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ORIGINAL ARTICLE

No Compelling Evidence that Self-Reported Personality Traits Explain Basal Testosterone and Cortisol's Associations with Status-Relevant Behavior

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Abstract

Objective A goal of behavioral neuroendocrinology is to understand how basal hormone levels relate to behavior. Studies of human participants sometimes measure self-reported personality traits, in addition to or instead of direct behavioral observation. Although personality traits often predict their respective behaviors, whether personality explains hormone-behavior relationships remains unclear.

Methods We obtained data from eight previous studies (total $N=985$) that examined baseline testosterone and cortisol as predictors of status-relevant behavior (competitiveness, dominance, risk-taking, aggression, affiliation, and social status). We tested whether the previously reported hormone-behavior relationships are mediated by self-reported personality traits (e.g., trait dominance, prestige, extraversion). As a secondary research question, we also tested whether trait dominance moderated the testosterone-behavior relationships.

Results As expected, self-reported personality traits often predicted status-relevant behaviors, but there was little evidence that traits also correlated with basal testosterone or the testosterone × cortisol interaction. Across all eight studies, personality traits did not significantly mediate hormone-behavior relationships. Indeed, the effect sizes of the hormone-behavior relationships were robust to the inclusion of personality traits as covariates. Further, we did not find strong or consistent evidence that trait dominance moderates the testosterone-behavior association.

Conclusion Results suggest that basal testosterone and cortisol predict status-related behavior independent of self-reported personality. We discuss how these results may have broader implications for the physiological mechanisms by which testosterone and cortisol influence behavior, a process that could be unconscious and automatic. We also discuss alternative explanations, limitations, and future directions.

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Keywords Testosterone · Cortisol · Status · Dominance · Leadership · Personality · Self-reports

A major objective of behavioral neuroendocrinology is to understand how basal hormone levels predict behavior. Research with human participants sometimes includes self-reported personality questionnaires, in addition to or instead of direct behavioral observation. Self-reported personality traits represent general self-perceptions about one's own behavior, and are often positively related to their respective behaviors. However, it remains unclear whether self-reported personality traits explain basal hormone-behavior relationships. In the current project, we re-examined data from eight previously published studies to test whether self-reported personality traits mediate associations between basal hormone levels (testosterone or the testosterone by cortisol interaction) and status-related behaviors. The degree to which individual differences in self-reported personality explain basal hormone-behavior relationships in these studies could provide initial insight into the underlying mechanism by which hormones influence behavior, and highlight the utility of personality as a variable in future research.

Testosterone is a steroid hormone involved in the energetic and behavioral investment in mate pursuit and competition for mates (Gray et al., 2020; Grebe et al., 2019b; Muller, 2017; Roney, 2016; Rosvall et al., 2020; Wingfield et al., 2001) and, more broadly, social contests for status (Archer, 2006). Influential theoretical frameworks postulate that increased testosterone levels are beneficial for mounting the appropriate behavioral response to achieve success in these situations (Archer, 2006; Mazur & Booth, 1998; Roney, 2016; Zilioli & Bird, 2017). In line with this theorizing, research indicates that higher testosterone concentrations are positively related to behaviors implicated in the pursuit and maintenance of higher status, including competitive behavior, social dominance, aggressive behavior, risk taking, and actual status attainment (for review, Carré & Archer, 2018; Casto & Mehta, 2019; Eisenegger et al., 2011; Geniole et al., 2020). However, other studies revealed non-significant associations (e.g., Casto et al., 2020; Dekkers et al., 2019), and some work found negative associations between testosterone concentrations and similar behaviors (e.g., Buades-Rotger et al., 2016). Further, meta-analyses have shown weak aggregate effects and substantial heterogeneity in the associations between individual differences in basal testosterone levels and status-relevant behaviors (aggression: Geniole et al., 2020; risk-taking: Kurath & Mata, 2018; leadership: van der Meij et al., 2016)[1].

Cortisol is a glucocorticoid produced by the hypothalamic-pituitary-adrenal (HPA) axis in response to psychological and physical stress (Dickerson et al., 2009; Kemeny, 2009; Putman & Roelofs, 2011). Individual differences in levels of basal cortisol are thought to reflect relative differences in stress exposure, with higher levels being linked to greater social avoidance and mood disorder symptomology (Bertsch et al.,

[1] Although the current study is focused on basal hormone levels, some research suggests that effect sizes for associations between context-specific acute testosterone changes and behavior may be larger compared to effect sizes for associations between basal testosterone levels and behavior (e.g., Geniole et al., 2020; Wingfield et al., 1990).

2011; Lombardo et al., 2019) as well as diminished social status (for review, Sherman & Mehta, 2020 – although these relationships are somewhat inconsistent: McEwen, 2019; Staufenbiel et al., 2013). The dual-hormone hypothesis, a model that accounts for the moderating role of cortisol, was proposed as one explanation for some of the inconsistent findings regarding basal testosterone's relationship with status-relevant behavior (Knight et al., 2020b; Mehta & Josephs, 2010). According to the original formulation of the dual-hormone hypothesis, higher levels of basal testosterone are hypothesized to be related to increased status-seeking behaviors when basal cortisol levels are low. However, when basal cortisol levels are high, higher basal testosterone levels are expected to be unrelated or negatively related to status-seeking behaviors.

A number of studies have provided initial support for the dual-hormone hypothesis with a broad set of outcome variables relating to social standing and status-seeking motivation (for review, Knight et al. 2020, b; Mehta & Prasad, 2015; Sarkar et al., 2018). Other studies, however, found non-significant dual-hormone interactions (e.g., Geniole et al., 2013; Mehta et al., 2017) or significant interactions in the opposite direction from what is predicted by the dual-hormone hypothesis (e.g., Denson et al., 2013; Lee et al., 2015). That is, these latter studies showed a "reverse" dual-hormone effect, whereby higher testosterone was positively related to aggressive and cheating behaviors among individuals with relatively *high* cortisol levels (for review, Knight et al.2020, b). A recent meta-analysis reported that overall support for the dual-hormone hypothesis is weak (Dekkers et al., 2019; Grebe, Del Giudice, et al., 2019), and that there is considerable heterogeneity in the direction and magnitude of the effect across studies (for review, Knight et al. 2020, b). Given the mixed evidence, there is a need for greater theoretical clarity and specificity regarding testosterone and cortisol's associations with status-relevant behavior.

One potential reason for inconsistencies in both the direct and interactive effects of these hormones is that some studies use self-reported personality traits as the outcome of interest instead of direct behavioral observation (e.g., Grebe, Del Giudice, et al., 2019; Sundin et al., 2021; Torrance et al., 2018). Doing so makes the assumption that general self-awareness about status-motivated behavior is an effective proxy for status-related behavior in attempting to identify a hormone-behavior relationship. Indeed, basal levels of cortisol and testosterone show moderate day-to-day stability when measured around the same time of day (Liening et al., 2010; Sellers et al., 2007). Similarly, personality is defined as a behavioral tendency that is stable over time (Wagner et al., 2019), and is generally positively correlated with a task-based or naturalistic observation of that behavior. However, the mechanism of particular hormone-behavior relationships within an eliciting context could be more tightly coupled than generalized self-awareness about that behavior across contexts (Carré & Archer, 2018; Roney, 2016; Zilioli & Bird, 2017). Thus, it may be the case that hormones regulate status-relevant behavior independent of self-reported personality traits.

Several lines of research support the possibility that hormone-behavior relationships are coordinated through mechanisms that circumvent self-awareness about personality. Whereas self-report inventories represent explicit consciously-accessible perceptions about the self (e.g., "I am a dominant person"), there is increasing evidence that hormones, including testosterone and cortisol, alter perceptual systems

and behavior *implicitly*, outside of conscious awareness (Mossink et al., 2015; Quirin et al., 2009; Schultheiss, 2013; Stanton & Schultheiss, 2009; Wegner et al., 2015). For example, Terburg & van Honk (2013) concluded that "…testosterone's influence on reactive-reflexive dominance and social aggression is automatic, unconscious, and subcortically driven by phylogenetically ancient brain mechanisms humans share with most other vertebrates."

