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)

This paper reviews evidence for the dual-hormone hypothesis, a novel hypothesis that was recently proposed to account for the inconsistencies 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
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

---

**Table 1**

<table>
<thead>
<tr>
<th>Year</th>
<th>Reference</th>
<th>Sample size</th>
<th>Sample characteristics</th>
<th>Dependent variable(s)</th>
<th>Context or individual difference moderator</th>
</tr>
</thead>
<tbody>
<tr>
<td>1991</td>
<td>Dabbio et al.</td>
<td>113 M</td>
<td>Late-adolescent offenders in the U.S.</td>
<td>Real life crime/juvenile delinquency –</td>
<td></td>
</tr>
<tr>
<td>2007</td>
<td>Popma et al.</td>
<td>103 M</td>
<td>12–14 year old delinquent adolescents in the Netherlands</td>
<td>Self-reported trait aggression –</td>
<td></td>
</tr>
<tr>
<td>2010</td>
<td>Mehta and Josephs (study 1)</td>
<td>45 M/49 F</td>
<td>U.S. undergraduates</td>
<td>Dominant leadership behavior –</td>
<td></td>
</tr>
<tr>
<td>2010</td>
<td>Mehta and Josephs (study 2)</td>
<td>57 M</td>
<td>U.S. undergraduates</td>
<td>Competitive decisions, testosterone change Victory versus defeat</td>
<td></td>
</tr>
<tr>
<td>2011</td>
<td>Geniole et al.</td>
<td>74 M</td>
<td>Canadian undergraduates</td>
<td>Aggressive behavior Social inclusion versus exclusion</td>
<td></td>
</tr>
<tr>
<td>2013</td>
<td>Edwards and Casto</td>
<td>74 F</td>
<td>U.S. Female athletes</td>
<td>Teammates’ ratings of social status –</td>
<td></td>
</tr>
<tr>
<td>2012</td>
<td>Zilioli and Watson</td>
<td>70 M</td>
<td>Canadian undergraduates</td>
<td>Testosterone change Victory versus defeat</td>
<td></td>
</tr>
<tr>
<td>2013</td>
<td>Pfattheicher et al.</td>
<td>72 M</td>
<td>German students</td>
<td>Punishment in a public goods game –</td>
<td></td>
</tr>
<tr>
<td>2013</td>
<td>van den Bos et al.</td>
<td>26 M</td>
<td>U.S. undergraduates</td>
<td>Overbidding –</td>
<td></td>
</tr>
<tr>
<td>2014</td>
<td>Tackett et al.</td>
<td>47 M/57 F</td>
<td>13–18-year-old adolescents in the U.S.</td>
<td>Externalizing behaviors Personality traits (disagreeableness, emotional instability)</td>
<td></td>
</tr>
<tr>
<td>2014</td>
<td>Zilioli et al.</td>
<td>323M/146 F</td>
<td>U.S. MBA students</td>
<td>Empathy –</td>
<td></td>
</tr>
<tr>
<td>2015</td>
<td>Mehta et al. (study 1)</td>
<td>53 M/62 F</td>
<td>U.S. undergraduates</td>
<td>Risk-taking (self report and informant report) –</td>
<td></td>
</tr>
<tr>
<td>2015</td>
<td>Mehta et al. (study 2)</td>
<td>160 M</td>
<td>U.S. undergraduates</td>
<td>Risk-taking (balloon analog risk task) –</td>
<td></td>
</tr>
</tbody>
</table>

**Studies that report basal testosterone × basal cortisol interactions consistent with the standard predictions of the dual-hormone hypothesis**

**Studies that report basal testosterone × basal cortisol interactions showing a reversal of the dual-hormone hypothesis**

**Studies that report acute testosterone change × cortisol change interactions**

**Studies that report ultimatum bargaining decision processes**

---

**Current Opinion in Behavioral Sciences 2015, 3:163–168** www.sciencedirect.com
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


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.


In this study, basal testosterone interacted with basal cortisol to predict social status in collegiate female sports teams (soccer, softball, tennis, and volleyball teams).


Basal testosterone interacted with basal cortisol to predict criminal violence among late-adolescent male offenders.


Basal testosterone interacted with basal cortisol to predict self-reported overt aggression among 12-14-year-old delinquent male adolescents.


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


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


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


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.


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


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.


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.


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).


