145.

This paper demonstrates that the context of social exclusion/inclusion moderates the dual-hormone interaction effect on aggressive behavior. In the social inclusion condition, basal testosterone and basal cortisol interacted to predict aggressive behaviors with a pattern consistent with the dual-hormone hypothesis.

22. • Tackett JL, Herzhoff K, Harden KP, Page-Gould E, Josephs RA: **Personality × hormone interactions in adolescent externalizing psychopathology**. *Personal Disorders Theory Res Treat* 2014, **5**:235.

This paper demonstrates that the personality traits of disagreeableness and neuroticism moderate the dual-hormone interaction on externalizing psychopathology. Only among adolescents who scored higher on these personality traits did basal testosterone and basal cortisol interact to predict externalizing behaviors.

27. • Mehta PH, Mor S, Yap A, Prasad S: **Dual-hormone changes track bargaining performance**. *Psychol Sci* 2015 http://dx.doi.org/10.1177/0956797615572905. Advance online publication.

This paper demonstrates that acute changes in testosterone and cortisol interact to predict bargaining outcomes in a face-to-face competitive negotiation (study 1) and a laboratory-based bargaining game (study 2).

28. Lin H, Yuan KM, Zhou HY, Bu T, Su H, Liu S, Ge RS: **Time-course changes of steroidogenic gene expression and steroidogenesis of rat Leydig cells after acute immobilization stress**. *Int J Mol Sci* 2014, **15**:21028-21044.

29. Burnstein K, Maiorino C, Dai J, Cameron D: **Androgen and glucocorticoid regulation of androgen receptor cDNA expression**. *Mol Cell Endocrinol* 1995, **115**:177-186.

30. Johnson EO, Kamilaris TC, Chrousos GP, Gold PW: **Mechanisms of stress — a dynamic overview of hormonal and behavioral homeostasis**. *Neurosci Biobehav Rev* 1992, **16**:115-130.

31. Tilbrook AJ, Turner AI, Clarke IJ: **Effects of stress on reproduction in non-rodent mammals: the role of glucocorticoids and sex differences**. *Rev Reprod* 2000, **5**:105-113.

32. Denson TF, Ronay R, von Hippel W, Schira MM: **Endogenous testosterone and cortisol modulate neural responses during induced anger control**. *Soc Neurosci* 2013, **8**:165-177.

33. Hermans EJ, Ramsey NF, van Honk J: **Exogenous testosterone enhances responsiveness to social threat in the neural circuitry of social aggression in humans**. *Biol Psychiatry* 2008, **63**:263-270.

34. Goetz SM, Tang L, Thomason ME, Diamond MP, Hariri AR, Carré JM: **Testosterone rapidly increases neural reactivity to threat in healthy men: a novel two-step pharmacological challenge paradigm**. *Biol Psychiatry* 2014, **76**:324-331.

35. Hermans EJ, Bos PA, Ossewaarde L, Ramsey NF, Fernández G, Van Honk J: **Effects of exogenous testosterone on the ventral striatal BOLD response during reward anticipation in healthy women**. *Neuroimage* 2010, **52**:277-283.

36. Op de Macks ZA, Moor BG, Overgaauw S, Güroğlu B, Dahl RE, Crone EA: **Testosterone levels correspond with increased ventral striatum activation in response to monetary rewards in adolescents**. *Dev Cogn Neurosci* 2011, **1**:506-516.

37. Mehta PH, Beer J: **eural mechanisms of the testosterone–aggression relation: the role of orbitofrontal cortex**. *J Cogn Neurosci* 2010, **22**:2357-2368.

38. Peper JS, Koolschijn PCM, Crone EA: **Development of risk taking: contributions from adolescent testosterone and the orbito-frontal cortex**. *J Cogn Neurosci* 2013, **25**:2141-2150.

39. Montoya ER, Terburg D, Bos PA, Van Honk J: **Testosterone, cortisol, and serotonin as key regulators of social aggression: a review and theoretical perspective**. *Motivation Emotion* 2012, **36**:65-73.

40. van Wingen G, Mattern C, Verkes RJ, Buitelaar J, Fernández G: **Testosterone reduces amygdala–orbitofrontal cortex coupling**. *Psychoneuroendocrinology* 2010, **35**:105-113.

41. Maner JK, Gailliot MT, Menzel AJ, Kunstman JW: **Dispositional anxiety blocks the psychological effects of power**. *Personal Soc Psychol Bull* 2012, **38**:1383-1395.

42. Denson TF, Mehta PH, Ho Tan D: **Endogenous testosterone and cortisol jointly influence reactive aggression in women**. *Psychoneuroendocrinology* 2013, **38**:416-424.

43. Bedgood D, Boggiano MM, Turan B: **Testosterone and social evaluative stress: the moderating role of basal cortisol**. *Psychoneuroendocrinology* 2014, **47**:107-115.

44. Welker KM, Lozoya E, Campbell JA, Neumann CS, Carré JM: **Testosterone, cortisol, and psychopathic traits in men and women**. *Physiol Behav* 2014, **129**:230-236.

45. Tackett JL, Reardon KW, Herzhoff K, Page-Gould E, Harden KP, Josephs RA: **Estradiol and cortisol interactions in youth externalizing psychopathology**. *Psychoneuroendocrinology* 2015, **55**:146-153.

46. Davis J, Mehta PH: **An ideal hormone profile for leadership: can you help yourself be a better leader?** *Neuroleadership J* 2015, **5**:1-10.