Although not a direct test of this assertion, studies have tested whether relationships between hormones and behavior remained after controlling for self-reported personality traits. In one study, baseline testosterone predicted status-relevant behavioral outcomes, with and without controlling for self-reported trait dominance (Study 3: Josephs et al., 2006). In a similar vein, Geniole et al. (2013) reported that increased testosterone was positively related to aggressive behavior with and without controlling for self-reported psychopathic traits. Another study measured basal testosterone and cortisol, self-reported personality traits, and group-level performance among business students (Akinola et al., 2016). Results from this study showed that group-level mean testosterone and cortisol interacted to predict how well the group performed on a computerized group decision-making exercise in models that included and excluded self-reported traits (e.g., dominance). Other research found that testosterone and cortisol predicted cheating behavior, with highly similar results when excluding and including self-reported trait anxiety (Lee et al., 2015)[2]. Overall, there is only initial evidence in a limited set of studies suggesting that testosterone and cortisol predict status-relevant behavior while controlling for status-related personality traits.

However, other studies have indicated that testosterone and cortisol could show modest relationships with some personality traits (e.g., baseline testosterone and dominance or extraversion, Grebe, Del Giudice, et al., 2019; Sellers et al., 2007; Smeets-Janssen et al., 2015). Trait dominance has also been found to interact with testosterone to predict status-relevant behavior (Carré et al., 2017; Geniole et al., 2013; Mehta, van Son et al., 2015; Slatcher et al., 2011). Thus, personality may still play an important part in basal hormone effects on status-relevant behavior (but see Sundin et al., 2021; Knight et al., 2022).

The present research draws on data from eight prior studies that examined basal testosterone or its interaction with basal cortisol in relation to competitive behavior, dominant behavior, risk-taking behavior, aggressive behavior, affiliative behavior, and social status. In these prior studies, self-reported traits that correspond to each behavior of interest were also collected (e.g., trait dominance corresponding to observed dominant behavior). Here, we report new analyses that examine whether personality mediates the observed hormone-behavior relationships (Baron & Kenny, 1986; Hayes, 2020). As a secondary set of analyses, we also test whether trait dominance moderates the testosterone-behavior relationships for six of the eight studies that have relevant data. We examine these questions across multiple studies where a variety of status-related behavioral outcomes were assessed under various contexts.

[2] This conclusion comes from the published paper as well as personal communication with the first author. As reported earlier in the introduction, the basal testosterone x basal cortisol interaction slope was positive in this study, consistent with a "reverse" dual-hormone effect.

This approach allows for a broad understanding of basal testosterone, cortisol, and behavior when accounting for personality.

Although the present research does not provide a direct test of implicit or other alternative mechanisms, this new research does represent a critical initial step in investigating the extent to which basal testosterone and cortisol associate with status-relevant behavior independently from *explicit* self-reported personality traits. Examining our research questions across these eight studies can provide initial insight into the mechanism by which hormones influence behavior, and can inform future work that differentiates between the effects of implicit versus explicit mental processes on behavior.

Methods

For the present research, we culled datasets from prior published studies and conducted new analyses with self-reported personality traits. Our criteria for inclusion were that the prior dataset was available for additional analyses or was shared upon request by the corresponding authors. Additionally, datasets were selected if they included all three of the following variable types: (1) a measure of basal testosterone (which could also include basal cortisol); (2) a measure of behavior broadly related to status-seeking, leadership, or dominance; and (3) a self-reported personality trait broadly related to the behavioral outcome measure or status-seeking. These traits were selected because we expected an association between the trait and the behavioral outcome measure included in the respective study. An overview of the methods for each study is summarized in Table 1.

Participants

A total of 985 participants from eight separate prior studies were included in the present report. Two of the studies recruited community participants (Study 1: Mean Age: 44.29, *SD*: 10.96; Study 5: Mean Age: 27.9, *SD*=4.9). The other six studies recruited student samples (Study 3: Mean Age=20.7, *SD*=6.1; Study 4: Mean Age=20.6, *SD*=3.0; Study 6: Mean Age=21.9, *SD*=2.9; Study 7: Mean Age=19.0, *SD*=1.1; Study 8: Mean Age=20.3, *SD*=2.1; age data were not available for Study 2). Race/ethnicity data are only reported for the sample in Study 4 (38.2% Caucasian, 19.4% Black, 18.1% Asian, 4.8% Latino, 0.6% Native American, and 18.8% Other), Study 5 (85.4% Caucasian; 4.9% Asian, 7.3%; Mixed Race, 2.4% Hispanic), and Study 8 (41.5% Caucasians, 20.3% African American, 9.3% Asian, 0.8% Native American, 10.2% Middle Eastern, 5.1% Multiracial and 10.2% others). Study 3 excluded oral contraceptive users from participating.

Behavioral Tasks

There were a wide range of tasks employed to measure status-relevant behavior across the studies (Table 1). More detailed descriptions of the procedures are included in the prior publications, but for the purpose of understanding the various contexts and

Table 1 Summary of the methods – sample size, sample characteristics, behavioral task and outcomes, and self-reported personality measures – employed across all eight studies

Study	*N*	% Female	Sample	Task(s)	Behavioral Outcome	Self-reported Personality Measures	Previous Publications
1	184	49.5	Community dog-agility competitors in the US	Dog-agility competition and post-competition behavioral interaction with dog co-competitor	Time spent engaging in affiliative behavior with dog co-competitor, in seconds (based on video recording)	Extraversion and Agreeableness[1]	(Jones & Josephs, 2006; Mehta et al., 2008, Study 1; Sherman et al., 2017)
2	100	50	US university students	Acting as "leader" in a block design task	Observer ratings of dominance behavior in leaders (based on video-recording)	Dominance[2]; Extraversion[3]; Assertiveness[4]	(Mehta & Josephs, 2010, Study 1; Sundin et al., 2021)
3	53	100	Australian university students	A provocation procedure (speech performance with insulting feedback by a confederate competitor) followed by a competitive reaction time task	Reactive aggression (composite of intensity and duration score of noise blast) following an insult	Dominance[2]; Aggression[5]	(Denson et al., 2013)
4	160	0	US university students	Balloon Analog Risk-Taking Task (BART)	BART score: behavioral measure of risk-taking	Self-control and Persistence[6]	(Mehta, Welker, et al.,2015, Study 2; Sundin et al., 2021; Welker et al., 2015, 2019)
5	40	0	Community rugby players in Canada	The Cognitive Social Structures (CSS) task for establishing social network matrices of relationships	Network centrality operationalized as three facets: (1) popularity; (2) gregariousness; (3) betweenness	Dominance and Prestige[7]	Grebe et al. 2019a, Ponzi, Ziliioli et al., 2016)
6	140	69	Dutch university students	Balloon Analog Risk-Taking Task (BART)	BART score: behavioral measure of risk-taking	Overconfidence[8]; Dark Triad[9]; Self-esteem[10]	(Ronay et al., 2018)

Table 1 (continued)

Study	*N*	% Female	Sample	Task(s)	Behavioral Outcome	Self-reported Personality Measures	Previous Publications
7	190	69	US university students	Competitive Will Task; weight-holding competition for time	Competitive Performance: Amount of time the participant held up weight, in seconds	Competitiveness Index (Enjoyment and Contentiousness)[11]; Power Motivation[12]	(Casto et al., 2020 Study 1, 2021)
8	118	0	US university students	Problem solving puzzle: Tracing geometric shapes using a continuous line (following a win/loss intervention)	Task Persistence: Amount of time spent working to solve unsolvable puzzles	Dominance and Prestige[7]	(Welker & Carré, 2015)

Note. *This study used hair samples as a source of basal testosterone and cortisol; the rest used salivary samples

1) NEO Personality Inventory (NEO-PI-R; Costa & McCrae, 2008).

2) Personality Research Form, Dominance subscale (PRF; Jackson, 1974).

3) Ten Item Personality Inventory (TIPI; Gosling et al., 2003).

4) Assertiveness Facet of the Revised NEO Personality Inventory (NEO-PI-R; Costa & McCrae, 2008).

5) The Aggression Questionnaire (Buss & Perry, 1992).

6) The International Personality Item Pool (Goldberg et al., 2006).

7) Dominance-Prestige Scales (Cheng et al., 2010).

8) Operationalized by the value of overestimation of one's actual performance on a general knowledge test (Ronay et al., 2018).

9) Short Dark Triad (SD3; Machiavellianism, narcissism, and psychopathy (Jones & Paulhus, 2014).

10) Rosenburg Self-Esteem (Rosenberg, 1979).

11) Competitiveness Index Subscales Enjoyment and Contentiousness (Houston et al., 2002; Smither & Houston, 1992).

