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ORIGINAL ARTICLE

Testosterone and Cortisol Interact to Predict Within-Team Social Status Hierarchy among Olympic-Level Women Athletes

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Abstract

Objectives The dual-hormone hypothesis posits that social status is positively related to testosterone levels when cortisol levels are relatively low and negatively related to testosterone levels when cortisol is high. In the present study, we test this hypothesis with Olympic-level women athletes using a novel status-hierarchy generation task that establishes rank-order among teammates along three dimensions: leadership ability, popularity, and skill.
Methods Participants completed the hierarchy generation task and then, testosterone and cortisol levels were obtained from samples provided on a neutral-day baseline and immediately prior to competing in an international match.
Results The interaction between cortisol and testosterone predicted social status among teammates for both baseline and pre-match samples. Specifically, there was a negative association between testosterone and status for those who were relatively high in cortisol.
Conclusions These results provide support for the dual-hormone hypothesis using a new, ecologically valid method for determining rank-order among members of a social group, in a special population of women athletes competing at the highest level of their sport.

Keywords Testosterone · Cortisol · Dual-hormone hypothesis · Social status

In the year leading up to the Olympic Games, coaches and staff members from all different kinds of sports must decide who will make the Olympic Team roster and who

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will have the opportunity to play in test matches to secure one of these coveted spots. Beyond individual skill on the field or in the arena, athletes of team sports must also demonstrate commitment to the team and their fit within the social system of other players – social factors that make or break team cohesion and ultimately, performance at the Games. Jockeying for social position on an Olympic team is an intense and complex process, one in which social standing among others is both highly salient and consequential. Thus, there is perhaps no better group and setting than an Olympic team leading up to the Games to study the psychology and physiology of social status.

Individual members of social groups differ in their ability to lead. Those who are confident, charismatic, socially adept, competent, and show commitment to the group attain greater social status than those lacking these qualities (Anderson et al. 2015; Anderson and Kilduff 2009; Cheng et al. 2010). The status that is reflected in the deference and admiration of other group members is a type of social dominance known as *prestige* or *eminence* (Chapais 2015; Cheng et al. 2010; Kemper 1990). Even though only a select few in a group attain this uppermost level of status, social power is typically distributed across a hierarchical system with group members, more-or-less, rank-ordered among each other (Cheng et al. 2013; Magee and Galinsky 2008). Higher social status in a hierarchy confers greater access to resources including social power, the ability to influence others and control outcomes (Fiske 2010; Keltner et al. 2003). Investigating the structure, cause, and consequences of social hierarchies within groups is essential for understanding intra-group dynamics related to group stability, cohesion, cooperation, and conflict.

Rank within a social hierarchy results from repeated interactions between individuals in which status-related behaviors establish relative position among group members. Behaviors that aid in attaining and maintaining social status are thought to be influenced by and reflected in baseline levels of steroid hormones, testosterone and cortisol (Casto and Mehta 2019). Testosterone, a steroid hormone produced in males and females, appears to promote dominant, aggressive, and competitive behavior and reflect higher status rank within relevant social contexts (Eisenegger et al. 2011; Mazur and Booth 1998; Terburg and van Honk 2013; Wingfield et al. 1990). Indeed, recent studies have shown that high testosterone is related to higher prestige within a social network (Cheng et al. 2018), greater willingness to take financial risks in order to gain social status (Cardoos et al. 2017), the use of context-dependent aggression or generosity to promote status (Dreher et al. 2016), and the use of self-enhancing, yet risky financial decisions (Mehta et al. 2017).

Acute psychological experiences of stress, particularly social-evaluative stress combined with a perceived lack of control over one's environment and outcomes, produces reliable and transient increases in cortisol (reviewed by Dickerson and Kemeny 2004). Long-term activation or dysregulation of cortisol secretion is energetically costly and can result in deleterious effects on physical and psychological health including immune system functioning (Cohen et al. 2012; McEwen 2004; Whitworth et al. 2005). Social hierarchy rank is thought to be inversely related to basal cortisol due to the increasing life adversity and resource depletion experienced by increasingly lower ranking individuals (Knight and Mehta 2014; Sapolsky 2004). Evidence from studies with human participants in real-world settings has shown that lower cortisol levels are related to higher peer ratings of likability and influence (Decker 2000), higher socio-economic status (Cohen et al. 2006), occupying a leadership position (Sherman et al. 2012), and high gregariousness and friendship maintenance (Kornienko et al. 2014, 2016).