12) Desiring Power subscale of the Feeling Powerful and Desiring Power Scales (FPDPS; Murphy et al., 2022).

operationalizations of status-seeking for the present study, we detail key aspects of the behavioral tasks and study designs below.

Study 1- Affiliative behaviors This was a naturalistic study of individuals who took part in a dog agility competition. Dog-handler teams compete by moving through an obstacle course wherein the dog must respond appropriately to the guiding cues of the handler without leash or physical contact from the handler. The speed and accuracy of course completion is judged and ranked among competitors. The context is status-relevant in that dog-handler teams prepare and train for weeks or longer and their performance, in the presence of large numbers of spectators, often qualifies the teams for higher-value future events. The behavioral outcome of interest was time

spent interacting with the dog in an affiliative manner in the two minutes immediately following their performance. Three trained researchers coded video clips of the handlers' behaviors towards their dog, recording how many seconds each handler performed each behavior (inter-rater reliability = 90.2%). Affiliative behaviors included play (e.g., tug-of-war, chase) and petting of the areas around the ears, neck, and chin. Affiliative behavior in the present study is viewed as the converse to the behavioral expression to social dominance. This theorizing is based on the challenge hypothesis, which postulates that elevated testosterone levels during periods of social challenge (e.g., competition) are related to increased dominant behaviors and reduced affiliative behaviors (e.g., Wingfield et al., 1990).

Study 2- Dominant leadership behaviors Participants were randomly assigned to the position of "leader" or "follower" (Newman et al., 2005) and then completed a leadership block design task while being videotaped (the WAIS-III Block Design Task, Wechsler, 1997). The follower was seated at a table with blocks while the leader stood behind the follower. The leader directed the follower to move blocks in order to make the block design, which was repeated for nine block design puzzles. Participants alternated leadership positions so that leadership behaviors could be observed in both participants within each dyad. Seven independent observers (4 women, 3 men) watched the videotaped interactions and rated all leaders using a measure that was specially developed to assess dominance in leaders in the block design task (Anderson & Kilduff, 2009; Buss & Craik, 1980). The leadership measure included 19 items that tapped into dominance (e.g., leader-like, confident, shy/timid (reverse-scored), gave clear instructions, assertive, indecisive (reverse-scored), dominant, comfortable giving instructions) using a 7-point Likert scale. The 19 items were rated by all observers and were averaged to create an overall index of dominance in leaders (for more details, see Mehta and Josephs, 2010). Dominant behavior has been positively related to higher social status in prior research (Anderson & Kilduff, 2009). Dominance in this study was conceptualized as a behavioral style that is assertive and self-assured, and the 19 items were selected accordingly (Anderson & Kilduff, 2009). This conceptualization of dominance is different from another conceptualization of dominance that involves threatening and intimidating behaviors that induce fear in others (Cheng et al., 2010). This study did not examine the latter, more anti-social form of dominance.

Study 3- Reactive aggression This study used a two-part behavioral task that included an initial provocation procedure in which a fictitious female participant, who was actually a confederate, insulted the quality and delivery of a two-minute speech given by the female participant. This was followed by a competitive reaction-time task (speed of on-screen button pressing) against the same fictitious female participant. Participants also decided the loudness and duration of a white noise blast to be delivered to their opponent. The status-relevant outcome of interest, reactive aggression, was operationalized as the composite of intensity and duration scores (0—10) selected by participants on the first of the 25 trials of the reaction time competition. This score has been previously validated by Denson et al., (2010; 2011) as a measure of reactive aggression. Reactive aggression is theorized to be motivated by a desire to

protect or enhance one's social status (Daly & Wilson, 1988). Further, aggression in a competitive context is considered one viable method, albeit antisocial, of achieving social status and power over others (Cheng et al., 2010).

Study 4- Risk-taking This study employed the Balloon Analog Risk Task (BART) (Lejuez et al., 2003), a validated laboratory task of risk-taking behavior. For this task, participants earned "money points" for each click of an on-screen button (collected points contributed towards a raffle to win a $150 gift card). Each press of the button gradually inflated an on-screen image of a balloon. If the balloon burst, no money points were awarded. Because the balloon was randomly programed to burst anywhere between 1 and 30 presses, each decision to press incured more risk of bursting. Thus, risk-taking was operationalized as the average number of presses, or "pumps", of all non-burst balloons. Risk-taking is considered a status-relevant behavior based on previous theorizing and research because engaging in competitions risks loss or personal injury, but is also necessary for status to be gained (e.g. Ellis et al., 2012).

Study 5- Social network centrality To assess the social network centrality of each member of a rugby team, the Cognitive Social Structures (CSS, Casciaro et al., 1999; Krackhardt, 1987) procedure was followed. Each member of the rugby team was asked to answer the questions, "Among your teammates, who likes to hang out with *i*?", and, "Among your teammates, who does *i* like to hang out with?", where *i* was every player on the team, including the respondent. From these responses, relationship matrices were constructed for each individual and three measures of centrality were determined: (1) betweenness (the number of times a person lies within the shortest pathway between two others in the network), the level of social influence this subject has over the flow of information within the network; (2) popularity (in-degree centrality), the number of teammates that reported liking to hang out with that participant; (3) gregariousness (out-degree centrality), the number of teammates each participant reported to like hanging out with. Social network centrality is related to higher status attainment. Of the three measures of centrality examined in this study, betweenness centrality is especially indicative of higher social status, such as leadership emergence (Ponzi, Ziloli et al., 2016). For more information on how network centrality scores were calculated, see Ponzi, Zilioli et al. (2016).

Study 6- Risk-taking This study also employed the Balloon Analog Risk Task (BART) described above. The procedure was largely the same as in Study 4, the only difference being that the probability of balloon bursting (no money awarded for that trial) was increased incrementally with each pump (1/128 for the first pump, 1/127 for the second pump, etc. – average breakpoint was 64 pumps). Further, participants were paid 10% of their winnings at the conclusion of the experiment ($M_{euro} = 0.76$, $SD = 0.21$) and informed that the participant who earned the most across all sessions would receive a cash prize of 50 euros. As with Study 4, risk-taking was operationalized as the average number of presses, or "pumps", of all non-burst balloons.

Study 7- Competitive persistence This study was designed to explore the relationship between testosterone and persistence in a test of "competitive will." Participants

held a small amount of weight (a common dumbbell used for resistance training; 1 lb. for women, 2 lbs. for men) at arm's length and shoulder height, with arm extended from the body at a 90° angle, for as long as they felt they could in competition against other participants, according to the procedure in Casto et al. (2020). To incentivize the competition, participants were informed that a $20 cash prize would be offered to the one participant who held their arm up the longest of all the participants. Competitive performance or persistence in this task was operationalized as the time in seconds that a participant held up their arm before quitting the contest. Performance in the competitive will task is positively correlated with self-reported status-seeking (e.g. competitiveness, dominance motivation, and task-specific desire to win; Casto et al., 2020).

Study 8- Task persistence Participants completed a persistence task in which they were told that performance indicated differences in "problem solving abilities." The task consisted of tracing geometric shapes completely without interrupting the line or retracing, and participants were told to complete as many puzzles as they would like and to alert the experimenter when they no longer wished to continue. After a small set of solvable puzzles, participants were given a set of impossible (unsolvable) puzzles. Task persistence was operationalized as the amount of time spent attempting to solve the unsolvable puzzles. Persistence behavior has been previously linked to status attainment (Welker & Carré, 2015).

Other Aspects of the Study Designs

As reported in the original published papers, the behavioral tasks were conducted in status-relevant contexts (e.g., competition) and the studies sometimes included additional context factors as potential moderators of hormone-behavior associations. In the present research, we examined associations between basal hormones, behavior, and personality across the whole sample for each study independent of context factors because our primary research question focused on personality. Personality, by definition, captures a person's behavioral tendency across situations. In accordance with this view, previous research examined basal hormones and personality associations independent of context. The current research builds on this previous work in order to examine the extent to which basal hormone-behavior associations, independent of context factors, are explained by self-reported personality traits.

Personality Measures

A variety of personality inventories were used across the prior studies to assess individual differences in self-reported traits related to status-striving (Table 1) such as extraversion, assertiveness, dominance, prestige, competitiveness, self-control, self-esteem, and confidence. In some cases, these inventories were included as a part of the design, but not included in the analyses used in prior publications. In other cases, the inventory was reported as a part of the study methods and analyses but was not included as a covariate or mediating variable in the original analyses. Thus, in all

cases, what we present here are, to the best of our knowledge, new analyses of the data for the purpose of testing the explanatory role of self-reported personality in the associations between basal hormones and status-relevant behavioral outcomes. All of the personality assessments have been used in prior published studies, and (some more than others) have demonstrated reliability and validity evidence (references to sources for each measure are listed in the notes of Table 1).

Saliva Sampling and Hormonal Assays

For all studies, basal testosterone, and in most cases cortisol, were assessed via saliva or hair (Study 6) samples, using standard collection and storage procedures. For studies assaying hormones from saliva, a small volume (e.g., 1–3 mL) of saliva was provided into a plastic (e.g., polystyrene) tube via unstimulated (Studies 3, 4, 5, 7, 8) or stimulated (Study 1, using sugar free gum) passive drool (Study 2 did not specify). A summary of the saliva collection timings and assay procedure for each study are briefly listed below.

Study 1 Saliva samples were collected 90 min prior to the competition, between 12:00 and 1:00 PM. Hormone assays were completed using enzyme immunoassay kits from Salimetrics (State College, PA). The inter-assay coefficient of variance (CV) for testosterone was 3.7% and for cortisol was 2.5%. If the intra-assay CV for a given sample was greater than 7.5%, the sample was assayed again; this occurred for seven samples.

Study 2 Saliva samples were collected after arrival to the laboratory between the hours of 11:30 AM and 4:30 PM. Hormone assays were completed at the Yerkes Biomarkers Laboratory (Emory University, Atlanta, GA) using radioimmunoassays kits from Diagnostic Systems Laboratories (Webster, TX). The inter-assay CVs for testosterone was 10.67% and for cortisol was 3.65%. The intra-assay CV for both testosterone and cortisol was less than 20%.

Study 3 Saliva samples were provided following a 30-min nature video (to best capture resting baseline) between the hours of 11:30 AM and 7:30 PM. Salivettes were used to obtain samples for cortisol and a separate passive drool sample was taken for testosterone. Hormone assays were completed using chemiluminescence-immunoassay kits from IBL International (Hamburg, Germany). Intra- and inter-assay CVs were below 10%.

Study 4 Saliva samples were provided following the completion of questionnaires for approximately 25–30 min between the hours of 11:00 AM and 5:00 PM. Hormone assays were completed using enzyme immunoassay kits from DRG international (Springfield, NJ). The inter-assay CV for testosterone was 9% and for cortisol was 6%. The intra-assay CV for testosterone was 6%, and for cortisol was 6%.

Study 5 Saliva samples were provided between 6:00 and 7:00 PM. Hormone assays were completed using enzyme immunoassays from Salimetrics (State College, PA).

The inter-assay CV for testosterone was 5.85% and for cortisol was 6.39%. The intra-assay CV for testosterone was 3.84% and for cortisol 8.89%.

Study 6 Testosterone and cortisol concentrations were determined from hair samples with liquid chromatography tandem mass spectrometry (LC-MS/MS; Gao et al., 2013). Three hair strands were cut with scissors as close as possible from the scalp from a posterior vertex position and tied with a thread, placed in aluminum foils and sent to the Dresden Lab (Germany) for analyses. Inter- and intra-assay CVs for testosterone and cortisol were between 3.1% and 8.8%.

Study 7 Saliva samples were provided following approximately 15 min of completing questionnaires between 2:00 and 4:00 PM. Hormone assays were completed by Emory Clinical Translational Research Laboratory (Atlanta, GA) using enzyme immunoassay kits from Salimetrics (State College, PA). Inter-assay CV for testosterone for low and high controls were 18.0 and 6.2% (Intra-assay values could not be calculated).

Study 8 Saliva samples were collected between 11:00 AM and 5:00 PM. Hormone assays were completed using enzyme immunoassay kits from DRG International (Springfield, NJ). The inter-assay CV for testosterone was 16.59% and intra-assay CV was 9.19%.

Statistical Analysis Strategy

Data transformations and analyses Testosterone concentrations were standardized within sex and winsorized to values at three SD of the mean[3]. Cortisol concentrations were natural log-transformed, and subsequently standardized and winsorized to concentrations at 3 SD of the mean. These data transformations were largely consistent with the approach adopted by prior publications for each dataset. We winsorized outliers instead of excluding them because the former approach allowed us to retain all datapoints while accounting for their extreme place within the distribution of values.

Primary Analyses

Across eight studies, we tested the direct effects of testosterone (Studies 1, 7, & 8), and the interactive effects of testosterone and cortisol (Studies 2–6), predicting status-relevant behaviors using a mediation model. Because the purpose of the present study was to explore the explanatory role of personality traits in prior hormone-behavior findings, the decisions to test testosterone's main effects or dual-hormone interactions were based on whether the original studies focused on direct effects of

[3] In Study 3, testosterone concentrations were log-transformed prior to standardization because skew in the distribution contributed to violations of regression model assumptions; this approach was consistent that adopted in the original paper (Denson et al., 2013). In Study 6, testosterone and cortisol concentrations were log-transformed, not standardized, and analyzed separately across men and women, consistent with the approach adopted by the original paper (Ronay et al., 2018).

testosterone or dual-hormone interaction effects (see R code: https://osf.io/phgky/ for additional analyses with these datasets)[4].

To conduct the mediation analysis, we used the Baron and Kenny (1986) method (see also, Frazier et al., 2004; Judd & Kenny, 1981) in which multiple regressions were applied via a step-wise approach to explore each pathway in the mediation model. First, we tested the effects of hormones on status-relevant behaviors (path c of the mediation model; this step replicates prior analyses with these datasets). In the regression models examining the direct effects of testosterone, status-relevant behaviors were regressed on basal testosterone concentrations (standardized within sex). In the models testing the interactive effects of testosterone and cortisol, status-relevant behaviors were regressed on basal testosterone concentrations, basal cortisol, and their interaction. Second, we tested whether hormones predicted personality traits: personality traits (the outcome variable) were regressed on testosterone or testosterone × cortisol interactions (path a of the mediation model). Third, to examine the extent to which personality traits predicted status-relevant behaviors, controlling for hormone levels (path b of the mediation model), we regressed status-relevant behaviors on both personality traits and hormones (testosterone or the testosterone × cortisol interactions). Fourth, using a similar regression model as the previous step, we assessed whether hormones predicted status-relevant behaviors when controlling for personality traits (individually and all together in the same model; path c' of the mediation model). This fourth step allowed us to determine the magnitude of mediation by comparing the hormonal effects on behavior when controlling for personality traits (standardized betas of path c') to the original hormonal-behavioral effects when not controlling for personality traits (standardized betas of path c). The models with testosterone × cortisol interactions also controlled for the main effects of testosterone and cortisol.

We used the PROCESS macro in R to compute the effect size for mediation, i.e., the indirect effect (path a × path b), and to compute the bias-corrected bootstrapped confidence intervals of the indirect effect (Hayes, 2020; Hayes & Scharkow, 2013; Tibbe & Montoya, 2022). In the PROCESS models that tested mediation of the direct effect of testosterone, testosterone was treated as the independent variable, status-relevant behaviors as the outcomes, and self-reported personality traits as mediators (Model 4 in PROCESS). In the PROCESS models that tested mediation of the dual-hormone interaction, cortisol was included as a moderator for the paths of testosterone predicting self-reported personality, and of testosterone predicting behavior (Model 8 in PROCESS).

[4] In Study 1, while cortisol was assayed and is reported in two other publications (Mehta et al., 2008; Sherman et al., 2017), cortisol change rather than basal cortisol was the focus in these prior papers, and neither of these papers examined interactions between basal cortisol and basal testosterone to test the dual-hormone hypothesis. In Study 7, cortisol levels were assayed but not reported in any published manuscript. We include additional R code (https://osf.io/phgky/) for tests of the dual-hormone interaction hypothesis in these datasets.

Secondary Analyses

Some prior work suggests that testosterone's effects on status-relevant behaviors depend on levels of trait dominance (e.g., Carré et al., 2009; Geniole et al., 2019; Knight et al., 2017; Mehta, Son, et al.,2015; Slatcher et al., 2011), though other studies did not find clear evidence for trait dominance × testosterone interactions (e.g., Knight et al., 2022). For most of the studies included in this report (all but Study 1 and 6), trait dominance was one of the status-relevant personality traits that was assessed (Table 1). To contribute to the prior literature on the moderating role of trait dominance, we used linear regressions to test testosterone × trait dominance effects on status-relevant behaviors.