That both testosterone and cortisol appear related (in opposite directions) to social status, and that cortisol inhibits, suppresses, or otherwise antagonizes testosterone secretion and action at target tissues (Burnstein et al. 1995; Johnson et al. 1992), has prompted researchers to test the direct interaction of these two hormones in relation to status. In a laboratory study that would form the basis for the *dual-hormone hypothesis*, Mehta and Josephs (2010) showed that the frequency of dominance and competitive decision-making behaviors by persons in a group setting were positively related to individual differences in baseline testosterone, but this was true only for low-cortisol individuals. Relatively high cortisol levels appeared to block, or even reverse, the relationship between testosterone and dominance behaviors. Subsequent studies have provided support for the dual-hormone hypothesis (for initial review, Mehta and Prasad 2015). For example, only at low levels of cortisol did high testosterone predict a higher number of subordinates among male business executives (Sherman et al. 2016), higher leadership ability in women athletes as ranked by teammates (Edwards and Casto 2013), and higher social network centrality (a proxy for popularity) in male rugby players (Ponzi et al. 2016). The dual-hormone hypothesis has also been supported using collective hormone profiles in groups – Akinola et al. (2016) showed that high collective testosterone was positively related to group performance among MBA students competing in a decision-making task, but only if the group's collective cortisol was relatively low. However, some studies have found no moderating effect of cortisol on the relationship between testosterone and status-related behaviors and personality characteristics (e.g., Geniole et al. 2013; Mehta et al. 2017, for review, Grebe et al. 2019).

A recent meta-analysis of 49 effect sizes from 33 studies provided only marginal support for the dual-hormone hypothesis, but effect sizes were largest for direct measures of status as opposed to measures of dominance-related behaviors like aggression and risk-taking (Dekkers et al. 2019). Theories about the process by which high cortisol suppresses or inhibits testosterone's relationship with status support the notion that the dual-hormone effect may be specific to measures of actual status rather than other status-related concepts (Casto and Mehta 2019). That is, high testosterone individuals may desire social status and engage in status-seeking behaviors, but only successfully attain it if their cortisol is relatively low – high testosterone/high cortisol individuals may behave in ways unfavorable to status achievement. Thus, perhaps cortisol more reliably moderates testosterone's relationship with the actual possession of status, while measures of dominance-based behavior and personality, particularly those that cause social affront (e.g., aggression, psychopathy), could less reliably produce this effect.

Status rank as determined by the opinion of others within a distinct social group is an ecologically valid measure of social status. In one previous study that has provided support for dual-hormone effect, members of five different teams of women athletes rated each of their teammates on a Likert scale measure of leadership ability ($N = 74$, Edwards and Casto 2013). Summing across all the teammates' ratings, each person received a score that represented a numerical estimate of her status with her teammates based on hours together in training, competition, and group-oriented social events. In the present study, we build on this prior work and introduce a novel procedure for meaningful determination of status hierarchy among teammates. Each member of a team of elite women athletes preparing for the 2016 Olympic Games in Rio de Janeiro constructed a set of hierarchies that rank-ordered each of her teammates with respect to leadership ability, likability, and sport-specific skill – attributes that would confer status (Anderson et al. 2001; Lease et al. 2002; Lucas and Lovaglia 1998).

Among athletes whose group membership is determined based on athletic ability, skill in this study represents the competence component of status, translated in terms of ability to contribute to the group goal (winning matches). We used the resulting hierarchies to test for dual-hormone effects in predicting status-rank.