All statistical analyses were conducted in R (version 4.2.1). Linear regressions were conducted using the lm command in base R. Simple slope estimates and graphical visualization of the interactions were obtained using the interactions package (Long, 2021). Standardized coefficients for the linear regressions were also estimated using the sjplot package, which refits models on standardized data (Gelman, 2008; Lüdecke et al., 2021).

Results

Descriptive Statistics

Table S1 shows the descriptive statistics of status-relevant behaviors, self-reported personality traits, and raw testosterone and cortisol concentrations, across all studies.

Primary Analyses: Do Personality Traits Mediate hormone-behavior Associations?

Hormones predicting status-relevant behaviors (path c) Across the eight datasets, testosterone independently (Studies 1, 7, and 8), and the testosterone × cortisol interaction (Studies 2–6), predicted a suite of status-relevant behaviors consistent with findings reported in the original studies (see Table 2 Column 1 and Table S2 Column 1 for a summary of hormone-behavior results across all studies). Further, these findings remained robust to the inclusion of relevant, non-personality covariates (see Tables S2 Column 2).

Hormones predicting self-reported personality traits (path a) Generally, we did not find strong evidence that testosterone and testosterone × cortisol interactions predicted self-reported personality traits (see Table 2 Column 2 and Table S3). There were three exceptions to this general pattern. In Study 1, testosterone was negatively related to extraversion. The direction of this association is consistent with Sundin et al., (2021) but inconsistent with Smeets-Janssen et al. (2015). In Study 3, the testosterone × cortisol interaction predicted trait aggression with a positive slope, which is in the same direction as the behavioral effect found in that study. This positive interaction slope is also somewhat consistent with the interaction effect result for women in one previous study (Armstrong et al., 2021) but in the opposite direction from the

interaction effects found in some other studies (Grotzinger et al., 2018; Popma et al., 2007). In Study 6, the testosterone × cortisol interaction in men predicted the dark triad of personality: at low levels of cortisol, testosterone was positively associated with the dark triad, but at high levels of cortisol, the testosterone-personality association was suppressed. This interaction effect was directionally inconsistent with the effect reported for one of the dark triad traits (trait psychopathy) in Welker et al., (2014); (cf. Pfattheicher, 2016 for null interaction effects).

Personality traits predicting status-relevant behaviors (path b) Personality traits often predicted behavior in the expected direction both with the inclusion of hormones as covariates (path b; see Table 2 Column 3 and Table S4 Column 2) and without the inclusion of hormones as covariates (see Table S4 Column 1). In particular, trait agreeableness was positively related to affiliative behavior (Study 1); trait dominance, extraversion, and assertiveness were positively related to dominant leadership behavior (Study 2); trait prestige was positively related to social network centrality (betweenness, popularity, and gregariousness, Study 5); and trait competitiveness as well as trait dominance were positively related to competitive performance (Study 7). In some cases, the evidence for personality-behavior associations was more ambiguous. For example, in Study 3, the point estimate indicated a small positive relationship between trait aggression and aggressive behavior, which was in the expected direction, but the 95% CI overlapped with zero. We did not find any instance in which the personality-behavior association was robust yet in the opposite direction than expected.

Hormones predicting status-relevant behaviors controlling for self-reported personality traits (path c′) Testosterone and testosterone × cortisol interactions predicted status-relevant behaviors over and above the inclusion of self-reported personality traits (entered individually and all together) as covariates (see Table 2 Column 4 and Table S5 Columns 1 and 2). To understand the directional pattern of the testosterone × cortisol effects, the interactions were further broken down into their simple slopes (see Table S5 Column 2) and are graphically represented (Figures S1 to S5) in the Supplement. Consistent with the original studies, there was some nuance in the direction of the dual-hormone effect. Studies 2, 4, 5, and male (but not female) participants in Study 6 showed a testosterone × cortisol interaction effect with a negative slope in line with the original formulation of the dual hormone hypothesis: relatively high testosterone was positively related to status-related behavior, but only among those with relatively low cortisol. Study 3 results showed a dual-hormone interaction effect with a positive slope (a "reverse" dual-hormone effect), where higher testosterone positively predicted reactive aggression only for those relatively high in cortisol (consistent with the original findings in Denson et al., 2013).

The effect sizes (standardized betas) of the testosterone and testosterone × cortisol interaction effects controlling for personality traits were consistent with the size for the original hormonal effects that did not include personality covariates (see Table 2 Column 4 for standardized betas). The 95% CIs of the standardized betas in the models that included personality variables generally included the standardized beta of the

Table 2 Summary of key results for testing statistical mediation across all studies (Baron & Kenny, 1986; Hayes, 2020). Column 1: Standardized point estimates and corresponding 95% CIs of hormones predicting status seeking behaviors (path c). Column 2: Standardized point estimates and corresponding and 95% CIs of hormones predicting personality traits (path a). Column 3: Standardized point estimates and 95% CIs of personality predicting behaviors, controlling for hormones (path b). Column 4: Standardized point estimates and 95% CIs of hormones predicting status seeking behaviors, controlling for personality traits (path c'). Column 5. Indirect effect estimates and corresponding 95% CIs for personality-mediated pathway of hormone-behavior associations. *Key*: T- Testosterone and C- Cortisol; M- Males and F- Females

1. Hormones → Behavior (path c)	2. Hormones → Personality (path a)	3. Personality → Behavior Controlling for Hormones (path b)	4. Hormones → Behavior Controlling for Personality (path c')	5. Indirect effect
STUDY 1				
T and affiliative behavior: β=-0.26 [-0.40, -0.12]	T and trait agreeableness: β=-0.06 [-0.20, 0.09]	Trait agreeableness and affiliative behavior, controlling for T: β=0.23 [0.10, 0.37]	T and affiliative behavior, controlling for trait agreeableness: β=-0.24 [-0.38, -0.11]	T and affiliative behavior, with trait agreeableness as a mediator: ω=-0.19 [-0.77, 0.22]
	T and trait extraversion: β=-0.27 [-0.41, -0.13]	Trait extraversion and affiliative behavior, controlling for T: β=0.03 [-0.12, 0.18]	T and affiliative behavior, controlling for trait extraversion: β=-0.25 [-0.40, -0.10]	T and affiliative behavior, with trait extraversion as a mediator: ω=-0.11 [-0.79, 0.44]
STUDY 2				
T × C and dominant leadership behavior: β=-0.29 [-0.52, -0.06]	T × C and trait dominance: β=-0.11 [-0.34, 0.12]	Trait dominance and dominant leadership behavior, controlling for T × C: β=0.28 [0.08, 0.48]	T × C and dominant leadership behavior, controlling for trait dominance: β=-0.26 [-0.48, -0.04]	T × C and dominant leadership behavior, with trait dominance as a mediator: ω=-0.03 [-0.12, 0.02]
	T × C and trait extraversion: β=-0.04 [-0.27, 0.19]	Trait extraversion and dominant leadership behavior, controlling for T × C: β=0.32 [0.12, 0.52]	T × C and dominant leadership behavior, controlling for trait extraversion: β=-0.28 [-0.50, -0.06]	T × C and dominant leadership behavior, with trait extraversion as a mediator: ω=-0.01 [-0.11, 0.05]
	T × C and trait assertiveness: β=-0.14 [-0.37, 0.09]	Trait assertiveness and dominant leadership behavior, controlling for T × C: β=0.23 [0.02, 0.44]	T × C and dominant leadership behavior, controlling for trait assertiveness: β=-0.27 [-0.49, -0.04]	T × C and dominant leadership behavior, with trait assertiveness as a mediator: ω=-0.03 [-0.11, 0.01]

Table 2 (continued)

1. Hormones → Behavior (path c)	2. Hormones → Personality (path a)	3. Personality → Behavior Controlling for Hormones (path b)	4. Hormones → Behavior Controlling for Personality (path c')	5. Indirect effect
STUDY 3				
T × C and reactive aggression: β=0.42 [0.10, 0.74]	T × C and trait aggression: β=0.39 [0.06, 0.73]	Trait aggression and reactive aggression, controlling for T × C: β=0.05 [-0.26, 0.35]	T × C and reactive aggression, controlling for trait aggression: β=0.46 [0.10, 0.83]	T × C and reactive aggression, with trait aggression as a mediator: ω=0.05 [-0.23, 0.56]
	T × C and trait dominance: β=0.17 [-0.19, 0.54]	Trait dominance and reactive aggression, controlling for T × C: β=0.01 [-0.27, 0.29]	T × C and reactive aggression, controlling for trait dominance: β=0.48 [0.14, 0.83]	T × C and reactive aggression, with trait dominance as a mediator: ω=>0.00[-0.12, 0.19]
STUDY 4				
T × C and risk-taking: β=-0.20 [-0.34, -0.06]	T × C and trait self-control: β=0.01 [-0.13, 0.15]	Trait self-control and risk-taking, controlling for T × C: β=0.11 [-0.05, 0.26]	T × C and risk-taking controlling, for trait self-control: β=-0.20 [-0.34, -0.07]	T × C and risk-taking with trait self-control as a mediator: ω=>0.00 [-0.06, 0.09]
	T × C and trait persistence: β=-0.02 [-0.16, 0.12]	Trait persistence and risk-taking, controlling for T × C: β=0.10 [-0.06, 0.25]	T × C and risk-taking controlling, for trait persistence: β=-0.20 [-0.34, -0.06]	T × C and risk-taking with trait persistence as a mediator: ω=-0.01 [-0.10, 0.03]
	T × C and trait dominance: β=-0.04 [-0.18, 0.10]	Trait dominance and risk-taking, controlling for T × C: β= -0.08 [-0.24, 0.07]	T × C and risk-taking controlling, for trait dominance: β=-0.20 [-0.34, -0.07]	T × C and risk-taking with trait dominance as a mediator: ω=0.01 [-0.02, 0.12]

Table 2 (continued)

1. Hormones → Behavior (path c)	2. Hormones → Personality (path a)	3. Personality → Behavior Controlling for Hormones (path b)	4. Hormones → Behavior Controlling for Personality (path c')	5. Indirect effect
STUDY 5				
T × C Network Centrality- Betweenness: β=-0.49 [-0.88, -0.11]	T × C and trait dominance; β=0.33 [-0.13, 0.79]	Trait dominance and betweenness, controlling for T × C: β= -0.20 [-0.49, 0.09]	T × C and betweenness, controlling for trait dominance: β=-0.43 [-0.82, -0.03]	T × C and betweenness with trait dominance as a mediator: ω=-0.14 [-0.49, 0.03]
	T × C and trait prestige: β=-0.09 [-0.57, 0.39]	Trait prestige and betweenness, controlling for T × C: β=0.35 [0.10, 0.60]	T × C and betweenness, controlling for trait prestige: β=-0.46 [-0.82, -0.11]	T × C and betweenness with trait prestige as a mediator: ω=-0.02 [-0.34, 0.28]
T × C Network Centrality-Popularity: β=-0.49 [-0.91, -0.06]		Trait dominance and popularity, controlling for T × C: β= -0.20 [-0.52, 0.12]	T × C and popularity, controlling for trait dominance: β=-0.42 [-0.85, 0.01]	T × C and popularity with trait dominance as a mediator: ω=-0.27 [-1.09, 0.07]
		Trait prestige and popularity, controlling for T × C: β=0.45 [0.18, 0.71]	T × C and popularity, controlling for trait prestige: β=-0.44 [-0.82, -0.07]	T × C and popularity with trait prestige as a mediator: ω=-0.05 [-0.95, 0.68]
T × C Network Centrality- Gregariousness: β=-0.09 [-0.53, 0.35]		Trait dominance and gregariousness, controlling for T × C: β= -0.04 [-0.37, 0.30]	T × C and gregariousness, controlling for trait dominance: β=-0.08 [-0.54, 0.38]	T × C and gregariousness with trait dominance as a mediator: ω=-0.03 [-0.55, 0.37]
		Trait prestige and gregariousness, controlling for T × C: β=0.45 [0.17, 0.73]	T × C and gregariousness, controlling for trait prestige: β=-0.05 [-0.44, 0.34]	T × C and gregariousness with trait prestige as a mediator: ω=-0.04 [-0.75, 0.53]

Table 2 (continued)

1. Hormones → Behavior (path c)	2. Hormones → Personality (path a)	3. Personality → Behavior Controlling for Hormones (path b)	4. Hormones → Behavior Controlling for Personality (path c')	5. Indirect effect
STUDY 6				
T × C and risk-taking[6]: *M:* β=-0.51 [-0.88, -0.14] *F:* β=0.13 [-0.10, 0.36]	T × C and trait self-esteem M: β=0.05 [-0.35, 0.45] F: β=-0.07 [-0.30, 0.16]	Trait self-esteem and risk-taking, controlling for T × C: M: β= -0.03 [-0.33, 0.27] F: β= -0.13 [-0.34, 0.08]	T × C and risk-taking, controlling for trait self-esteem: M: β=-0.51 [-0.88, -0.14] *F:* β=0.12 [-0.11, 0.36]	T × C and risk-taking with trait self-esteem as a mediator: M: ω=-0.17 [-33.71, 20.20] F: ω=1.39 [-2.82, 14.61]
	T × C and dark triad M: β=-0.40 [-0.78, -0.02] F: β=0.14 [-0.09, 0.37]	Dark triad and risk-taking, controlling for T × C: M: β=0.06 [-0.25, 0.37] F: β=-0.02 [-0.22, 0.19]	T × C and risk-taking, controlling for the dark triad: M: β=-0.49 [-0.87, -0.10] F: β=0.13 [-0.10, 0.37]	T × C and risk-taking with dark triad as a mediator: M: ω=-5.81 [-45.19, 24.49] F: ω=-0.34 [-10.89, 4.56]
	T × C and overconfidence M: β=0.23 [-0.16, 0.62] F: β=0.05 [-0.18, 0.28]	Trait overconfidence and risk-taking, controlling for T × C: M: β= -0.07 [-0.37, 0.23] F: β= -0.01 [-0.22, 0.20]	T × C and risk-taking, controlling for trait overconfidence: M: β=-0.50 [-0.87, -0.12] F: β=0.13 [-0.10, 0.37]	T × C and risk-taking with trait overconfidence as a mediator: M: ω=-3.44 [-43.53, 10.65] F: ω=-0.06 [-5.22, 3.34]

[6] Results are reported separately across males (M) and females (F) (consistent with that reported in the original paper; Ronay et al., 2018).

Table 2 (continued)

1. Hormones → Behavior (path c)	2. Hormones → Personality (path a)	3. Personality → Behavior Controlling for Hormones (path b)	4. Hormones → Behavior Controlling for Personality (path c')	5. Indirect effect
STUDY 7				
T and competitive performance: β=0.17 [0.02, 0.31]	T and trait competitiveness index- enjoyment: β=-0.01 [-0.14, 0.13]	Trait competitiveness index-enjoyment and Competitive performance, controlling for T: β=0.21 [0.07, 0.35]	T and competitive performance, controlling for trait competitiveness index- enjoyment: β=0.16 [0.03, 0.30]	T and competitive performance with competitiveness index- enjoyment as a mediator: ω=0.10, [-2.34, 2.43]
	T and trait competitiveness index- contentiousness: β=-0.06 [-0.20, 0.07]	Trait competitiveness index-contentiousness and Competitive performance, controlling for T: β= -0.07 [-0.21, 0.07]	T and competitive performance, controlling for trait competitiveness index- contentiousness: β=0.16 [0.02, 0.31]	T and competitive performance with competitiveness index- contentiousness as a mediator: ω=0.26 [-0.38, 2.75]
	T and trait power motivation: β=0.04 [-0.09, 0.18]	Trait power motivation and Competitive performance, controlling for T: β=0.20 [0.06, 0.34]	T and competitive performance, controlling for trait power motivation: β=0.15 [0.01, 0.29]	T and competitive performance with trait power motivation as a mediator: ω=0.95 [-1.01, 4.11]
STUDY 8				
T and task persistence: β=0.23 [0.05, 0.42]	T and trait dominance β=-0.17 [-0.36, 0.02]	Trait dominance and persistence controlling for T: β=-0.05 [-0.24, 0.14]	T and task persistence, controlling for trait dominance: β=0.22 [0.03, 0.41]	T and task persistence with trait dominance as a mediator: ω=0.08 [-0.21, 0.62]
	T and trait prestige: β=-0.05 [-0.24, 0.14]	Trait prestige and persistence controlling for T: β=-0.04 [-0.22, 0.15]	T and task persistence, controlling for trait prestige: β=0.23 [0.04, 0.42]	T and task persistence with trait prestige as a mediator: ω=0.01 [-0.13, 0.36]

original hormonal effects (see Table 2 Columns 1 and 4). We also found that these models were generally robust to the inclusion of non-personality covariates (e.g., time of day), in addition to the personality covariates (see Table S5 Column 3).