Recent meta-analytic studies of the dual-hormone hypothesis have highlighted the need for continued research that focuses on both replicability and increased ecologically validity (Dekkers et al. 2019; Grebe et al. 2019). This study extends previous work with teams of female athletes in a new context, one in which status presumably reflects both social power among teammates and an opportunity to participate in the Olympic Games.

Methods

Participants

Twenty-two members of the 2015–2016 United States Women's National Field Hockey Team participated in this study. Because only 18 members had been on the team long enough to determine status rank, four women who recently joined the team were excluded from analyses involving status (more on this below). Members of this team trained together daily at their Olympic Training Facility in Lancaster, Pennsylvania. This study took place in the months leading up to the 2016 Olympic Games in Rio de Janeiro when status among teammates was highly salient (e.g., Olympic team roster and starting positions were being determined). This research was approved by the Emory University's Institutional Review Board and participants gave written informed consent prior to participation. As part of the consent procedure women were asked to provide information regarding oral contraceptive use.

Status Hierarchy Ranking Task

Three attributes of social status – leadership, popularity, and field-hockey skill – were selected for constructing hierarchies among teammates based on theoretical and empirical understanding of how social power is conferred among small groups (Anderson et al. 2001; Lease et al. 2002; Lucas and Lovaglia 1998). Over the course of the morning to early afternoon on a neutral training day (9 AM to 1 PM), each member of the team met with the experimenter (KC) individually in a private room at the training facility. Participants were told "Using these cards with each of your teammate's names on them, you will construct a hierarchy ranking of your teammates on three categories of social status [leadership, popularity, and skill – see below for descriptions] one at a time. None of your teammates will see what you construct and rankings by name will not be shared publicly or with the team. Only I will see the individual rankings of each person by name in order to code for status." The deck of cards also included a card with the participant's own name; they were instructed to place their own name within the hierarchy as well. Participants were shown sample hierarchies without names (Fig. 1) for guidance and encouraged to be as honest and open as possible. In all cases, rankings based on leadership ability were constructed first, followed by rankings based on popularity, and then field-hockey-skill. Each hierarchy was photographed for coding and then the note-cards were collapsed and re-shuffled. To ensure that the hierarchies were constructed with the same

understanding of each of the status components the following definitions were given to each participant as they were constructing the hierarchy:

> *Leadership*: Possess qualities that makes her a good leader such as commitment to the team, a positive attitude, confidence, the ability to delegate responsibilities, be decisive and inclusive, communicate clearly, and motivate teammates.
> *Popularity*: Likable, cool, fun to hang out with.
> *Skill*: Field hockey-specific ability.

To code for status, each level of each individual hierarchy was assigned a numerical value starting with "1" at the bottom and ascending "2," "3," "4," and so on depending on the number of levels. Then, the average numerical value based on the hierarchies constructed for each member of the team was calculated for each of the three status components. Thus, individuals with low placements for any given status component ended up with a lower average score for the component than individuals with higher

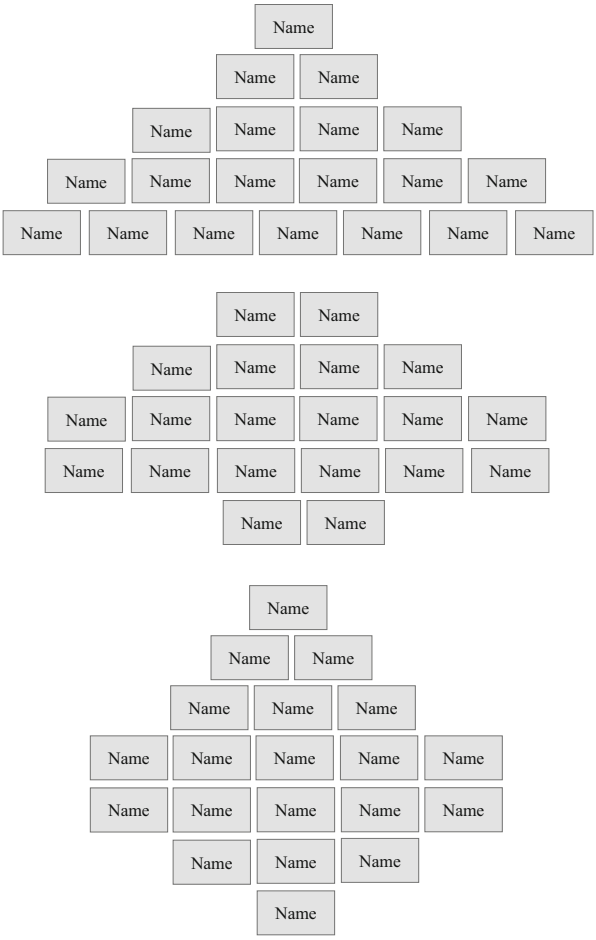

Fig. 1 Sample hierarchy shapes

placements. To create an overall "status among teammates" score, the sum of the three status components was calculated with higher status indicated by higher scores.

An individual's "self-ranking," the level at which a participant placed herself, was not included in the status variable calculations. However, these data were recorded to generate an exploratory variable, "actual vs. perceived status" (self-status rank minus teammate-status rank). Thus, positive values indicate status over-estimation and negative values indicate status under-estimation.

Hormone Sampling and Assay

Baseline Sample At 2 PM the day after completing the hierarchy construction task, every member of the team provided a saliva sample via passive drool into a 2.0 mL plastic vial. This was a day in which the team did not practice, but only completed a light yoga session earlier in the day. Samples were immediately put in a cooler with dry ice and transported to a -80° C freezer within 8 h.

International Competition Pre-Match Sample Approximately two months later, the participants in this study competed in an international competition against Japan's national team at the team USA home facility in Lancaster, PA. The match began at 7 PM in the evening and resulted in a 2–0 win for team USA. At 5 PM in the afternoon participants in this study provided a pre-game saliva sample using the same procedure described above.

Samples from both collection times were assayed in duplicate for testosterone and cortisol by the Emory Clinical Translational Research Laboratory (Atlanta, GA) using competitive enzyme immunoassay kits from Salimetrics. The average intra-assay CV percents for testosterone and cortisol were 2.5–7% and 4–7%, respectively, and average inter-assay CV percents were 6–14%, 3–11%, respectively.

Interpreting Statistical Tests

Access to the US Women's National Field Hockey team allows for a unique-population test of the dual-hormone hypothesis with elite women athletes. Sample size for the study is limited to the number of women on the team and, as a result, statistical power is low and the risk of false-positive significance tests is high. We attempt to internally replicate baseline sample findings with the inclusion of pre-match competition-day samples. To increase transparency and for meta-analytic purposes, syntax and output for all analyses are included in the supplementary data publicly available on the open science framework (https://osf.io/5zyxj/).

Results

The descriptive statistics for raw testosterone and cortisol levels for baseline and pre-match samples are shown in Table 1. Testosterone levels were lower on average for the pre-match sample than on the neutral day baseline sample; cortisol levels were

Table 1 Descriptive statistics for testosterone (pg/ml) and cortisol (μg/dl)

	Mean (SD)	95% Confidence Interval	N
Baseline Testosterone	42.40 (17.16)	33.86–50.93	18
Baseline Cortisol	.1177 (.0576)	.0890–.1463	18
Pre-match Testosterone	29.42 (15.81)	20.99–37.85	16
Pre-match Cortisol	.1100 (.0559)	.0802–.1398	16

equivalent. Some participants ($N = 11$) were using oral contraceptives. Oral contraceptive users had significantly lower baseline testosterone levels on average compared to non-users (30.52 pg/ml vs. 52.91 pg/ml; $t(20) = 4.79$, $p < .001$, $d = 2.04$). Pre-match testosterone levels were also lower for oral contraceptive users, but the difference was not significant (23.10 pg/ml vs. 34.63 pg/ml; $t(18) = 1.87$, $p = .08$, $d = .88$). Mean cortisol levels for oral contraceptive users were not significantly different from means for non-users at either time point.