Simple slopes analyses for the dual-hormone models that included personality traits also provided support for testosterone-behavior associations at high vs. low levels of cortisol in the same direction as the original findings (see Table S5 Column 2 and Figures S1 to S5). We also computed the median percentage change in the standardized beta point estimates for the main effects of testosterone and the testosterone × cortisol interaction effects reported in Table 2 Column 1 (models with no personality covariates) versus Column 4 (models with personality covariates included). There was a median shrinkage of 4.35% in the standardized betas when personality covariates were added to the models. These analyses indicate that the hormone-behavior associations were of similar magnitude in models with and without personality covariates.

Indirect effects of basal hormones on status-relevant behaviors via self-reported personality traits Finally, we explored the indirect effect of self-reported personality traits mediating the relationship of testosterone and testosterone × cortisol interactions on status-relevant behaviors. We did not find support for an indirect personality-mediated pathway between the hormones and behaviors (see Table 2 Column 5). That is, personality traits did not significantly mediate the pathway between the direct effects of testosterone, and the interactive effects of testosterone and cortisol, on status-relevant behaviors.

In summary, self-reported personality traits often modestly predicted behavioral outcome measures in the expected directions (path b), even when controlling for hormone concentrations. However, there was little evidence for hormones predicting self-reported personality traits (path a). More importantly, hormones continued to predict status-relevant behaviors even after controlling for personality traits, and these hormone-behavior relationships had the same directional pattern and similar effect sizes as the original effects. The clear lack of evidence for a personality-mediated pathway between hormones and behavior may highlight the presence of alternative pathways for hormone-behavior relationships. We return to this point in the discussion.

Secondary Analyses: Moderation by Trait Dominance

In 5 of the 6 datasets, self-reported trait dominance did not significantly moderate the effects of testosterone on status-relevant behaviors (see Table S6 for key statistics from individual models and Figures S6 to S11 for the directional pattern). However, in Study 4, there was a significant testosterone × trait dominance interaction in the opposite of the expected direction: for those relatively high in dominance, basal testosterone was negatively related to risk-taking (Fig S8). Collectively, there is not strong and consistent evidence that trait dominance moderates the association between basal testosterone and status-oriented behavior, although this effect may be specific to the particular task and behavior.

Discussion

The broad purpose of the present research was to examine the role of personality in explaining previously-identified relationships between basal hormones and status-related behaviors. Data from eight prior studies on basal testosterone and basal cortisol as predictors of status-relevant behavior were re-examined with new analyses that included self-reported status-related personality traits (total $N = 985$). Self-reported traits were often correlated with the behavioral outcomes in the expected direction. For example, trait dominance was positively related to dominant leadership behavior in a videotaped interaction (Study 2), and trait competitiveness was positively related to competitive performance in a weight-holding task (Study 7). However, the collective results show no compelling evidence that personality mediates the hormone-behavior relationships that were tested. Indeed, the magnitude of these relationships was largely unaffected by the inclusion of personality in the models. That is, the direct effect of basal testosterone and the interactive effect of basal testosterone and basal cortisol on status-relevant behavior emerged above and beyond the variance explained by personality.

These consistent findings across eight studies, along with related evidence in previous research, provide insight into the mechanisms for hormone-behavior relationships (Akinola et al., 2016; Geniole et al., 2013; Grebe et al., 2019a; Josephs et al., 2006; Lee et al., 2015; Sundin et al., 2021). One potential explanation for these results is that hormone regulation of behavior may be *mechanistically* independent from self-reported personality. That is, it is possible that the physiological effects of testosterone and cortisol on neural pathways that regulate behavior do not simultaneously act directly on perceptual systems involved in conscious awareness. Self-reported personality questionnaires are explicit measures that involve reporting one's consciously available, stable self-perceptions. Thus, while behaviors play an important role in forming these explicit self-perceptions over time, hormone-behavior relationships could be unconscious, automatic, and independent of self-reported personality. An implicit pathway for testosterone-behavior associations is supported by evidence from neuroscientific research (Bos et al., 2012; Dedovic et al., 2009; Duell et al., 2021; Losecaat Vermeer et al., 2016; Putman et al., 2007; Radke et al., 2015; Terburg & van Honk, 2013; Volman et al., 2011).

An implicit mechanism for testosterone and cortisol's effects on behavior is also in line with prior research and theorizing about hormonal modulation of implicit dominance motives, threat perception, and stress response (Köllner et al., 2018; Mossink et al., 2015; Quirin et al., 2009; Schultheiss, 2013; Stanton & Schultheiss, 2009; van Honk et al., 2004; Wegner et al., 2015). For example, Terburg et al. (2012) found that participants given testosterone treatment compared to placebo showed significantly greater social dominance in a non-conscious (rapidly shown) face gaze-aversion task but showed no differences in self-reported affective state. Complementary research by Wirth and Schultheiss (2007) found that endogenous testosterone was positively related to instrumental learning in responses to angry faces when the faces were presented outside of conscious awareness, but testosterone was unrelated to learning when faces were presented supraliminally (enabling conscious processing). Another study found that exogenous testosterone affected an automatic early threat bias

(within 200 milliseconds of face presentation), but not later neural processes (greater than 200 milliseconds; van Peer et al., 2017).

Cortisol also appears to influence behavior implicitly. Across a variety of validated self-report measures including real-time sampling, cortisol is either unrelated or only weakly related to subjective experiences of stress (Gidlow et al., 2016; Joseph et al., 2021; Schmidt et al., 2020; Wells et al., 2014). Studies that have employed both explicit and implicit measures of stress-related mood and affect showed that the implicit tests predicted various metrics of basal and reactive cortisol, but the explicit tests did not (Mossink et al., 2015; Quirin et al., 2009). One such study even found that a measure of implicit power motivation, but not explicit dominance, predicted cortisol reactivity to psychosocial stress (Wegner et al., 2015). Thus, testosterone and cortisol and their interaction may *implicitly* relate to behavior largely independent of *explicitly* measured, i.e., self-reported, personality traits.

The endocrine system is understood to operate by coordinating adaptive and context-relevant behavioral responses to specific environmental stimuli and conditions. Whereas self-reflection and social learning can provide us with a generally accurate understanding of how we typically behave in most contexts (as reflected in self-reported personality traits), hormone levels may reflect more automatic and reflexive needs and motives that are activated "*in the heat of the moment*" within specific contexts. Indeed, context tends to play an essential role in moderating hormone-behavior effects (e.g., Carré & Archer, 2018; Duell et al., 2021; Josephs et al., 2006; Losecaat Vermeer et al., 2020; Prasad et al., 2017). In contrast, personality is, by definition, relatively context-independent. Thus, it is possible that hormonal effects on behavior bypass the general self-knowledge indexed by self-reported personality traits and instead, influence behavior through context-dependent mechanisms that occur outside of conscious awareness. Although the present research cannot speak to context-dependence directly, future research should be conducted to compare variability in hormone-behavior relationships and personality-behavior relationships across different social contexts.

Some previous studies have found that self-reported trait dominance moderates the association between testosterone and status-relevant behavior (Carré et al., 2009, 2017; Geniole et al., 2019; Knight et al., 2017; Mehta et al., 2015c; Slatcher et al., 2011). Specifically, testosterone has shown stronger effects on dominance, aggression, and competitive behavior among individuals high in trait dominance. Other studies, however, have not found robust evidence for trait dominance × testosterone interactions in predicting status-relevant behavior (e.g., Knight et al., 2022; Casto et al., 2020). In the present research, in secondary analyses, we examined whether an effect of basal testosterone on status-relevant behavior depends on individual differences in trait dominance. We found mixed support. In one study, higher basal testosterone predicted more risk-taking behavior, but only among those low in trait dominance; for those high in trait dominance, higher basal testosterone predicted less risk-taking (see Figure S8). In another study, higher basal testosterone was modestly related to higher persistence behavior especially among those high in trait dominance, but the confidence interval of the interaction term slightly overlapped with zero (see Figure S11). In the other studies, the trait dominance × testosterone effect sizes were small with confidence intervals that overlapped substantially with zero

and with no consistent pattern in the direction of the interaction effects (see Figures S6, S7, S9, and S10). Collectively, this mixed pattern of evidence suggests that trait dominance × testosterone interaction effects may not be robust. We recommend additional research that further examines this hormone by trait interaction effect to identify important boundary conditions.