Four members of the team joined 1–3 weeks prior to the collection of data and as a result, many members of the team reported being not familiar enough with these individuals to rank them on leadership, popularity, or skill. Scores for these individuals were excluded from the status analyses leaving a sample size of 18. Hormone values were z-scored to standardize across the different units of measurements for testosterone and cortisol and to adjust for non-normal distributions (results using raw values were the same, and output for those analyses are provided in supplementary data). The correlation matrix including hormone values, overall status, and each status component is shown in Table 2. The three components of status were strongly and positively correlated. Additionally, the average measures intra-class correlation coefficient for the three status components was sufficiently high to warrant combining them for conducting the main analyses ($ICC = .76$, *95%CI* [.47, .90], $p < .001$). Thus, overall "status among teammates" is the sum of the three status components; higher status is indicated by higher scores. Testosterone levels at baseline and prior to competition were positively correlated, while cortisol levels at these two times were not correlated.

Table 2 Correlation matrix for study variables

	Baseline Test	Baseline Cort	Pre-match Test	Pre-match Cort	Status	Leadership	Popularity
Baseline Test	–						
Baseline Cort	−.06	–					
Pre-match Test	.55	−.30	–				
Pre-match Cort	−.09	.10	.35	–			
Status	−.16	.19	−.11	.23	–		
Leadership	−.22	.21	−.19	.22	.88**	–	
Popularity	.08	.14	.07	.04	.78**	.49	–
Skill	−.26	.10	−.15	.33	.82**	.65**	.45

Hormonal Predictors of Social Status among Teammates

Baseline Testosterone and Cortisol Hierarchical regression analysis was used to test the interaction between cortisol and testosterone in predicting status rank using PROCESS version 3.0 software in SPSS (http://processmacro.org). Values were mean centered for the construction of products. Results of the analysis revealed that neither testosterone, nor cortisol alone significantly predicted status. However, there was a statistically significant baseline testosterone × cortisol interaction ($R^2_{change} = .34$, $b = -1.46$, $SE = .52$, $95\%CI$ [−2.57, −.35], $t(14) = -2.83$, $p = .013$; Fig. 2). Simple slope analysis indicated that the negative relationship between testosterone and status among those with relatively high cortisol (1 standard deviation above the mean on cortisol) was significant (+1SD: $b = -1.91$, $SE = .74$, $t(14) = -2.59$, $p = .021$), but the positive relationship between baseline testosterone and status among those with relatively low cortisol (1 standard deviation below the mean on cortisol) was not significant (-1SD: $b = 1.01$, $SE = .69$, $t(14) = 1.47$, $p = .163$). The Johnson–Neyman technique (Preacher et al. 2007) showed that cortisol level at a value of .149 (μg/dl) is the turning point from non-significance to significance for the effect of testosterone on status. That is, based on this predictive model, only individuals with cortisol values (unstandardized) between .149 μg/dl and .244 μg/dl (upper bound limit for this sample), 28% of the participants, showed a significant relationship with status.

The interaction between testosterone and cortisol in predicting status among teammates was also tested for each individual status component and the same overall trends for the interaction between testosterone and cortisol were observed (supplementary data). However, effect sizes were lower and the interaction was non-significant for Popularity. Effects were also generally replicated when including hormonal contraceptive use as a covariate in all analyses (supplementary data).

Pre-Match Testosterone and Cortisol Two members of the team who were present for data collection at baseline were not present for the competition and thus, pre-match hormone values were not obtained for these individuals leaving a sample size for related analyses of 16. Hierarchical regression analysis was used to test the interaction between pre-match cortisol and testosterone in predicting status rank using the same procedure as above. Supporting results from the baseline samples, results of this analysis revealed a statistically significant baseline testosterone × cortisol interaction ($R^2_{change} = .34$, $b = -1.29$,

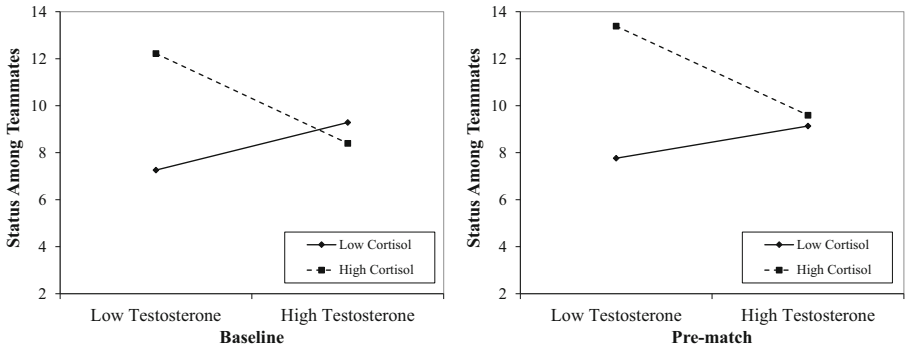

Fig. 2 Simple slopes of the interaction between testosterone and cortisol in predicting status among teammates

SE = .48, *95%CI* [−2.34, −.24], $t(12) = -2.67$ $p = .020$; Fig. 2). Simple slope analysis indicated that the negative relationship between testosterone and status among those with relatively high cortisol was significant (+1SD: $b = -1.90$, *SE* = .77, $t(12) = -2.47$, $p = .029$), but the positive relationship between baseline testosterone and status among those with relatively low cortisol was not significant (-1SD: $b = .68$, *SE* = .73, $t(12) = .94$, $p = .368$). The Johnson–Neyman technique (Preacher et al. 2007) showed that cortisol level at a value of .147 (μg/dl) is the turning point from non-significance to significance for the effect of testosterone on status. That is, based on this predictive model, only individuals with cortisol values (unstandardized) between .147 and .257 (upper bound limit for this sample), 19% of the participants, showed a significant relationship with status.

The interaction between pre-match testosterone and cortisol in predicting status among teammates was also tested for each individual status component and again, the same overall trends for the interaction between testosterone and cortisol were observed (supplementary data). However, effect sizes were lower and the interaction was non-significant for Skill. Effects were also generally replicated when including hormonal contraceptive use as a covariate in all analyses (supplementary data).

Hormonal Predictors of Status Over- and under Estimation

The same analyses performed earlier for baseline and pre-match testosterone and cortisol were conducted with 'actual vs. perceived status' as the outcome variable. Neither testosterone, cortisol, nor their interaction predicted the degree with which an athlete's self-ranking for status differed from her teammates' ratings of her status (see supplementary data for output from these analyses).

Discussion

The teammate-generated sorting procedure we used to create a status hierarchy is easy to use and adaptable for small groups with any number of sorting components. In the present study, we used it to place each member of a team into a status hierarchy based on a combination of teammates perceptions of leadership, popularity, and skill. Although these attributes are conceptually different, combined teammate ratings of each were positively correlated. Combining scores across the three facets provides a measure of status that is reflective of the multifaceted nature of this construct (e.g., Anderson et al. 2001). Individuals who were high on one attribute, but lower on another would receive a sum status rank score above those who were rated low on all attributes, but below those who were rated high on all attributes. Thus, this method also effectively captures the stratified nature of social hierarchy within groups (Halevy et al. 2012).

Consonant with previous research on the dual-hormone effect, the interaction of testosterone and cortisol, rather than either hormone alone, predicted status among teammates. Specifically, for high cortisol individuals, testosterone was inversely related to status. For those individuals low in cortisol, there was a positive, although non-significant relationship between testosterone and status. The interaction of testosterone and cortisol in predicting status was replicated when using hormone levels collected immediately prior to competing in an international field hockey match, a context in

which status rank is particularly salient and where status relationships among teammates could affect individual and team performance (how well they play and how effectively they work together as a team). Additionally, the rank-order measure of status was determined by the opinions of each participant's teammates, reflecting her actual leadership, likability, and demonstrated competence within her group. Thus, the present study directly addresses calls for future research focused on ecological validity and replicability in recent meta-analytic reports of the dual-hormone effect (Dekkers et al. 2019; Grebe et al. 2019). In this study, we also tested the relationship between testosterone and cortisol, and their interaction in relation to actual vs. perceived status rank (the tendency to over- or under-estimate status). In contrast to Cashdan's (2003) report that testosterone was positively related to status overestimation, we found no such effect for testosterone or for the testosterone-cortisol interaction.