Limitations and Future Directions

In all but one of the eight studies, basal hormone levels were determined by a single sample of saliva at baseline. Although basal hormone levels are relatively stable day-to-day within an individual, multiple samples at rest would produce a more valid estimate of individual differences in testosterone and cortisol (e.g., Crewther et al., 2020). Study 6 examined hormone levels from hair. Hair hormone levels could be a more useful test than saliva for estimating long-term testosterone and cortisol exposure levels in future research (Greff et al., 2019; Grotzinger et al., 2018; Shields et al., 2021). Further, salivary hormone concentrations were assessed using immunoassays in all but one of the eight studies. Recent work suggests that immunoassays may be limited in their capacity to accurately measure salivary testosterone, especially at low levels (e.g., in females; Chafkin et al., 2022; Prasad et al., 2019; Taieb et al., 2003). Future studies may consider using mass spectrometry to assess testosterone and cortisol concentrations (Schultheiss et al., 2019), as was done in Study 6.

Our theorizing about implicit mechanisms for hormonal influences on behavior versus the explicit nature of self-reported traits could be bolstered by directly testing how testosterone and cortisol predict self-reported personality in comparison to implicit motive tests (as in Mossink et al., 2015; Wegner et al., 2015). This theorizing could also be bolstered by neuroscience studies that directly examine hormone-brain-behavior pathways in human participants (e.g., Duell et al., 2021; Mehta & Beer, 2010).

Self-reported traits capture people's understanding of how they generally behave across various situations. However, knowledge about general behavior and awareness of one's behavior *in the moment* are different cognitive experiences and the relevant self-knowledge is formed across different timescales. As argued earlier, hormone levels may influence behavior through automatic and reflexive mechanisms that are activated "*in the heat of the moment*" within specific contexts. It is possible that self-reported states, rather than traits, capture part of this contextually-activated mechanism for hormone-behavior associations. This possibility can be addressed in future work by measuring relevant *states* (e.g., personality states, Kordsmeyer & Penke, 2019; reward-related states, Geniole et al., 2019; Mehta et al., 2017; Mehta, Snyder, Mehta et al. 2015, b).

In the current research, there was no compelling evidence that self-reported personality traits mediated the observed hormone-behavior associations. This collective pattern across eight studies is consistent with some initial research (Akinola et al., 2016; Geniole et al., 2013; Josephs et al., 2006; Lee et al., 2015). Mediation effects could be detected for other hormones, traits, or behaviors in future studies. Further, if mediation effects are non-zero but very small, they may be detected in future studies with larger sample sizes. These larger studies would also enable adequate tests

of more complex three-way interaction models that include hormones, personality variables, and contextual factors (e.g., win/loss).

The current project focused on basal hormone levels. We did not find compelling evidence that personality traits mediated basal hormone-behavior associations, but personality may still be involved in explaining acute hormone reactivity (for discussion, see Carré & Archer, 2018; Casto et al., 2020; Kordsmeyer & Penke, 2019). For example, self-reported personality traits have been shown to predict acute testosterone and cortisol reactivity to competition (e.g., Geniole & Carré, 2018; Kordsmeyer & Penke, 2019; Mehta, Mor, et al.,2015a). Furthermore, acute testosterone reactivity alone or in interaction with acute cortisol reactivity have been shown to mediate associations between self-reported personality traits and competitive behaviors (Casto et al., 2020; Mehta, Mor, et al.,2015a). These findings suggest that acute hormone changes may serve as biological mechanisms for personality-behavior relationships. Thus, personality might determine who finds a particular context status-relevant or stressful, indicating for whom acute testosterone and cortisol response is activated. These personality-driven biological changes, in turn, are expected to influence subsequent status-relevant behavior (Casto & Edwards, 2021; Geniole et al., 2019; Mehta, Mor, et al., 2015a). Future projects can be designed to provide a more in-depth understanding of personality traits as predictors of acute hormone reactivity in status-relevant contexts.

Across all studies included in this report, personality traits were measured with self-report inventories. Although self-report is the most common approach to personality measurement and self-reported traits do indeed predict behavior, there are other approaches to personality measurement, including informant reports (Vazire, 2010) and the analysis of online social media profiles (Facebook: Back et al., 2010). Some of these other approaches to personality assessment capture variance in behavioral outcomes above and beyond self-report questionnaires (Back & Vazire, 2015; Vazire, 2010). Thus, it is possible that personality assessment beyond self-report may partially explain hormone-behavior associations, which can be tested in future studies.

This project used cross-sectional correlational designs, and thus, the causal pathways linking hormones, personality, and behavior remain unclear. Future longitudinal and experimental studies would be helpful to enable causal inference. However, it is challenging to conduct relevant studies that allow for strong causal conclusions. For example, existing pharmacological challenge paradigms involve acute changes in hormone levels, whereas experimental manipulation of basal hormone levels in humans likely requires different approaches such as long-term hormone administration or chemical castration in clinical samples. Even if a researcher could overcome the feasibility challenges of doing such work, it is unclear whether these experimental approaches are directly comparable to naturally occurring endogenous hormone levels in healthy volunteers. Similarly, personality traits are difficult to manipulate experimentally on short timescales, though longer interventions such as clinical therapy have been shown to alter personality traits (Roberts et al., 2017). Thus, although we recommend experimental studies to examine causality, we acknowledge that this type of work has its own limitations and challenges.

Hormone-behavior relationships varied across the eight studies we re-examined[5]. Basal testosterone significantly predicted behavior in some of the studies, whereas the interaction between basal testosterone and cortisol was a significant predictor of behavior in other studies. Further, the direction of the effects were inconsistent; dual-hormone interactions went in opposite directions across some of the studies. One plausible explanation for these variable effects is context-dependence. As discussed earlier, personality is, by definition, relatively context independent, whereas context plays an important role in moderating hormone-behavior relationships (e.g., Carré & Archer, 2018; Duell et al., 2021; Josephs et al., 2006; Losecaat Vermeer et al., 2020; Knight et al., 2022; Prasad et al., 2017). The lack of compelling evidence for personality mediation of hormone-behavior pathways in the eight studies presented here is consistent with the notion that hormones may influence behavior through context-dependent neural pathways, rather than context-independent, personality-mediated pathways. Future research is required to identify the specific contextual factors that explain apparent inconsistencies in hormone-behavior effects.

Conclusion

Behavioral neuroendocrinology aims to understand how hormones influence behavior. The present research investigated the role of self-reported personality traits in explaining hormone-behavior relationships. We examined eight prior studies of basal testosterone and basal cortisol as predictors of status-relevant behavior and tested whether these effects were mediated by status-relevant self-reported personality traits. We did not find compelling evidence that self-reported personality traits mediated the hormone-behavior relationships. Basal testosterone and its interaction with basal cortisol predicted status-relevant behavior, but in most cases, did not significantly predict self-reported personality traits. Although personality traits were often associated with the related behaviors in the predicted direction, the magnitude of the hormone-behavior relationships were robust to the inclusion of these explicit trait factors. Further, there was no overall compelling and consistent evidence that the testosterone-behavior relationships depended on individual differences in trait dominance.

In line with prior theorizing, we discuss these results in light of two proposed explanations: (1) that hormonal regulation of behavior occurs implicitly, primarily outside of conscious awareness, and (2) that hormone-behavior relationships are context-dependent, whereas personality-behavior relationships are consistent across contexts. In advancing theorizing about testosterone's direct and interactive effect with cortisol on status-relevant behavior, this research and discussion contributes to a broader understanding of hormone-behavior relationships.

Supplementary Information The online version contains supplementary material available at https://doi.

[5] This conclusion is based on a qualitative assessment of the results. It is beyond the scope of the present research to quantify the degree of variability in the hormone-behavior associations, but future research can do so by estimating variance components across a given set of studies using a meta-analytic framework (Knight, McShane, et al., 2020a).

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Materials and Code availability The datasets for this study and code used analyze the data are available at the Open Science Framework repository: https://osf.io/phgky/.

Declarations

Ethics Approval All study procedures were approved by the respective university Institutional Review Boards. All persons gave their informed consent prior to their inclusion in the study.

Conflict of interest The authors declare that they have no conflict of interest.

Competing Interests The authors have no relevant financial or non-financial interests to disclose.

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