The mechanism by which cortisol affects the relationship between testosterone and status is not known. Previous reports have theorized that cortisol reflects a certain trait-based style of interacting with others within the social group that negatively influences the ability of a high testosterone individual to successfully achieve high status (Casto and Mehta 2019; Edwards and Casto 2013). That is, high cortisol/high testosterone individuals may interact with other members of the group in ways that constrain the establishment of deference, respect, and admiration. Although low cortisol has been previously associated with likability, gregariousness and friendship maintenance (Decker 2000; Kornienko et al. 2014, 2016), little is known about how high cortisol influences behaviors that would thwart a linear testosterone-social status relationship. Future research should explore how cortisol moderates testosterone's relationship with interpersonal styles of achieving status, particularly antisocial and prosocial behaviors related to achieving dominance and prestige, respectively (Cheng et al. 2013).

As with other studies of women and women athletes, those who were taking hormonal contraceptives at the time of sampling in this study had lower testosterone levels than those not using any hormonal form of birth control (Casto and Edwards 2016; Edwards and O'Neal 2009; Wiegratz et al. 1995; Zimmerman et al. 2014). There is increasing evidence that hormonal contraceptive users display altered social-emotional processing such as reduced fear extinction, dysregulated social reward mechanisms, and increased emotional reactivity to aversive stimuli (Montoya and Bos 2017). Although hormonal contraceptive use did not predict status rank or impact the dual-hormone effect on status in this study, little is known about the effects of hormonal contraceptive use on women's social achievement. The participants in this study are all relatively high-achieving women, being at the top level in their sport. Whether or not hormonal contraceptive use influences women's motivation for status and ability to achieve and maintain high status positions in larger samples of women across different levels of achievement is an important area for future research. Women are underrepresented in research on the dual-hormone effect and hormonal relationships to social status in general (Casto and Prasad 2017). However, a recent meta-analytic study of the dual-hormone hypothesis recommends that women continue to be excluded from future research due to the potential for reduced effect sizes in this population (Dekkers et al. 2019). Doing so would limit our knowledge about hormone-behavior relationships in women, eliminate the ability to test for meaningful sex effects, and substantially reduce advances in understanding how hormonal contraceptive use affects social-emotional functioning. Thus, it is imperative that future research include women in study designs.

Social status is highly context specific and, excepting society-level metrics (e.g., socio-economic status), relevant mostly within relatively small groups of individuals. Primate social groups and hunter-gatherer societies are relatively stable and capable of maintaining close personal ties at an average size of 12–20 members (Dunbar 1993; Zhou et al. 2005). A hormonal mechanism for maintaining hierarchical social structure would have evolved in the context of discrete, relatively small groups of primates. Thus, testing the dual-hormone hypothesis with ecologically valid sized groups would seem essential for understanding the nature of this effect. Although larger samples of individuals are helpful for the statistical models required for testing the dual-hormone effect and making assertions about hormone-behavior relationships in general, these large groups may not reflect the reality of social group structures.

The elite women athletes in this study were competing for places on the team that would represent the USA in Olympic competition later in the year. Near-daily interactions, on and off the field, over years of training and competing together resulted in stratified and apparently stable social order evidenced by the relatively good agreement between the independently-generated hierarchies of the participating athletes. That an individual's place in this order is related to cortisol and testosterone suggests that these two hormones figure in the interactions on which it is established. For women athletes with the highest levels of cortisol, testosterone was inversely correlated with status rank. This result should encourage further exploration of the relationship between cortisol, testosterone, and status using group-member generated status ranking among established groups, conditions in which ecological validity for hormone-behavior relationships is high.

Transparency and Supplementary Data

Output for all main analyses and additional analyses included as a robustness check of main effects are publicly available on the open science framework (https://osf.io/5zyxj/).

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Compliance with Ethical Standards

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

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